California Environmental Protection Agency

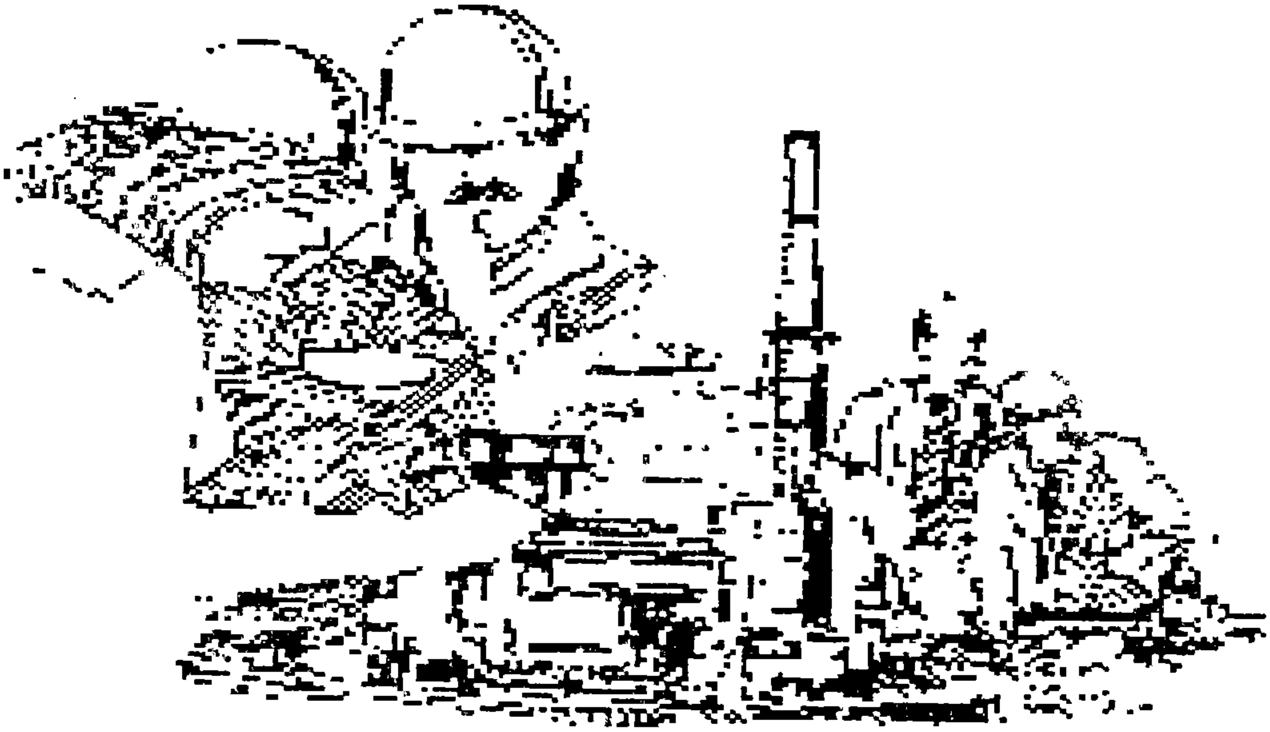
Air Resources Board

Compliance Division

presents

ARB Course #288

Petroleum Refineries



Student Handbook - Part 2

Student Handbook - Part 2
Table of Contents

NSPS by Subpart	Name of NSPS	Continuous Emission Monitoring (CEM) of What?
Subpart D	Fossil Fuel Fired Steam Generators	Opacity, SO_2, NO_X, Oxygen or CO_2
Subpart Da	Standards of Performance for Electric Utility Steam Generating Units for Which Construction is Commenced after September 18, 1978	Opacity, SO_2, NO_X, Oxygen or CO_2
Subpart Db	Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units	SO_2, Opacity, NO_X
Subpart Dc	Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units	SO_2, Opacity
Subpart J	Standards of Performance for Petroleum Refineries	Opacity, CO, SO_X,
Subpart K	Standards of Performance for Storage Vessels for Petroleum Liquids for which Construction, Reconstruction, or Modification Commenced after June 11, 1973 and Prior to May 19, 1978	Keep records of: (1) The petroleum liquid stored, (2) The period of storage, (3) the maximum true vapor pressure of that liquid during the respective storage period
Subpart Ka	Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced after May 18, 1978 and Prior to July 23, 1984	Keep records of: (1) The petroleum liquid stored, (2) The period of storage, (3) The maximum true vapor pressure of that liquid during the respective storage period
Subpart Kb	Standards of Performance for Volatile Organic Liquid Storage Vessels (including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced after July 23, 1984	Keep records of: (1) Dimension of the storage vessel, (2) The volatile organic liquid (VOL) stored, (3) The period of storage, (4) The maximum true vapor pressure of that VOL during the respective storage period
Subpart GGG	Standards of Performance for Equipment Leaks of VOC in Petroleum Refineries	VOC's
Subpart QQQ	Standards of Performance for VOC Emissions from Petroleum Refinery Wastewater Systems	Temperature and VOC's

SHB-A

rLr. 111

Concern Over Ozone

tmospheric ozone resents two distinct hallenges: preventing its uildup at ground levels, vhere it contributes to rban smog, and preventing its destruction in e stratosphere, where t protects us from ultraviolet rays.

Ozone, the three-atom variant of oxygen, seems an unrivaled paradox among gases in the earth's atmosphere. Ozone occurs in two separate regions of the atmosphere and creates a different concern n each place. Where ozone is essential, being diminished. Where it is unwanted, ozone sometimes accumulates.

In the stratosphere, which starts at 7–12 miles above the earth and extends to about 30 miles out in near space, a layer of ozone of about 300 parts per billion (ppb) helps sustain life on the planet by absorbing much of the sun's dangerous ultraviolet (UV) radiation.

In the lower reaches of the more familiar troposphere (which extends unevenly from the ground up to 6–10 miles), ozone is considered an air pollutant. A key component of urban smog, ozone can irritate lungs ~~or~~ and damage certain plants at concentrations near the ambient levels in many areas. Although ozone levels are typically much lower in the lower atmosphere, they can range from a few tens of ppb to a level greater than that in the stratosphere, depending on location. Ozone is not emitted directly from any source, yet over 60 major U.S. urban areas do not now meet federal air quality standards limiting ozone to 120 ppb.

Ozone is created naturally in the stratosphere through the chemical destruction of oxygen, which is induced by sunlight. Scientists have recently confirmed that chlorine and bromine from man-made sources are, at times, destroying stratospheric ozone faster than it is replenished, with potentially adverse consequences for human health and agriculture.

An unexpected, and still not completely explained, marked depletion of ozone—a hole the size of the United States or larger—over Antarctica has recently been observed for 4–6 weeks during the Antarctic spring. The hole is the result of both unique meteorological conditions and chemical reactions that apparently allow virtually every atom of chlorine that finds its way there to destroy, unchecked, up to 100,000 ozone molecules.

Major international controversy has developed over the call by many of the world's industrialized nations (including the United States) for the complete phaseout by the end of this century of the widespread use of chlorofluorocarbons (CFCs)—the major source of what ultimately becomes ozone-destroying free chlorine in the stratosphere.

Back at ground level, other battles of several dimensions are heating up again as Congress considers tightening provisions of the Clean Air Act, including those relating to tropospheric ozone. The Environmental Protection Agency, meanwhile, is pondering action against states with air quality districts that do not meet federal ozone standards.

As concern over tropospheric ozone pollution grows, prospects appear ever more likely for greater controls on the many man-made sources of ozone precursors—reactive hydrocarbon gases and nitrogen oxides—including motor vehicles and fossil-fuel-fired industrial plants, residential and commercial activities, and utility generating stations. Residents of southern California, for example, are facing far-reaching changes if efforts proposed to control ozone pollution there are adopted and enforced. Elsewhere, there is evidence that hydrocarbon emissions from natural sources can combine with nitrogen oxides to produce ozone levels that in some cases approach the limit set as the national air quality standard.

Lost in the ozone

"In trying to sort out reports of stratospheric ozone loss and the occasional summer smog 'ozone alert,' the public can get confused by the distinctly different environmental issues associated with this important gas," notes Chuck Hakkarinen, technical manager in EPRI's Environment Division. "The atmospheric and chemical processes involved are different for the two problems. But there may be a link because the loss of ozone in the upper atmosphere could increase the ultraviolet radiation that reaches the earth's surface. More UV radiation would mean more energy is available to drive the photochemical reactions that create ground-level ozone," Hakkarinen postulates.

SHB-1

Concerns that pollutants could damage stratospheric ozone were first raised in 1970 amid plans to develop [illegible] high flying supersonic transport (SST) aircraft. It was feared that nitric oxide derived from engine exhaust would destroy ozone through a catalytic chain reaction. The United States eventually abandoned SSTs on economic grounds (Britain and France went on to jointly develop the Concorde), and the impact of the small present SST fleet on stratospheric ozone has been shown to be small. But the controversy spurred scientific studies that established that the chemistry of the upper regions of the atmosphere could be upset by human activity.

In 1974, atmospheric scientists Sherwood Roland and Mario Molina theorized that emissions of several chlorinated compounds in the CFC family, although inert in the lower atmosphere, could be wafting all the way up to the stratosphere, where they are chemically decomposed by UV radiation, producing free chlorine that, in turn, attacks ozone vigorously.

Any significant net loss of ozone in the stratosphere was suspected of implying a range of potential negative biological effects, including increased human skin cancers and eye cataracts. The EPA has estimated that the increased UV from each 1% depletion in stratospheric ozone could lead to a 2% increase in skin cancers among fair-skinned people. No one knows if this estimate is reliable.

On the basis of little more than theory at the time, the United States, Canada, Sweden, and Norway banned the use of CFCs in aerosol cans in 1978. But more than a million tons of CFCs are still produced annually around the world for wide use as propellants, refrigerants, foam-blowing agents, and solvents. Halon gases containing bromine, which are used as fire-extinguishing agents, also destroy ozone. But halons are considered to account for less than 10% of stratospheric ozone destruction, because their emissions are a thousand times less than the emissions of CFCs.

Indications from satellite instrument data of stratospheric ozone loss first began to be seen over Antarctica around 1979, but for some time the data were discounted because of doubts about their accuracy and reliability. A British survey team's announcement in 1985, however, of a measured substantial decline in ozone concentrations above Antarctica over the preceding eight years, which was not predicted by any model or theory, sparked an intensive international scientific reassessment. The group reported a sharp drop in ozone during the months of September and October (the Antarctic spring)—a decline of almost 40% from levels routinely observed 20 years earlier.

Broad-based confirmation of such ozone depletion, as well as the measurement of very high levels of chlorine monoxide—the chemical link between ozone destruction and CFCs—prompted the 1987 Montreal Protocol, which some 36 nations (at last report) have ratified. It calls for a freeze in CFC production at 1986 levels to take effect this summer. The goal is a 50% reduction in total CFC use by 1999.

Because CFC compounds are inert—the essence of their commercial utility—they also can remain in the atmosphere for 40–150 years. Several CFC compounds also readily absorb infrared energy in the lower atmosphere, making them doubly indicted as both stratospheric ozone destroyers and as more-efficient greenhouse gases, molecule for molecule, than carbon dioxide.

Outlook now more mixed

At the time, the 1987 Montreal Protocol was hailed as a precedent-setting international agreement to take action in the face of scientific consensus on a clear threat of global environmental damage. Now, however, a more mixed outlook has developed for stratospheric ozone.

The recently measured loss over Antarctica is more complete (up to 90% some areas and lasts longer than was served earlier. Levels of UV radiation ty ical of summer were recorded in areas u derlying the zone of greatest ozone lo during the most recent Antarctic spring. Recently analyzed data suggest that ozone losses averaging 3% above model predictions have occurred over northern hemisphere latitudes (including North America) from 1978 to 1985; the losses have been greater at higher latitudes.

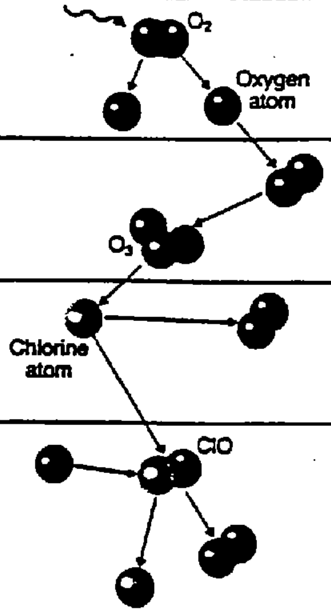
Extremely cold temperatures (−75°C to −85°C) and the formation of a massive, persistent polar vortex (rotating air mass) during the dark winter are now known to play a key role in the development of the ozone hole over Antarctica in spring. Ice crystals of water and nitric acid that form in the high-altitude clouds of the vortex enhance the release of free chlorine from otherwise inactive forms, helping to set in motion a cycle of ozone destruction. Similar, but less intense or ideal, conditions for ozone destruction have been confirmed over the Arctic region, although no hole over the North Pole has been observed so far.

Coupled with growing awareness tha even with a worldwide freeze on CFC emissions at current levels, the amount of chlorine in the stratosphere will continue to increase for decades, such news led to the dramatic call earlier this year by the European Community—quickly endorsed by the United States—for a complete phaseout of CFCs by 1996. The move coincided with a 123-nation conference organized by British Prime Minister Margaret Thatcher at which it appeared that many less-developed countries do not share the West's sense of urgency or conviction concerning CFCs.

Last May, at a meeting in Helsinki, Finland, sponsored by the United Nations Environment Program to review the Montreal Protocol, 80 nations declared support for a full CFC phaseout by 2000. Meantime, U.S. and international research groups are preparing for another major scientific review of the strato-

zone Chemistry in the Stratosphere

ratospheric ozone is created and destroyed in a natural cycle that has been functioning in relative equilibrium for thousands of years. The presence of chlorine, released from an-made chlorofluorocarbons by ultraviolet light, disrupts the cycle; each free chlorine om is thought to be capable of destroying as many as 100,000 ozone molecules.



Ultraviolet radiation breaks the chemical nd of an oxygen molecule (O_2), resulting two free oxygen atoms.

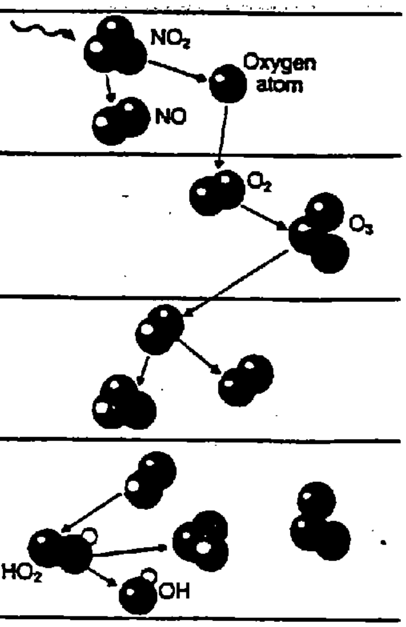
A free oxygen atom bonds with another oxygen olecule, creating a molecule of ozone (O_3).

A free chlorine atom reacts with the ozone, eaking its fragile bond to create chlorine oxide d an oxygen molecule.

A free atom of oxygen breaks up the chlorine ide and creates another oxygen molecule and free chlorine atom. The chlorine atom moves to react with another molecule of ozone.

one Chemistry in the Troposphere

opospheric ozone is also produced and destroyed in a natural cycle, this one involving ygen and nitrogen oxides (NO_x). The ozone is normally created and destroyed daily in ual amounts, but volatile organic compounds (VOCs) from both man-made and natural urces contribute reactive (free-radical) species that interfere with the normal cycle, lowing ozone to accumulate.



Ultraviolet radiation breaks nitrogen dioxide O_2) into nitric oxide (NO) and a free oxygen om.

The free oxygen atom bonds with an oxygen olecule (O_2) to form an ozone molecule (O_3).

The ozone molecule would normally react th the NO to produce NO_2 and an ordinary ygen molecule.

Instead, the NO combines preferentially with O_2, formed from photochemically reactive Cs, leaving the ozone molecule intact.

spheric ozone situation this August.

There is at least some good news about stratospheric ozone. There are indications of small to negligible effects on Antarctic plant and animal life from the increased UV radiation of the last few seasons. Ocean plants called phytoplankton at the bottom of the Antarctic food chain, believed most vulnerable to the extra UV, have been observed to be only somewhat less efficient in photosynthesis. And outside of Antarctica there have been no reports of measured increases in UV radiation.

An unanswered commentary of researchers, based on modeling results, is that the 11-year solar sunspot cycle may have had a negative effect on total stratospheric ozone equal to or greater than that of CFCs. A sunspot minimum during 1979–85 would have emitted less high-energy radiation at the earth, reducing molecular oxygen ionization and creating less ozone. The trend of declining stratospheric ozone could be totally masked or even reversed in the next few years until the solar cycle peaks in 1991. Beyond that, however, ozone depletion would be expected to accelerate again, possibly faster than it has up to now.

"The good news, for the time being, is that the magnitude of the reduction of stratospheric ozone is comparable with natural variation between the trough and the peak of the solar sunspot cycle," observed the British scientific journal *Nature* editorially last year. "If the secular reduction of stratospheric ozone so far can be swamped by the effects of the sunspot cycle, it cannot so far have done much damage. The next solar sunspot cycle could, of course, be a different case."

In the research into stratospheric ozone to date, EPRI has only counted itself among the interested observers of the work of others, mainly government agencies and university-based scientists. With a growing program focus on climate change and its direct and indirect implications for utility operations and the demand for electricity, however, EPRI's En-

StB-3

vironment Division now also plans to explore further the CFC-ozone issue.

"It's already been suggested that, even if we cut back on CFC emissions, the ozone loss is going to get worse before it gets better," notes Hakkarinen, who is managing the study. "So we're trying to identify more clearly what stratospheric ozone levels should look like over time if CFC production does decline. We would like to know when and what sort of changes in stratospheric ozone to anticipate so that industries could have some validation of whether the controls on CFCs are important."

In the near term, meanwhile, the most significant consequences of CFC controls will be felt indirectly by utilities through their customers. Because of the ubiquity of CFCs in commercial use, all manner of industries and their products stand to be affected by voluntary reductions and new EPA regulations implementing the Montreal Protocol. EPRI's Customer Systems Division is sponsoring analyses of the implications of CFC cutbacks and possible substitutes.

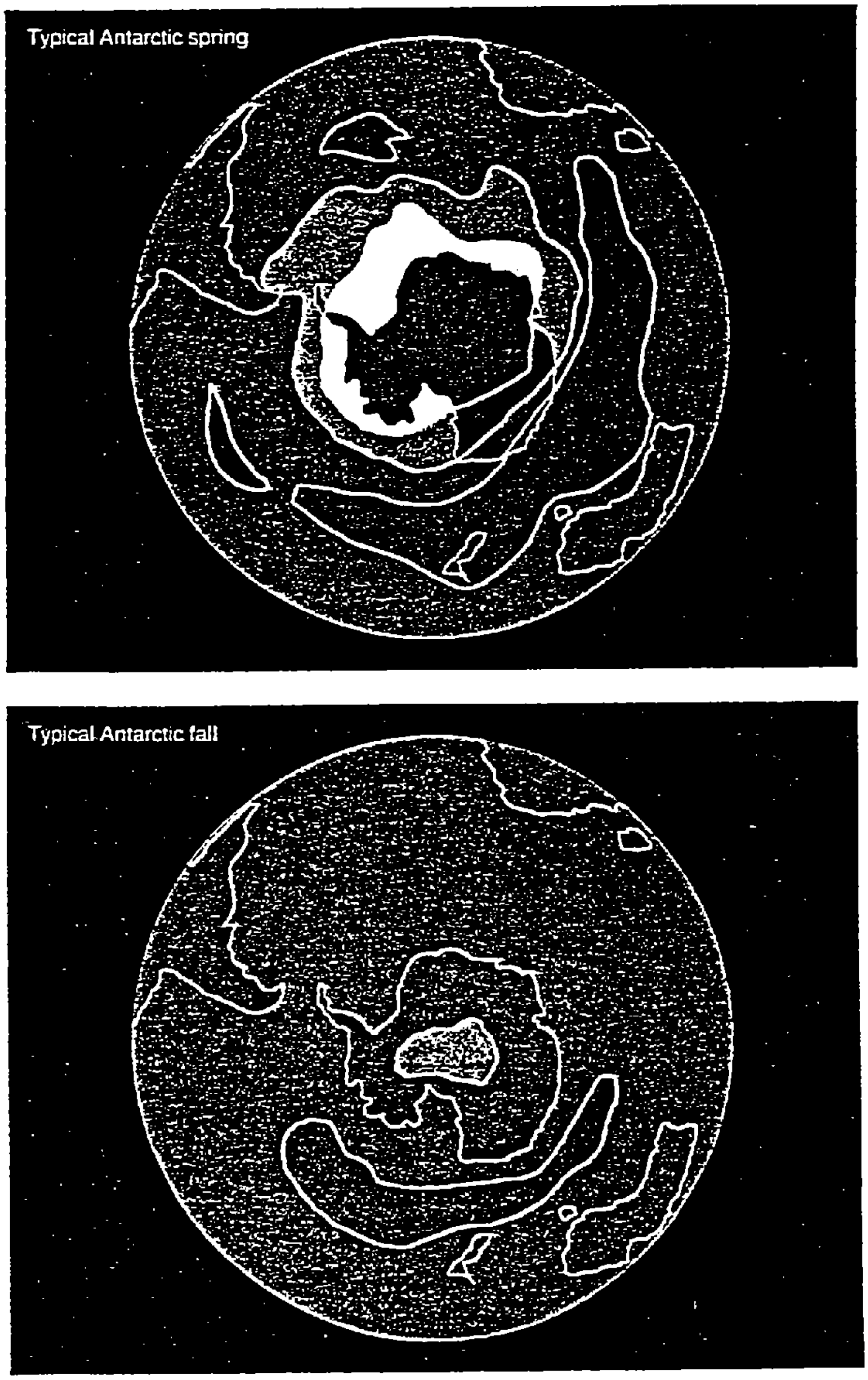
"The potential impact on electric power demand and energy consumption is very large," says Arnold Fickett, vice president and Customer Systems Division director. "Utilities have a strong interest in seeing that the alternatives that evolve will be safe and energy-efficient and not exacerbate loads."

Ozone closer to home

While much of the industrialized world has set in motion costly and controversial changes designed to stem the loss of high-flying ozone in the stratosphere, the problem closer to the ground is quite the opposite—even small concentrations can be too much. Here, ozone pollution accumulates when reactive hydrocarbon gases (from gasoline, solvents, and natural emissions), also known as volatile organic compounds (VOCs), disrupt the usual cycle of ozone formation and destruction involving molecular oxygen and nitrogen oxides (NO_x).

A Thinning Over the South Pole

The "hole" in the stratospheric ozone layer over Antarctica is actually a large zone of reduced ozone concentration observed during the Antarctic spring (September and October) over the last decade. Although the release of certain chlorofluorocarbons to the atmosphere is believed to be responsible for such reductions, the ozone hole is also dependent on Antarctica's unique climate and seasonal patterns. A large polar air mass, extremely cold temperatures at high altitudes, and the emergence of spring sunlight after the dark polar winter create chemical conditions ideal for ozone destruction. Ozone levels are similar to those elsewhere around the globe during other seasons of the year.



SHB-4

The ratio of VOCs to NO_x is known to ay a more important role than their ab[illegible]oncentrations in ozone formation ıd peak ozone levels. How fast ozone cumulates is closely related to the availility of highly reactive (free radical) spees produced when molecules of VOCs ecompose in sunlight. These species inrfere with the oxygen-NO_x reaction, so driven by sunlight, that normally eates and destroys equal amounts of zone.

The reactions and atmospheric processes involved are also related to the chemistry and physics of acid rain formation nd the production of aerosol particles. All of the end products of air pollution nat are suspected of being undesirable—rom sulfuric or nitric acid in precipitaion, to ozone, to aerosol particles that catter light and thus obscure our field of iew—are formed in the atmosphere from zone and precursor emissions, for the nost part, and the chemistry is interaci says Peter K. Mueller, EPRI program nanager for atmospheric sciences in the nvironment Division.

Emissions of both NO_x and VOCs have nan-made and natural sources. The bulk of the NO_x, however, amounting to some 20 million tons a year in this country, comes from the combustion of fossil fuels n motor vehicles, industry, commerce, and utility generating plants. Natural sources such as forest fires, decomposing plants, and lightning generate a comparatively small amount of NO_x; lightning can be a significant source locally for short periods.

Sources of VOCs are much more diverse. Trees and shrubs are a major natural source of reactive hydrocarbons, emitting an estimated 20 million tons each year, mostly as isoprene and pinene. Man-made VOC emissions, estimated to account for another 20 million tons per year in this country, originate from a wide ety of industrial processes, incomplete combustion in motor vehicle engines, other fossil fuel combustion, use of organic solvents (mostly petroleum)—even from gasoline vapors at the service pump.

Trace background levels of ozone are believed to have always been present in the troposphere, partly the result of convective transport from the stratosphere and partly due to natural tropospheric photochemistry. A long record of measurements on the outskirts of Paris around the turn of the century suggests that tropospheric ozone levels in central Europe 100 years ago averaged 10 ppb.

A current issue in atmospheric science is whether tropospheric ozone in industrial countries is increasing. Levels in rural areas of the United States with no significant man-made NO_x and VOC emissions are believed to be typically 30–40 ppb; at remote Pacific islands, levels are 20–30 ppb. At the other extreme, half a dozen U.S. cities frequently experience three-hour peak ozone concentrations of 150–200 ppb, particularly in summer when there are stable, high-pressure weather systems overhead. In Los Angeles, ozone has been measured at levels as high as 290 ppb.

According to the EPA, 65 urban areas in the United States exceed the National Ambient Air Quality Standard (NAAQS) for ozone of 120 ppb. The health-based NAAQS is a one-hour average concentration, not to be exceeded more than once a year over a three-year average. It is set by the EPA to protect sensitive people, such as children and heavily exercising people. Some recent research suggests that respiratory responses occur after extended exposure to ozone levels even lower than 120 ppb.

Meanwhile, some field as well as modeling studies suggest that natural VOC emissions from trees in rural areas can react with even trace levels of NO_x from nearby or more distant sources to generate ozone levels that approach the NAAQS. It has been suggested that such biogenic hydrocarbons may play a substantial role, for example, in the routinely high ozone levels in and around Atlanta, Georgia.

The amount of VOCs from the dense pine forests that surround the sprawling southeastern city is comparable to the amount of man-made hydrocarbons emitted in the urban area. Researchers at the Georgia Institute of Technology have suggested that, because a substantial reduction in the area's man-made VOC emissions in recent years has not resulted in a corresponding decrease in ozone, the remaining baseline of biogenic VOCs could mean that significant reductions in urban and power plant NO_x emissions also might be required before ozone levels would meet air quality standards.

Computer simulations of different urban airsheds suggest that NO_x reductions can increase or reduce ozone levels, depending on the relative proportions of VOCs and NO_x, sunlight, and other factors. The models also suggest that reducing VOCs will always tend to reduce ozone formation.

Most regulatory strategies for reducing urban ozone have, in fact, focused on reducing VOC emissions but have met with only mixed success. This is partly because of the ubiquity and numbers of sources, including every running motor vehicle, open can of paint or solvent, and dry cleaning establishment, to name just a few. Moreover, in the case of automobiles, growth in the number of vehicles and miles traveled in many regions has begun to outpace the emission reductions per vehicle mile achieved so far.

More than a health issue

The NAAQS for ozone is set primarily to protect human health. This month officials of the new administration were expected to outline what actions they will take in states with air quality districts out of compliance with ozone standards. Several bills in Congress could set tough new penalties for nonattainment areas, including steep permit fees for emissions sources, tighter tailpipe emissions limits, and gasoline vapor recovery require-

SHB-5

ments and VOC volatility restrictions.

Reducing ozone levels is the goal of a sweeping, new, long-term antismog plan proposed recently by authorities in southern California and intended to bring the four-county Los Angeles area into compliance with federal air quality standards by 2007. The far-reaching plan supersedes older ideas that should have achieved the NAAQS by now, and it could mean major changes in the way southern Californians live and work in the years ahead. Proposals, which center on further limiting VOC emissions, include bans on household sources such as charcoal-lighter fluid, gasoline-powered lawnmowers, and all aerosol cans, as well as drive-up service windows and free parking in commercial districts. Emissions controls would be placed on bakeries, breweries, and dry cleaners—all potential sources of VOCs.

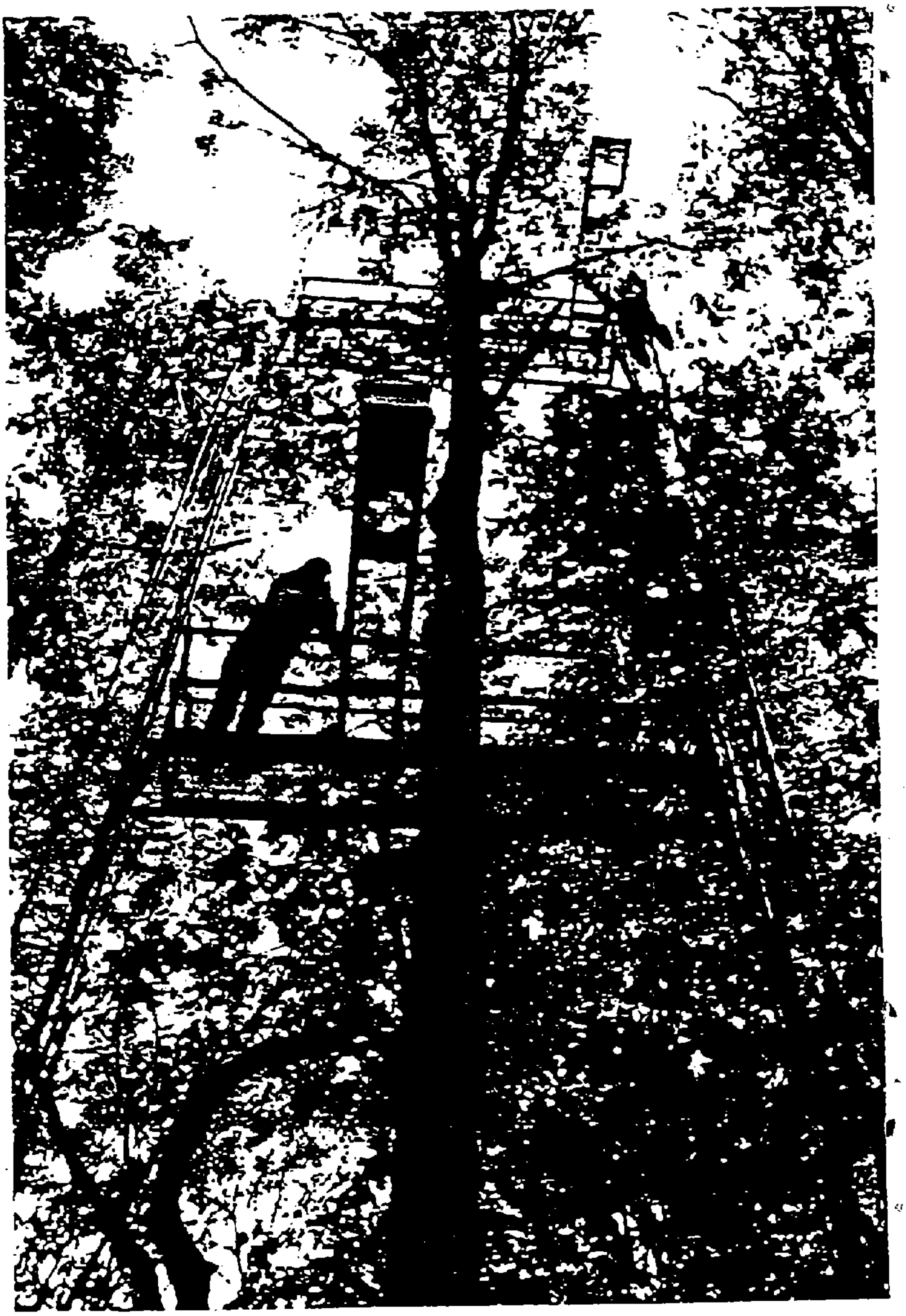
But protecting human health is not the only motivation for reducing ozone. For reasons analogous to why humans are sensitive to the highly reactive gas, so are many plants. Ozone interferes with photosynthesis, causing reduced yields in the case of crops and retarded growth in the case of sensitive tree species.

According to EPRI research managers, the evidence of significant damage to plant life from ozone is far less ambiguous than that for health effects. "Visible damage or reduced growth in certain crop and tree species is well documented, but ozone's effects on complex forest ecosystems are not as well understood," says Lou Pitelka, project manager in the Ecological Studies Program. "It may alter forest plant life by eliminating ozone-sensitive species, reducing nutrient levels, and changing mortality rates.

"On a regional basis, researchers regard ozone as potentially the most serious pollutant threatening American forests," adds Pitelka. "It is the primary cause of decline in the ponderosa pine forests of southern California. While it does not appear to be the primary cause of forest decline in the eastern United

Research on Crops and Forests

Most EPRI-funded research on ozone issues relates to tropospheric pollution. Besides air quality studies that model the atmospheric physics and chemistry of ozone in the larger context of pollutant emissions, EPRI has funded major plant and forest studies that have included a focus on ozone. This work has confirmed significant reductions in specific crop yields and reduced growth in certain tree species at common ambient levels. Continuing studies of forest systems are examining the interactive effects of ozone and other environmental factors.



SHB-6

ates, many researchers suspect ozone being a potential culprit in weakening rt species and making them vulnerble to other stresses, or in further damging species that are already weakened other factors."

EPRI has sponsored research on the efcts of ozone on crops and forest plants. ne work has confirmed significant yield ductions in soybeans, wheat, corn, and otatoes at ambient ozone levels. Morecent work on forest ecosystems is fousing on how ozone interacts with other ctors in affecting forest vegetation.

On the atmospheric sciences front, zone measurements and reaction chemtry have been explicitly accounted for in umerous EPRI-sponsored air quality udies. Now, according to Peter Mueller, esearchers are preparing for the next ep: to connect and integrate models of iffering spatial and temporal dimenons and specificity to provide a compreensive simulation of emissions and atospheric transport and conversion.

Such "embedded" modeling would r a long-sought improved capability f evaluating trade-offs inherent in difrent emissions control strategies. One oal of the modeling work is to be able to nalyze the potentially different role of ispersed versus point sources of, for exmple, NO_x emissions. Or, the locations f sources within a region might make a ifference in ozone levels, depending on ne sequence of reactant blending.

"One current issue is whether NO_x missions in rural areas are mixing with atural hydrocarbons from vegetation nd producing ozone levels that not only ave the potential for local damage to lants, but may also be transported into rban areas and be adding to what is lready there so that the air quality tandard is exceeded," explains Mueller. The embedded models that need to be leveloped would help to quantify and valuate suspicions along these lines.

"At the same time, the models would address what is happening with visiy and fine particles. You can't separate the fine-particle, acid aerosol, and ozone problems from the health effects issues in urban areas. We are moving toward addressing these in an integrated approach," Mueller adds.

Mueller also thinks there may be a further link between stratospheric ozone and tropospheric ozone production. "If stratospheric ozone has diminished significantly, we should be seeing increased levels of UV radiation all around the world, but so far more UV has only been seen in Antarctica. What could explain this? One possible explanation is that, because ozone, wherever it is, absorbs UV radiation, ozone in the troposphere may be offsetting whatever added UV radiation the earth may be getting from decreased ozone in the stratosphere. We certainly don't know the answer yet."

Spotlight on ozone

Ozone has emerged center stage in the complex web of global and regional environmental concerns related to man's influence on the environment. Discovery of an ozone hole in the stratosphere over Antarctica catalyzed an international response with significant near-term implications for technology and industries that depend on CFCs. But it has also revealed sharp differences among nations in their attitudes on the appropriate balance between economic development and protection of the global environment. Developments in the next few years could be a bellwether for the direction of change in response to broader policy questions involving world climate and greenhouse issues.

In America's everyday world of freeways, cars and trucks, record power demand, summer heat waves, and hazy, brown horizons, however, ozone is at the center of concern over the environmental and health effects of increasing air pollution and the focus of emissions control strategies. Although stratospheric ozone and tropospheric ozone really are separate issues, the continuing need for scientific insights to inform the policy and regulatory debates is a common thread between them. ■

Further reading

Beverly Tilton. "Health Effects of Tropospheric Ozone." *Environmental Science and Technology*, Vol. 23, No. 3 (March 1989), pp. 257–263.

John Seinfeld. "Urban Air Pollution: State of the Science." *Science*, Vol. 243, No. 4892 (February 10, 1989), pp. 745–752.

Michael McElroy and Ross Salawitch. "Changing Composition of the Global Stratosphere." *Science*, Vol. 243, No. 4892 (February 10, 1989), pp. 763–770.

F. Sherwood Roland. "Chlorofluorocarbons and the Depletion of Stratospheric Ozone." *American Scientist*, Vol. 77, No. 1 (January–February 1989), pp. 36–45.

National Research Council. *Ozone Depletion, Greenhouse Gases, and Climate Change*. Washington, D.C.: National Academy Press, 1989.

Cynthia Pollack Shea. *Protecting Life on Earth: Steps to Save the Ozone Layer*. Worldwatch Paper #87. Washington, D.C.: Worldwatch Institute, December 1988.

Ozone: One Gas, Two Environmental Issues. EPRI Environment Briefing, December 1988. EN.3003.12.88.

Philip Abelson. "Rural and Urban Ozone." *Science*, Vol. 241, No. 4872 (September 16, 1988), p. 1569.

W. L. Chameides et al. "The Role of Biogenic Hydrocarbons in Urban Photochemical Smog: Atlanta as a Case Study." *Science*, Vol. 241, No. 4872 (September 16, 1988), pp. 1473–1475.

Utility NO_x Emissions and Urban Ozone. Prepared by the EPRI Environment Division, July 1988. EN.1.9.88.

Michael Shepard. "The Politics of Climate." *EPRI Journal*, Vol. 13, No. 4 (June 1988), pp. 4–15.

Forest Health and Ozone. EPRI Environment Briefing, May 1988. EN.3001.5.88.

"Where the World Stands on Ozone." *Nature*, Vol. 332, No. 6162 (March 24, 1988), p. 291.

David Lindley. "CFCs Cause Part of Global Ozone Decline." *Nature*, Vol. 332, No. 6162 (March 24, 1988), p. 293.

Clive Rodgers. "Global Ozone Trends Reassessed." *Nature*, Vol. 332, No. 6161 (March 17, 1988), p. 201.

Donald Heath. "Non-Seasonal Changes in Total Column Ozone From Satellite Observations, 1970–86." *Nature*, Vol. 332, No. 6161 (March 17, 1988), pp. 219–227.

Andreas Volz and Dieter Kley. "Evaluation of the Montsouris Series of Ozone Measurements Made in the Nineteenth Century." *Nature*, Vol. 332, No. 6161 (March 17, 1988), pp. 240–242.

Richard Stolarski. "The Antarctic Ozone Hole." *Scientific American*, Vol. 258, No. 1 (January 1988), pp. 30–36.

U.S. Congress, Office of Technology Assessment. *Urban Ozone and the Clean Air Act: Problems and Proposals for Change*. 1988.

This article was written by Taylor Moore. Technical background was provided by Chuck Hakkarinen, Peter K. Mueller, and Lou Pitelka, Environment Division.

SH3-7

EPRI JOURNAL

EPRI JOURNAL is published by the
Electric Power Research Institute.

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

Address correspondence to:
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
3412 Hillview Avenue
Palo Alto, California 94303

EPRI
ELECTRIC POWER RESEARCH INSTITUTE
Headquarters: 3412 Hillview Avenue, Post Office Box 10412, Palo Alto, CA 94303 (415) 855-2000

SHB-8

Exhibit 15: Typical Material Outputs from Selected Petroleum Refining Processes

Process	Air Emissions	Process Waste Water	Residual Wastes Generated
Crude oil desalting	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), fugitive emissions (hydrocarbons)	Flow=2.1 Gal/Bbl Oil, H_2S, NH_3, phenol, high levels of suspended solids, dissolved solids, high BOD, high temperature.	Crude oil/desalter sludge (iron rust, clay, sand, water, emulsified oil and wax, metals)
Atmospheric distillation Vacuum Distillation	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons) Steam ejector emissions (hydrocarbons), heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons)	Flow=26.0 Gal/Bbl Oil, H_2S, NH_3, suspended solids, chlorides, mercaptans, phenol, elevated pH.	Typically, little or no residual waste generated.
Thermal Cracking/ Visbreaking	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons).	Flow=2.0 Gal/Bbl Oil, H_2S, NH_3, phenol, suspended solids, high pH, BOD_5, COD.	Typically, little or no residual waste generated.
Coking	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons) and decoking emissions (hydrocarbons and particulates).	Flow=1.0 Gal/Bbl High pH, H_2S, NH_3, suspended solids, COD.	Coke dust (carbon particles and hydrocarbons)
Catalytic Cracking	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), fugitive emissions (hydrocarbons) and catalyst regeneration (CO, NO_x, SO_x, and particulates)	Flow=15.0 Gal/Bbl High levels of oil, suspended solids, phenols, cyanides, H_2S, NH_3, high pH, BOD, COD.	Spent catalysts (metals from crude oil and hydrocarbons), spent catalyst fines from electrostatic precipitators (aluminum silicate and metals)
Catalytic Hydro-cracking	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), fugitive emissions (hydrocarbons) and catalyst regeneration (CO, NO_x, SO_x and catalyst dust).	Flow=2.0 Gal/Bbl High COD, suspended solids, H_2S, relatively low levels of BOD.	Spent catalysts fines (metals from crude oil, and hydrocarbons)

SHB-9

Process	Air Emissions	Process Waste Water	Residual Wastes Generated
Hydrotreating/ Hydroprocessing	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons) and catalyst regeneration (CO, NO_x, SO_x)	Flow=1.0 Gal/Bbl H_2S, NH_3, High pH, phenols suspended solids, BOD, COD.	Spent catalyst fines (aluminum silicate and metals).
Alkylation	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), vents and fugitive emissions (hydrocarbons)	Low pH, suspended solids, dissolved solids, COD, H_2S, spent sulfuric acid.	Neutralized alkylation sludge (sulfuric acid or calcium fluoride, hydrocarbons).
Isomerization	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), HCl (potentially in light ends), vents and fugitive emissions (hydrocarbons)	Low pH, chloride salts, caustic wash, relatively low H_2S and NH_3.	Calcium chloride sludge from neutralized HCl gas.
Polymerization	H_2S from caustic washing	H_2S, NH_3, caustic wash, mercaptans and ammonia, high pH.	Spent catalyst containing phosphoric acid.
Catalytic Reforming	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), fugitive emissions (hydrocarbons) and catalyst regeneration (CO, NO_x, SO_x)	Flow=6.0 Gal/Bbl High levels oil, suspended solids, COD. Relatively low H_2S.	Spent catalyst fines from electrostatic precipitators (alumina silicate and metals).
Solvent Extraction	Fugitive solvents	Oil and solvents	Little or no residual wastes generated.
Dewaxing	Fugitive solvents, heaters	Oil and solvents	Little or no residual wastes generated.
Propane Deasphalting	Heater stack gas (CO, SO_x, NO_x, hydrocarbons and particulates), fugitive propane	Oil and propane	Little or no residual wastes generated.
Merox treating	Vents and fugitive emissions (hydrocarbons and disulfides).	Little or no wastewater generated.	Spent Merox caustic solution, waste oil-disulfide mixture.
Wastewater treatment	Fugitive emissions (H_2S, NH_3, and hydrocarbons)	Not Applicable	API separator sludge (phenols, metals and oil), chemical precipitation sludge (chemical coagulants, oil), DAF floats, biological sludges (metals, oil, suspended solids), spent lime.
Gas Treatment and Sulfur Recovery	SO_x, NO_x, and H_2S from vent and tail gas emissions.	H_2S, NH_3, amines, Stretford solution.	Spent catalyst.

Process	Air Emissions	Process Waste Water	Residual Wastes Generated
Blending	Fugitive emissions (hydrocarbons)	Little or no wastewater generated	Little or no residual waste generated.
Heat exchanger cleaning	Periodic fugitive emissions (hydrocarbons)	Oily wastewater generated	Heat exchanger sludge (oil, metals, and suspended solids)
Storage Tanks	Fugitive emissions (hydrocarbons)	Water drained from tanks contaminated with tank product	Tank bottom sludge (iron rust, clay, sand, water, emulsified oil and wax, metals)
Blowdown and flare	Combustion products (CO, SO_x, NO_x and hydrocarbons) from flares, fugitive emissions	Little or no wastewater generated	Little or no residual waste generated.

Sources: *Assessment of Atmospheric Emissions from Petroleum Refining*, Radian Corp., 1980; *Petroleum Refining Hazardous Waste Generation*, U.S. EPA, Office of Solid Waste, 1994.

III.C. Management of Chemicals in Wastestream

The Pollution Prevention Act of 1990 (PPA) requires facilities to report information about the management of TRI chemicals in waste and efforts made to eliminate or reduce those quantities. These data have been collected annually in Section 8 of the TRI reporting Form R beginning with the 1991 reporting year. The data summarized below cover the years 1992-1995 and is meant to provide a basic understanding of the quantities of waste handled by the industry, the methods typically used to manage this waste, and recent trends in these methods. TRI waste management data can be used to assess trends in source reduction within individual industries and facilities, and for specific TRI chemicals. This information could then be used as a tool in identifying opportunities for pollution prevention compliance assistance activities.

From the yearly data presented below it is apparent that the portion of TRI wastes reported as recycled on-site has increased and the portions treated or managed through energy recovery on-site have decreased between 1992 and 1995 (projected). While the quantities reported for 1992 and 1993 are estimates of quantities already managed, the quantities reported for 1994 and 1995 are projections only. The PPA requires these projections to encourage facilities to consider future waste generation and source reduction of those quantities as well as movement up the waste management hierarchy. Future-year estimates are not commitments that facilities reporting under TRI are required to meet.

5HB-11

REFINING ORIENTATION

Hydrocarbon Chemistry

TABLE OF CONTENTS

Page

I. COMPOSITION OF HYDROCARBONS

II. CLASSIFICATION OF HYDROCARBONS

III. REFINING AND HYDROCARBON TYPES

IV. CONCLUSIONS

SHB-13

REFINING ORIENTATION
Hydrocarbon Chemistry

I. COMPOSITION OF HYDROCARBONS

Petroleum is composed of two elements, hydrogen and carbon, joined together in compounds called hydrocarbons. Two simple ways of looking at these hydrocarbons is by ratio and by weight.

A. Ratio Basis

The average ratio of hydrogen to carbon in petroleum hydrocarbons is 2 to 1. This means that although specific compounds may vary, crudes have about two atoms of hydrogen for every atom of carbon.

B. Weight Basis

A single carbon atom weighs 12 times as much as a hydrogen atom. Thus, despite the 2 to 1 ratio of hydrogen to carbon in 100 pounds (45 kilograms) of crude oil, roughly 84 pounds (28 kilograms) will be carbon and 14 (6 kilograms) will be hydrogen. The remaining 2 pounds (1 kilogram) are various impurities and must be greatly reduced because they are harmful to the environment and corrosive to both our refining equipment and the machinery in which our products must ultimately be used. These impurities include sulfur (0-3 lbs.), nitrogen (0-1 lb.), oxygen (0-.5 lbs.), and chlorine, nickel, vanadium, iron, copper, and other metals in traces so small they are measured in parts per million or parts per billion.

II. CLASSIFICATION OF HYDROCARBONS

There are so many different hydrocarbon compounds in crude oil that scientists can only guess at the exact number. Estimates range from 20,000 to 5,000,000; somewhere between 50,000 and 1,000,000 is a reasonable guess. With so many compounds, it's necessary to have systematic ways to classify them into manageable groupings. The two basic systems used are by carbon number and by molecular structure.

A. Carbon Numbers

The simplest classification is by carbon number. This is based on the number of carbon atoms found in a given hydrocarbon molecule. For example, methane (CH_4) has one carbon atom per molecule and is a C_1. Ethane (C_2H_6) and Ethylene (C_2H_4), though different compounds with different properties, are both classified C_2's.

SH3-15

The carbon number is important because it indicates the physical state of the compound. Basically, the higher the carbon number (i.e., the more carbon atoms per molecule), the higher the boiling point, the greater the viscosity (the rate at which it will flow through a small opening) and the higher the density (weight per volume).

Compounds from C_1 to C_4 are gases at room temperature. Those from C_5 to C_{17} are liquids, though some C_{17}'s may be solids. And those from C_{17} to C_{40} are solids. These solids are not like steel or concrete, but more like wax. They can be penetrated with a sharp instrument, but they won't pour or flow unless heated.

GASES

C_1 to C_4

C_1 (methane) is used as a fuel in the refinery. In addition it can be sold and transported by liquefying it by lowering its temperature to -255°F or -159°C. This reduces its volume by a factor of 1000 and thereby simplifies transportation.

C_2 (ethane) is used as a refinery fuel; C_2 ethylene is used in making polyethylene and other plastics.

C_3's (propane and propylene) are used in plastics manufacture; propane can also be liquefied for sale as LPG (Liquid Petroleum Gas).

C_4's, the largest gas molecule at room temperatures, can be combined to form C_8's (liquids) for use in gasoline. C_4's can also be added directly to gasoline to increase vapor pressure for better starts on cold mornings.

LIQUIDS

C_5 to C_{17}

Materials from C_5 to C_{12} are used directly in gasoline manufacture.

C_{13} to C_{17} are used as fuels and lubricants.

SOLIDS

C_{17} to C_{40}

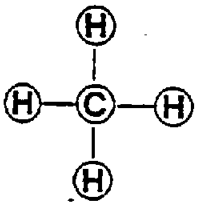
These materials are used for heavy fuels and asphalts. They are also used as charge stocks for refinery processes that break them down into smaller compounds with lower carbon numbers (the C_5 to C_{12} liquids) for use in gasoline.

B. Molecular Structure

A second, more complicated way to classify hydrocarbon compounds is by their molecular structure -- the actual arrangement of the carbon and hydrogen atoms.

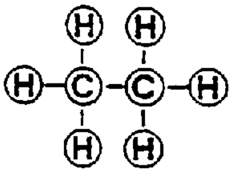
Every atom has the capacity to combine with a given number of other atoms; this is its valence number. The valence of hydrogen, for instance, is 1. One way of looking at that is to say it has a "hand" that can join with a "hand" from another atom to form a valence bond. Carbon has a valence of 4 which means that each carbon atom can combine with four other atoms.

Our simplest hydrocarbon, methane (CH_4) consists of one carbon atom whose four valence "hands" have joined with the valences of four separate hydrogen atoms.



METHANE

Methane is a C_1. To form a C_2, we link one of the carbon atom's valences to one of the valences of a second carbon atom. If we fill the second carbon atom's remaining three valences with hydrogen, we get the C_2 ethane.



SHB-17

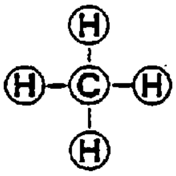
ETHANE

Although there are many hydrocarbon types based on the ratio and arrangment of hydrogen and carbon atoms, there are only four of interest to us in refining: paraffins, olefins, naphthenes, and aromatics.

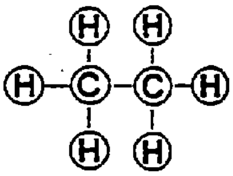
1. Paraffins (Basic formula: C_nH_{2n+2})

Paraffins, also called alkanes, were named when early chemists thought these compounds were relatively inactive.

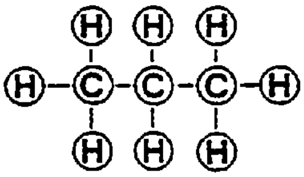
What distinguishes a paraffin is that every carbon atom is holding onto four other atoms. Consider three paraffin compounds below:



METHANE (CH_4)
(C_1 Paraffin)



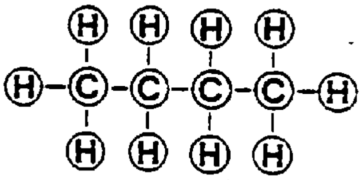
ETHANE (C_2H_6)
(C_2 Paraffin)



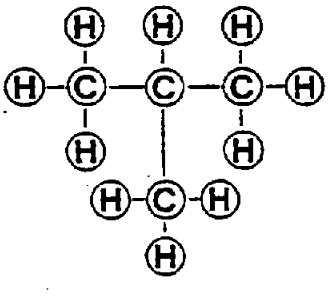
PROPANE (C_3H_8)
(C_3 Paraffin)

In each case, every carbon atom is linked either to a hydrogen atom or to another carbon atom, and the carbons are added together in a row.

When we get to C_4, butane, there are two ways to link the carbon atoms--in a row again, making normal butane, or with one of the carbon atoms connected in the middle, making isobutane



NORMAL BUTANE
(C_4H_{10})

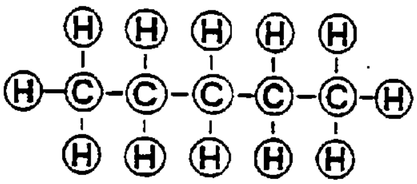


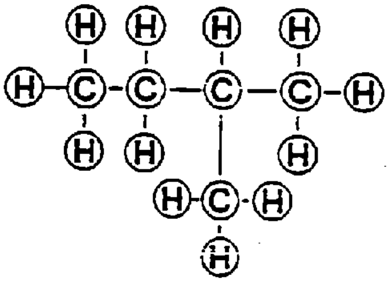
ISOBUTANE
(C_4H_{10})

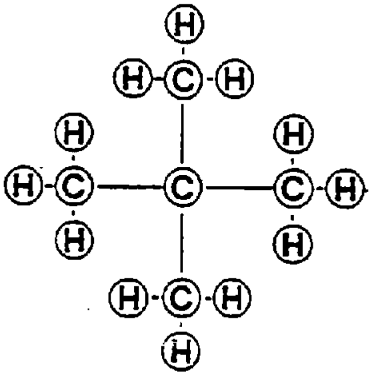
The word "normal" before a paraffin indicates the straight-chain structure, while the prefix "iso-" indicates paraffins with the more complicated branched structures.

Even though these two compounds consist of the same number of carbon and hydrogen atoms they differ chemically and have different boiling points, densities, and refractive indices. Most important from our point of view is that the simple, straight-chain paraffin has a much lower octane than the more compact, branched isoparaffin.

As the carbon number increases, the number of possible permutations (isoparaffins) increases astronomically. There are three combinations for C_5-pentane (C_5H_{12}), (normal pentane) and two isopentanes (called, by convention, isopentane and neopentane).


NORMAL PENTANE


ISOPENTANE


NEOPENTANE

Similarly, there are 9 possible combinations for the C_7 paraffin, heptane, 355 for C_{12}, and 62,491,178,805,132 combinations for C_{40}.

An important thing to remember is that no matter how complicated or how simple, all paraffins have the same ratio of two hydrogen atms for every carbon atom, plus two more hydrogens, one at each end of the chain to fill the remaining valences.

Chemists express this as C_nH_{2n+2}, the formula for all paraffins shown at the beginning of this section. If we have a two-carbon-atom paraffin, then n=2; thus there will be 2 x 2 + 2 = 6 atoms of hydrogen. C_2H_6 is, of course, ethane.

You might try going back and checking one or two of the other paraffins diagrammed above against the formula.

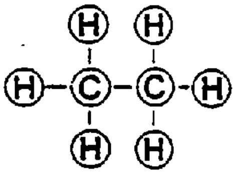
A final point to remember is that the valence bonds of paraffins are saturated with hydrogen. That is, every carbon atom is holding as much hydrogen as it can; every valence not needed to link it to another carbon atom is linked to a hydrogen atom.

2. Olefins (Basic formula: C_nH_{2n})

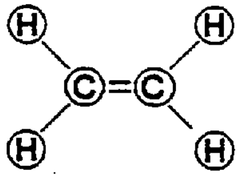
Olefins are the second type of hydrocarbon important to us. Olefins are not found naturally in crude oil, but are the product of the refining process.

What distinguishes olefins from paraffins is that olefins are <u>unsaturated</u>. Our C_2 paraffin, ethane, was saturated because it contained six hydrogen atoms. If we remove two of the hydrogens and bend the two vacated carbon valence bonds around to join with each other, we create a <u>double bond</u> or <u>unsaturated bond</u>. The resulting compound is ethylene, the C_2 olefin.

If it easy to see this difference graphically:



ETHANE (C_2H_6)
C_2 Paraffin



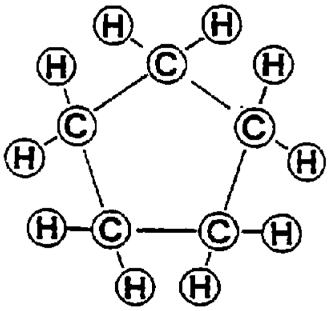
ETHYLENE (C_2H_4)
C_2 Olefin

Because of the double bond, all olefins contain exactly twice as many hydrogen atoms as carbon atoms. So the chemical formula for all olefins is C_nH_{2n}. Propylene and butylene are the C_3 and C_4 olefins respectively.

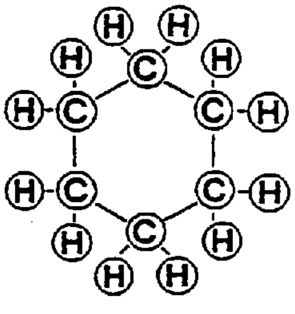
This double bond is also a kind of liability, because it makes olefins less stable than paraffins. Valence bonds are normally 120 degrees apart in three dimensional space. By "bending" the valences around to make them into a double bond, we've created a certain amount of "springiness" in the bond. As a result, when olefins are exposed to sunlight or oxidizing agents, these bonds are prone to springing back and combining readily with other compounds, causing the olefin to loose their double bond.

3. <u>Naphthenes (Basic formula: C_nH_{2n})</u>

Naphthenes, our third type of hydrocarbon, have the same ratio of two hydrogen atoms per carbon atom as do olefins. But they are more like paraffins because they are saturated compounds. This is possible because instead of being like the straight or branched structures we've seen so far, naphthenes exist in a ring structure.



CYCLOPENTANE (C_5H_{10})
C_5 Naphthene



CYCLOHEXANE (C_6H_{12})
C_6 Naphthene

S/63-20

It's as though we took a straight C_5 or C_6 paraffin chain, removed the hydrogen atom from each end, and then bent it around to join the valence of the first carbon atom with the last.

This distinctive ring shape is why naphthenes are also called cycloparaffins. The two naphthenes above, cyclopentane and cyclohexane, are the basis of all naphthenes; all naphthenes are formed by adding to either a cyclopentane or cyclohexane ring.

4. Aromatics (Basic formula: C_nH_{2n-6})

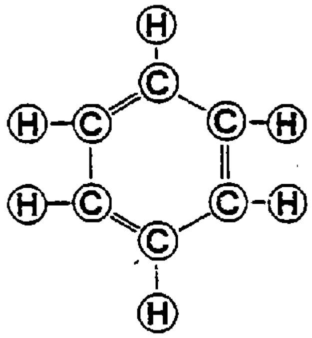
Aromatics gets their name from the fact that the earliest known members of this class had very strong smells.

All aromatics are based on benzene.

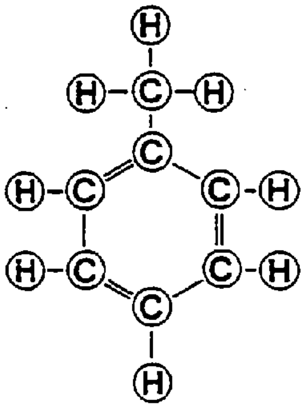
Like the naphthenes, benzene has a cyclic structure called a benzene ring.

But unlike the naphthenes, the benzene ring has double bonds. It is an un-saturated bond.

All the aromatics are formed by adding carbons and their associated hydrogens to the benzene ring creating extra branches and even additional rings. By adding a carbon and two hydrogens, for instance, we get toluene, the only C_7 aromatic.



BENZENE (C_6H_6)
C_6 Aromatic



TOLUENE (C_7H_8)
C_7 Aromatic

III. REFINING AND HYDROCARBON TYPES

The importance of these four hydrocarbon types is that the octane of any hydrocarbon is directly related to its structure or type.

There are many different octane rating systems, including research octane number, motor octane number, road octane, distribution octane, front end octane, AGAC octane, etc.

However, all of them amount to an expression of the amount of knock which a particular mixture of gasoline causes in an engine.

A. What is knock?

In an internal combustion engine, gasoline and air are pulled into (or, with turbocharging, pushed into) the cylinder chamber and compressed by the piston. The compressed fuel mixture is then ignited by the spark plug.

If the mixture burns evenly, it exerts a steady force, pushing the piston back down smoothly to turn the crankshaft.

But if the fuel mixture burns or has tendency to burn too rapidly, it explodes instead of burning evenly. The explosion is what we call engine knock. The greater the engine's compression, the smaller the space into which the fuel/air mix is squeezed before it's ignited, the more explosive it becomes and the greater the likelihood of knocking.

B. History of Octane Ratings

Octane numbers were developed in the early years of gasoline technology. The best fuel known at the time--the one that caused no knock even under high compression was isooctane. It became the standard for fuels and was given an octane number of 100.

Normal heptane, on the other hand, was the worst fuel known at the time because it burned the most explosively and caused the greatest knock. It was given an octane number or 0.

Different hydrocarbons were then tested in an experimental engine equipped with a device to alter the compression ratio. The point at which these various hydrocarbons began to knock was charted in terms of what percentage of isooctane, in an isooctane/normal heptane mix would have caused knock at that same compression. This percentage is octane number.

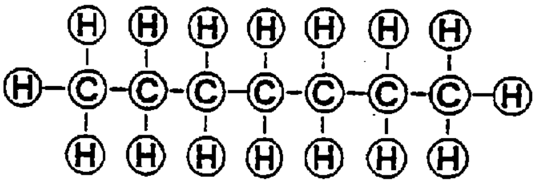
Thus an octane rating of 80 means that a fuel has the same knocking characteristics as a mixture of 80% isooctane and 20% heptane.

C. Octane and Molecular Structure

Octane rating is directly related to the molecular structure of a hydrocarbon. The long straight molecules of normal paraffins (see heptane, below) are most inclined to knock because their bonds are saturated. That is, they contain a great deal of hydrogen which burns readily.

In addition, the long chain structure makes the carbon atoms easily accessible.

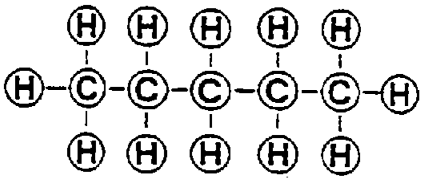
And finally, because of their structure, paraffins burn the cleanest of the hydrocarbon types. They leave little residue.



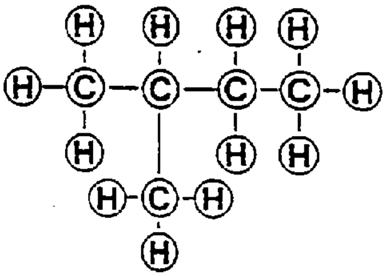
HEPTANE (C_7H_{16})
Normal C_7 Paraffin

The C_6 normal paraffin hexane has an octane of 25; the C_7 normal paraffin, heptane (above), has an octane of 0. And the longer the chain, the worse it gets. The C_8 and C_9 normal paraffins have octanes of -18 and -30 respectively. By the time we get to the C_{10} normal paraffin, we're down to an octane deficit of -41.

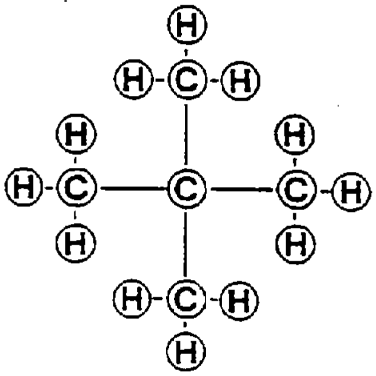
Conversely, the more branched and compact a molecule is--the less hydrogen it has and the less accessible its carbons are to combustion--the more slowly and evenly it burns. For example, isoparaffins with their branched structures have much higher octanes than normal paraffins. Compare the octane of the normal C_5 paraffin below with those of the increasingly compact C_5 isoparaffins known as isopentane and neopentane.



PENTANE (C_5H_{12})
62 Octane



ISOPENTANE (C_5H_{12})
92 Octane



NEOPENTANE (C_5H_{12})
120 Octane

Normal C_5 Paraffin

C_5 Isoparaffins

This same logic holds true for all hydrocarbons. Naphthenes, for example, with even more compact structures and with less hydrogen, have octanes averaging in the

80's and 90's. And the aromatics, with even less hydrogen in their unsaturated benzene ring structures, have the highest octanes of all, running from 100 to as high as 160. In summary, changing the molecular structure of hydrocarbon compounds changes the octane number.

Another way of changing the octane number is by adding Tetra Ethyl Lead (TEL or lead) to gasoline. The addition of lead results in a slower and smoother burning mixture that minimizes knock and increases the octane number.

D. The Refining Processes

The octane of gasoline is determined by the percentage of paraffins, olefins, naphthenes, and aromatics which it contains. This is referred to in refining as the PONA number.

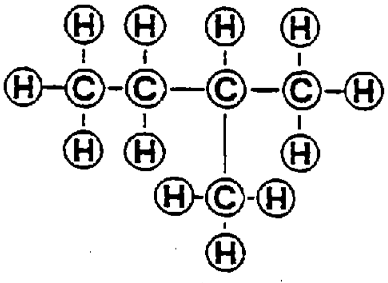
The business of refining is to upgrade the octane of the crude oil by changing one type of hydrocarbon into another of a higher-octane (paraffins into isoparaffins, naphthenes into aromatics, etc.) Various processes are used to do this and they are outlined below.

1. Catalytic Reforming.

The Catalytic reforming process takes materials that are already in the gasoline boiling range (C_5 to C_{12}) and increases their octane by using a catalyst to reform or reshape their molecules.

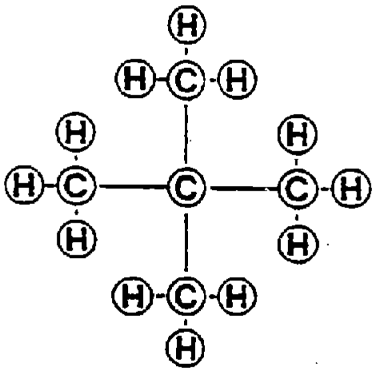
There are actually three reactions in such a reformer.

a. Isomerization: this reaction uses a reactor containing a platinum on alumina base catalyst and rearranges the atoms in low-octane normal paraffins (30-35 average octane) into higher-octane isoparaffins (65 average octane). For example, we can rearrange the atoms of the normal paraffin, pentane (62 octane), by moving one of the carbons below the chain to give us isopentane (92 octane).



SHB-24

ISOPENTANE (C_5H_{12})
92 Octane

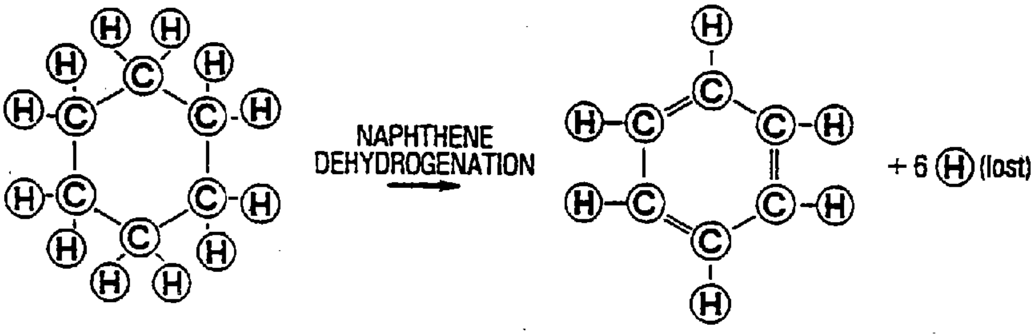


NEOPENTANE (C_5H_{12})
120 Octane

No atoms are lost in this reaction, and hence there is no reduction in volume--i.e., no barrels or cubic meters of liquid lost.

Because of physical limitations we can convert only about 70% of a charge of pentane into isopentane. Since isopentane boils at a lower temperature than normal pentane, however, it can be distilled out and collected while the remaining normal pentane is returned to the reactor for reprocessing.

b. <u>Naphthene Dehydrogenation</u>: This second reaction simply removes hydrogen atoms from naphthenes. For example, by removing 6 hydrogen atoms from cyclohexane, and using the freed valences to create double bonds, we can create the aromatic benzene.



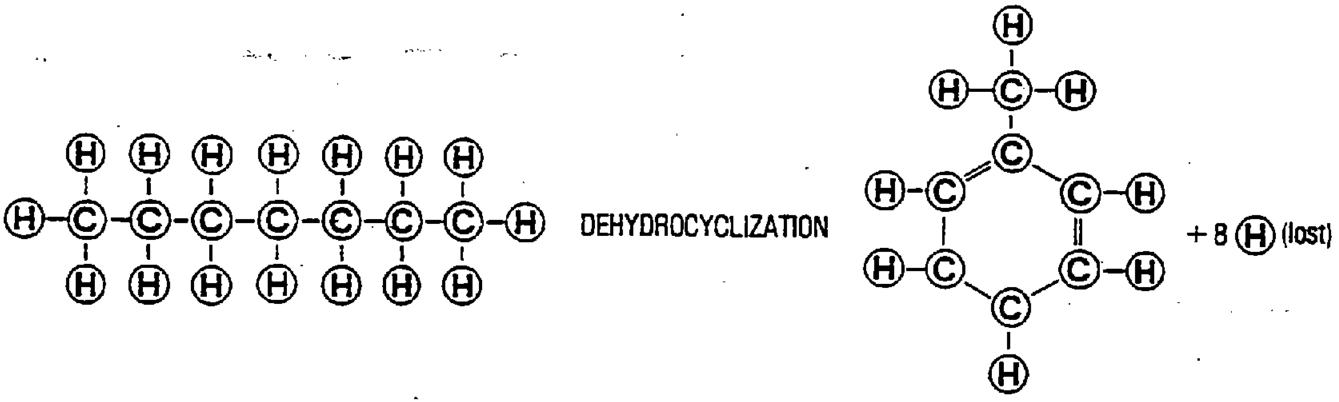
CYCLOHEXANE (C_6H_{12})
C_6 Naphthene
83 octane

BENZENE (C_6H_6)
C_6 Aromatic
100+ octane

Unlike isomerization, the removal of the hydrogen atoms causes some loss of volume.

c. <u>Dehydrocyclization</u>: this third reaction of catalytic reforming has two parts. First, we remove hydrogen from straight normal paraffin molecules (dehydro-) and then bend them around to form ring structures (-cyclization), making them naphthenes or aromatics.

For example, by removing 8 hydrogen atoms from heptane and bending it around to make a six-membered benzene ring with a branch for the seventh carbon atom, we get toluene.



HEPTANE (C_7H_{16})
C_7 Paraffin
0 Octane

TOLUENE (C_7H_8)
C_7 Aromatic
120 Octane

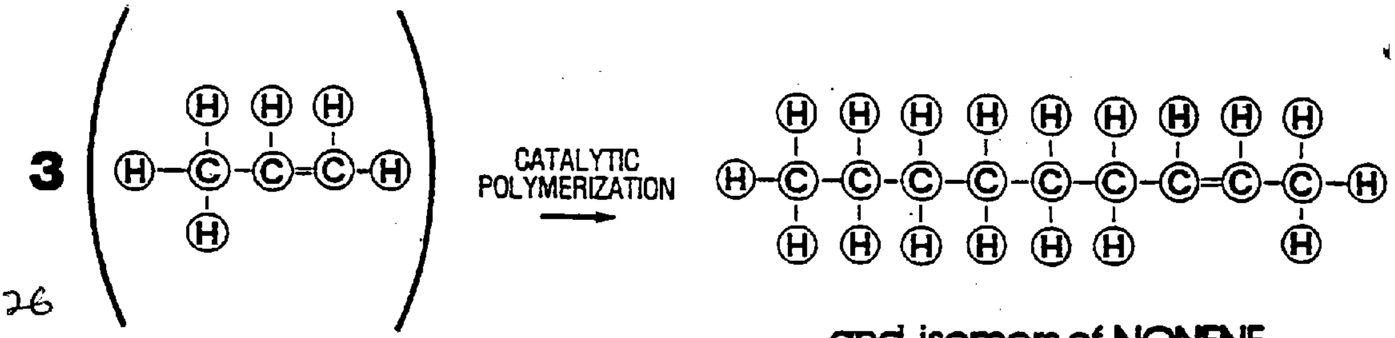
2. Cracking

In this second refining process, big molecules are broken down into smaller ones by breaking them apart or cracking them. For instance, a C_{20} paraffin in the crude will be a solid, useless for gasoline. But by cracking it into two smaller molecules, we can get $C_{10}H_{22}$, a paraffin, and $C_{10}H_{20}$, an olefin, both of which are useful gasoline components. The C_{10} olefin, for instance, has an octane over 90.

$$\underset{\text{Paraffin}}{C_{20}H_{42}} \xrightarrow{\text{Cracking}} \underset{\text{Paraffin}}{C_{10}H_{22}} + \underset{\text{Olefin}}{C_{10}H_{20}}$$

3. Catalytic Polymerization

This process is the opposite of cracking. Instead of making little molecules out of big ones, it is a build-up process that makes big molecules out of little ones. By combining three molecules of the C_3 olefin, propylene, a gas, we can make C_9, a liquid for gasoline blending.



SHB-26

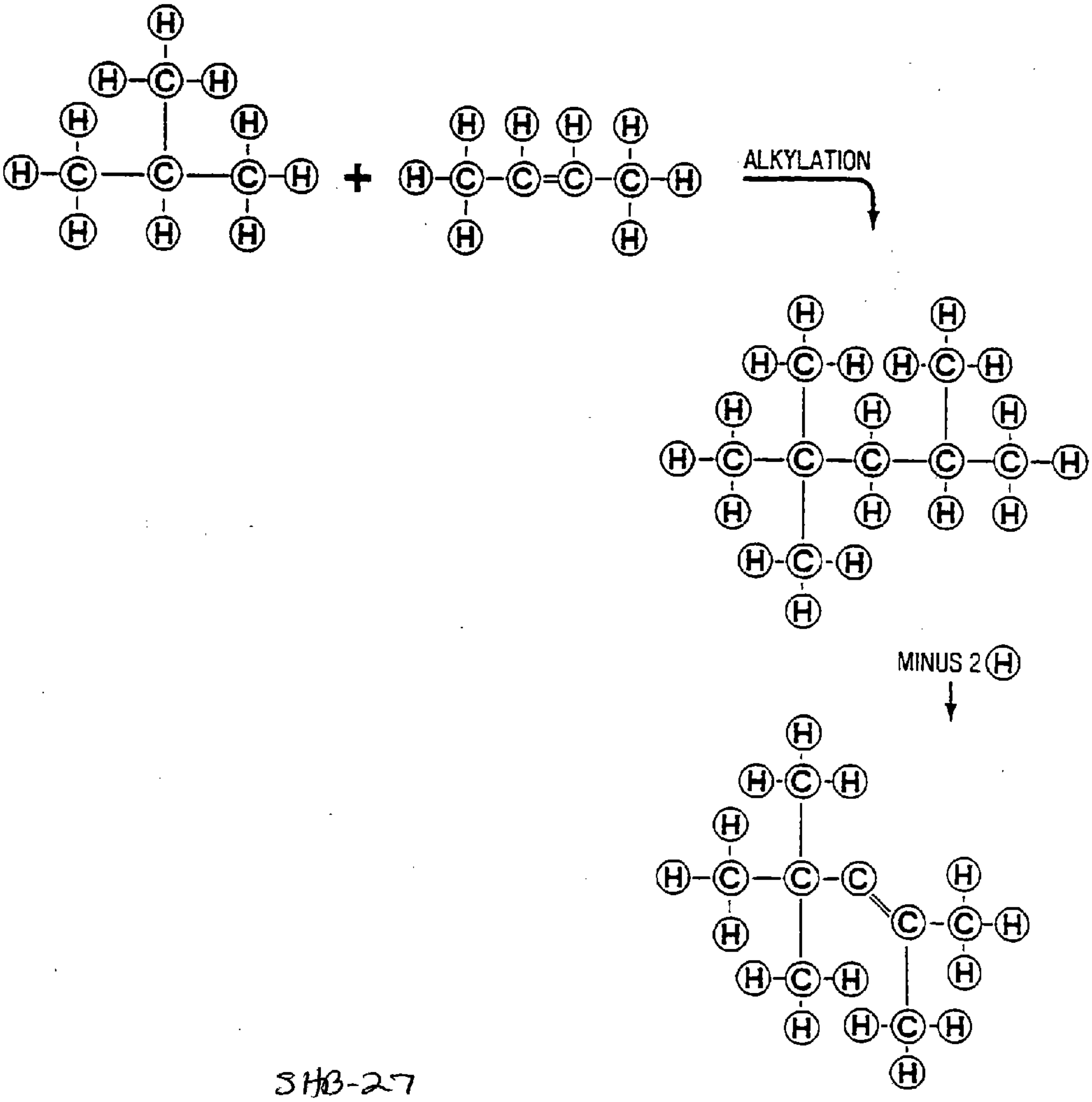
and isomers of NONENE

PROPYLENE (C_3 H_6)
C_3 Olefin

NONENE (C_9H_{18})
C Olefin

4. Alkylation

Alkylation is also a build-up process. Here we can take the C_4 isoparaffin (isobutane) and combine it with the C_4 olefin (butylene). The products of this process, called alkylates, are actually mixtures of many hydrocarbons. The major products are various isomers of C_8 paraffins (isooctanes, C_8H_{18}) which yields octanes (unleaded) in the range of 93 to 95.



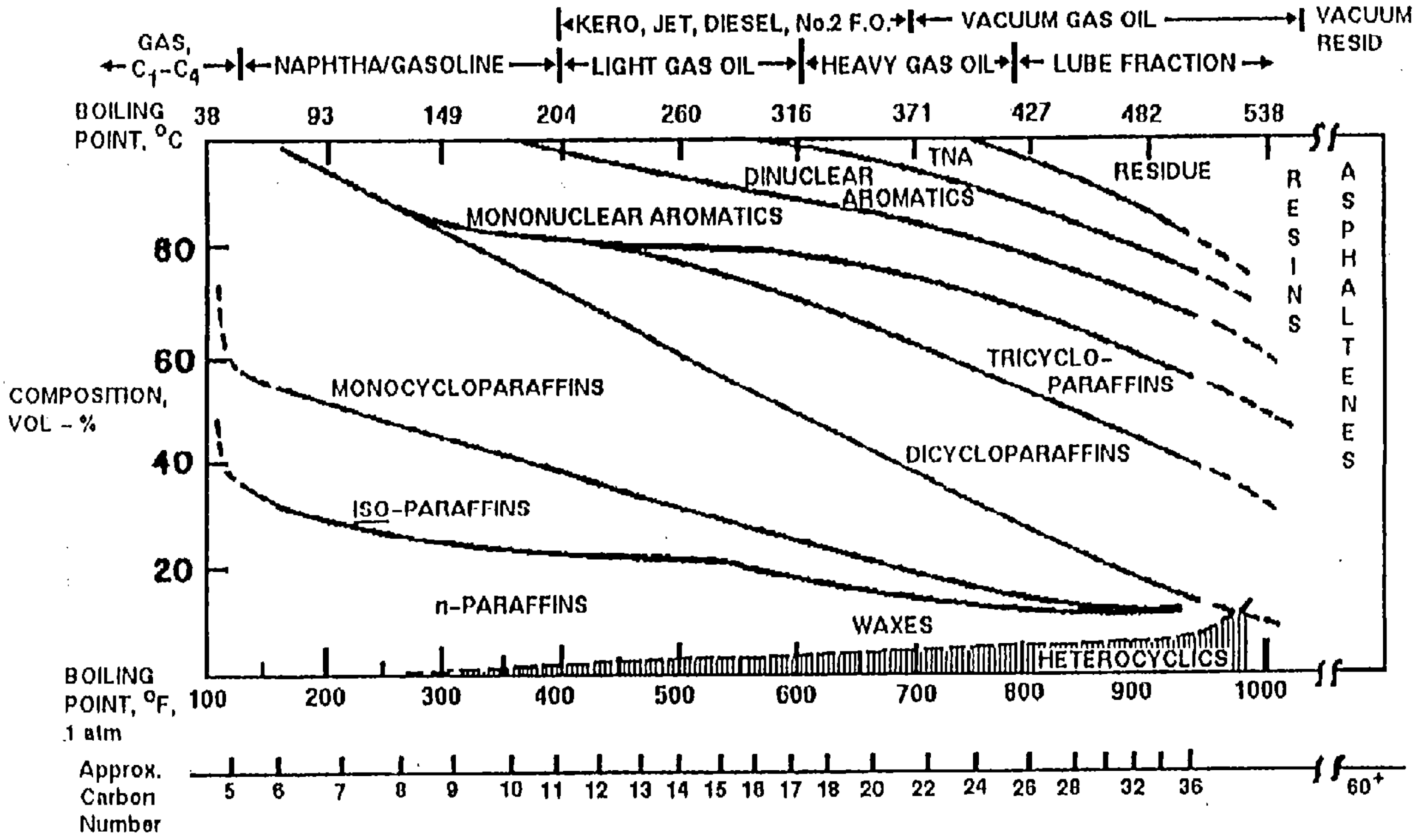
SHB-27

IV. CONCLUSION

As we've seen, every barrel of crude oil is roughly 98 percent hydrocarbons. Our job in the refinery is two fold. We have to get rid of most of the sulfur, nitrogen, oxygen and trace metals that could harm our environment and corrode machinery and equipment. Simultaneously, we have to convert the remaining hydrocarbon compounds into more useful and efficient hydrocarbon products, from fuels like propane and high-octane gasoline to lubricants, asphalts, and the raw materials for plastics and all the other necessities of modern life.

5/18 28

Appendix E. Composition of "typical crude" based on crude from Ponca City Field, Ponca City, Oklahoma.



SHB-29

ANS CRUDE BLEND REPORT FOR WEEK ENDING NOV 20, 1987

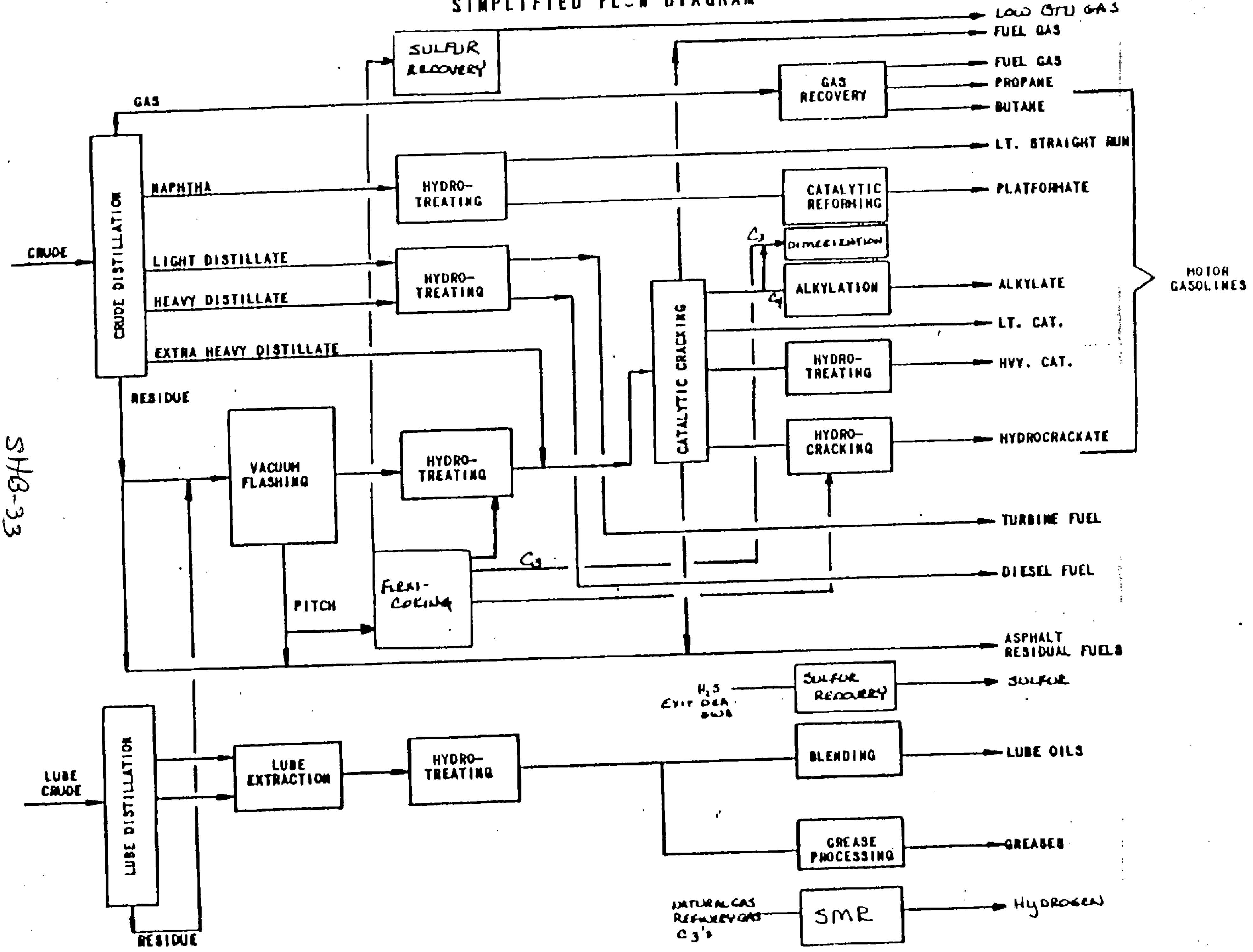
CRUDE PROPERTIES

Assay Gravity	27.1
Sulfur, wt%	1.16
Nitrogen, ppm	2009
Concarbon, wt %	4.79
Nickel,ppm	12
Vanadium, ppm	26

CRUDE BLEND DATA Defined Components Analysis	Vol%
C2	0.04
C3	0.33
iC4	0.44
nC4	1.53
iC5	0.81
nC5	1.14
C6+	95.71
Total	100.00

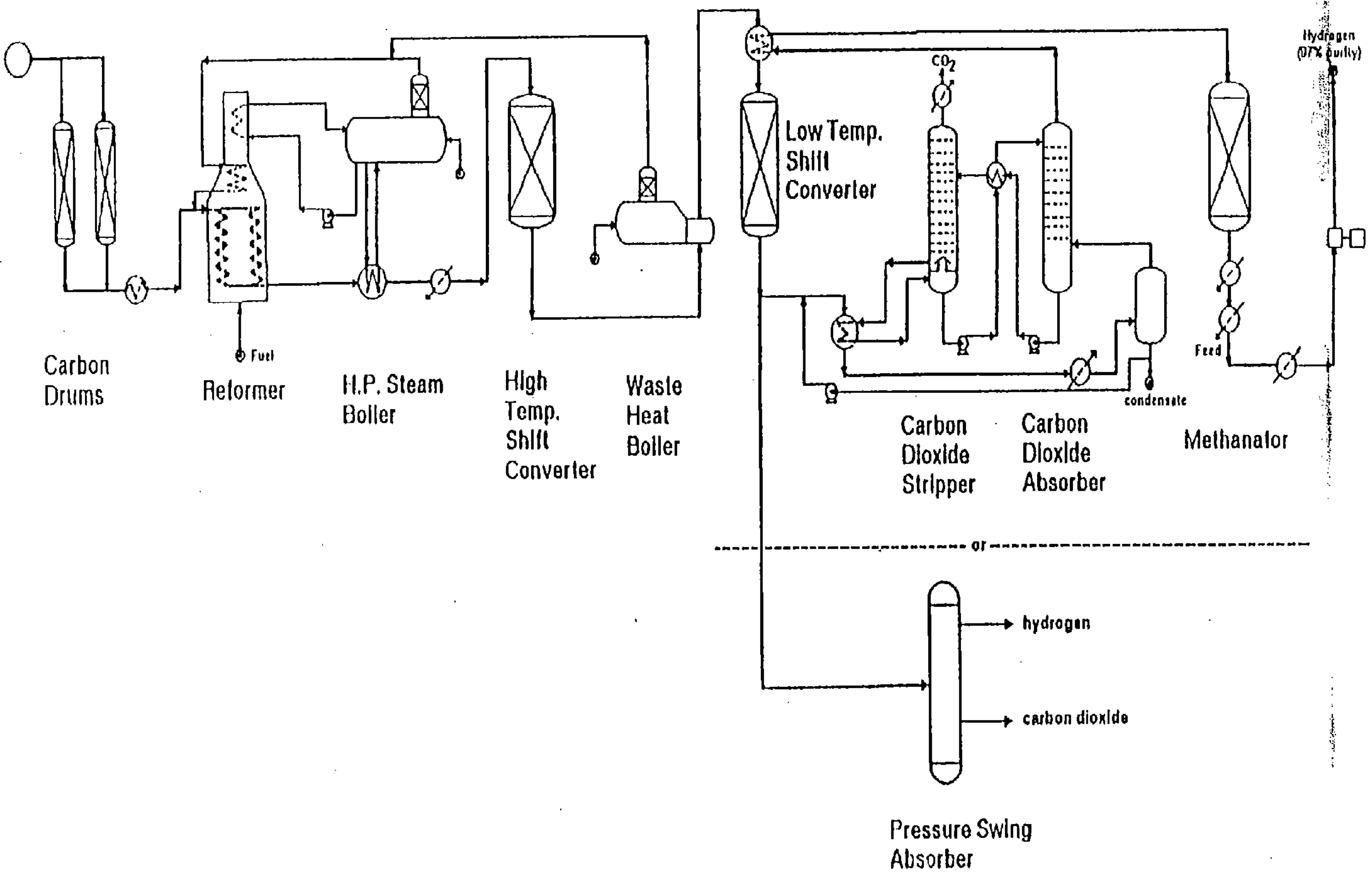
TBP Distillation	API Grav	Sulfur Wt%	Diff Vol %	Cum Vol %
C4-	124.0	0.00	2.4	2.4
150 F	74.7	0.00	3.5	5.9
200 F	59.6	0.00	2.4	8.2
250 F	54.3	0.00	3.1	11.3
300 F	50.0	0.00	3.6	14.9
350 F	47.1	0.00	3.7	18.5
400 F	43.5	0.01	3.9	22.5
450 F	36.8	0.10	4.9	27.3
500 F	34.0	0.30	5.2	32.5
550 F	31.7	0.47	4.7	37.2
600 F	30.6	0.64	5.7	42.8
650 F	27.0	0.85	5.5	48.3
700 F	25.4	0.99	4.1	52.4
750 F	23.8	1.09	4.4	56.8
800 F	22.5	1.21	4.1	60.9
850 F	20.9	1.34	4.3	65.1
900 F	19.5	1.49	4.0	69.1
950 F	17.6	1.64	4.2	73.3
1000 F	16.0	1.80	4.0	77.3
1050 F	13.6	1.89	3.9	81.2
1100 F	11.4	1.97	3.6	84.8
1100+ F	4.9	2.42	15.2	100.0

SIMPLIFIED FLOW DIAGRAM



SHB-33

HYDROGEN PLANT: STEAM REFORMING



SHB-35

Process Considerations for POLYBED® PSA [redacted] Systems

by

Geoffrey Q. Miller, UOP, Tarrytown NY
Michael J. Mitariten, UOP, Tarrytown NY

HYDROGEN SEPARATION PROCESS SELECTION

INTRODUCTION

Two of the major separation processes used to upgrade hydrogen in refineries and chemical facilities are the pressure swing adsorption (PSA) process and the permeation process. Each process employs a different separation principle, and this results in differing process characteristics. These differing characteristics often determine which process is appropriate for a given hydrogen upgrading application. Selection of the appropriate process should be based not only on design-point economics, but also on other project considerations such as turndown requirements, process flexibility, reliability, need for pretreatment, etc.

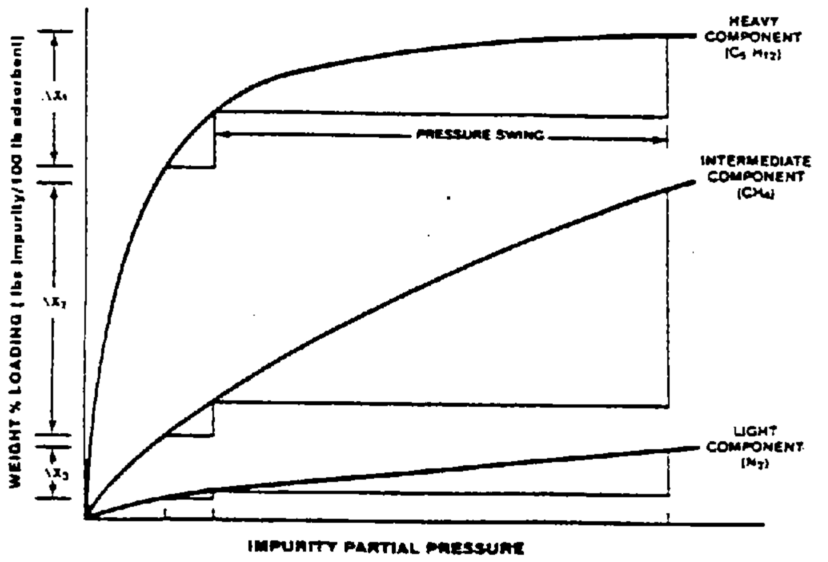
A brief overview of the process characteristics of the PSA and permeation separation processes is given below, along with a discussion of the impact of these process characteristics on other project considerations.

THE PRESSURE SWING ADSORPTION PROCESS

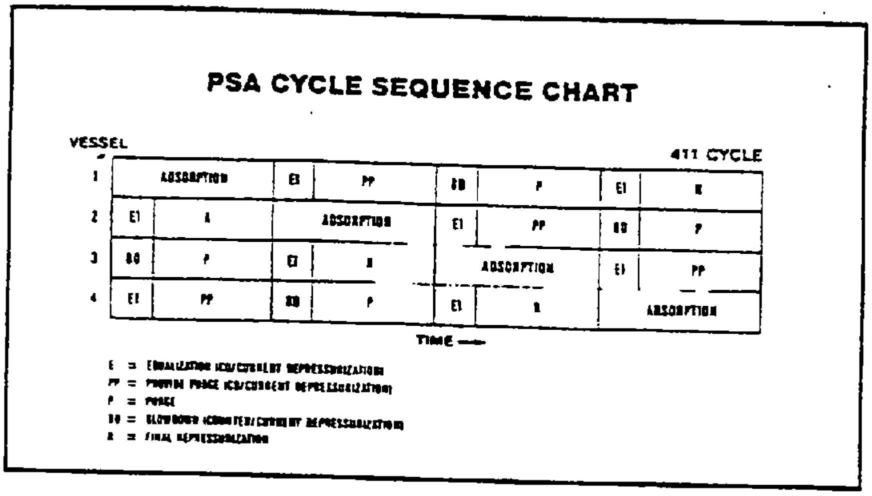
The PSA process for purifying hydrogen was first commercialized by UOP in 1966. Since that time, over 450 POLYBED PSA systems have been designed and supplied for hydrogen upgrading from numerous hydrogen-containing streams. The PSA process is based on the principle that adsorbents are capable of adsorbing more impurities at a higher gas-phase impurity partial pressure than at a lower impurity partial pressure. Hydrogen is essentially non-adsorbed. Thus, impurities are adsorbed in a fixed-bed adsorber at the high system pressure, producing a very high purity hydrogen product, and then rejected as the system pressure "swings" to a lower level. This is illustrated in Figure 1.

Figure 1

ADSORPTION ISOTHERMS



The PSA process is a batch process. However, by using multiple adsorbers, the process behaves as a continuous process from a battery limit standpoint. As an adsorber becomes saturated with impurities from the feed stream, the saturated adsorber is taken off-line, and the feed is switched to a fresh adsorber. In this manner, constant feed and product flows are maintained. The saturated adsorber is then regenerated in a series of steps. In order to recover a large portion of the valuable hydrogen trapped in the adsorber void spaces in the saturated adsorber, the adsorber is depressurized and high purity hydrogen is withdrawn. This hydrogen is used internally to the system for repressurizing and purging other adsorbers, and is therefore not lost from the system. Following these hydrogen recovery steps, the adsorber is depressurized to the lowest allowable system pressure, and the desorbed impurities are rejected to the PSA tail gas. The remaining impurities are then desorbed and rejected to the tail gas by purging the adsorber with hydrogen. The tail gas is almost invariably used as fuel. Finally, the adsorber is repressurized with pure hydrogen prior to being returned to the feed step. A simple PSA cycle sequence is shown in Figure 2.



The PSA process makes a separation in a chromatographic fashion. In general, the least strongly adsorbed impurities are the first to appear as contaminants in the hydrogen product. The relative strengths of adsorption of typical impurities in hydrogen-containing streams are shown in Figure 3.

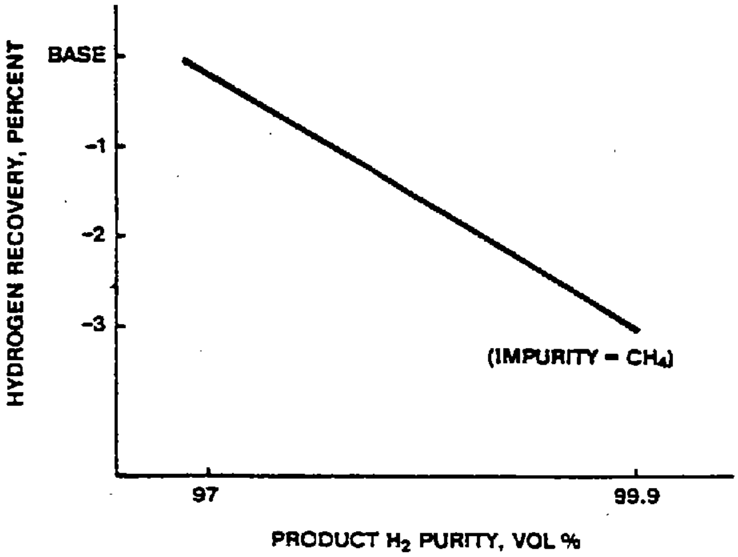
Figure 3
RELATIVE STRENGTH OF ADSORPTION
OF TYPICAL IMPURITIES

NON ADSORBED	LIGHT	INTERMEDIATE	HEAVY
H_2	O_2	CO	C_3H_6
He	N_2	CH_4	C_4H_{10}
	Ar	C_2H_6	C_5
		CO_2	H_2S
		C_3H_8	NH_3
		C_2H_4	BTX
			H_2O

One of the most important characteristics of the PSA process is its ability to remove virtually any vapor-phase impurity to any required (e.g., less than 0.1 ppmv) level, and to produce a very high purity hydrogen product. Typical hydrogen product purities from PSA systems range from 99 to 99.9999+ vol%. There is little effect of product purity on hydrogen recovery, as evidenced in Figure 4.

Figure 4

EFFECT OF PRODUCT PURITY ON PSA SYSTEM HYDROGEN RECOVERY



The PSA process usually requires that the tail gas be withdrawn at 2 to 5 psig in order to achieve hydrogen recoveries of 80-90% (hydrogen recovery is defined as the ratio of the hydrogen contained in the product to the hydrogen contained in the feed). Higher tail gas pressures result in significant reductions in recovery. Increasing the tail gas pressure from 2 to 60 psig can give a 15-20 percentage point reduction in recovery.

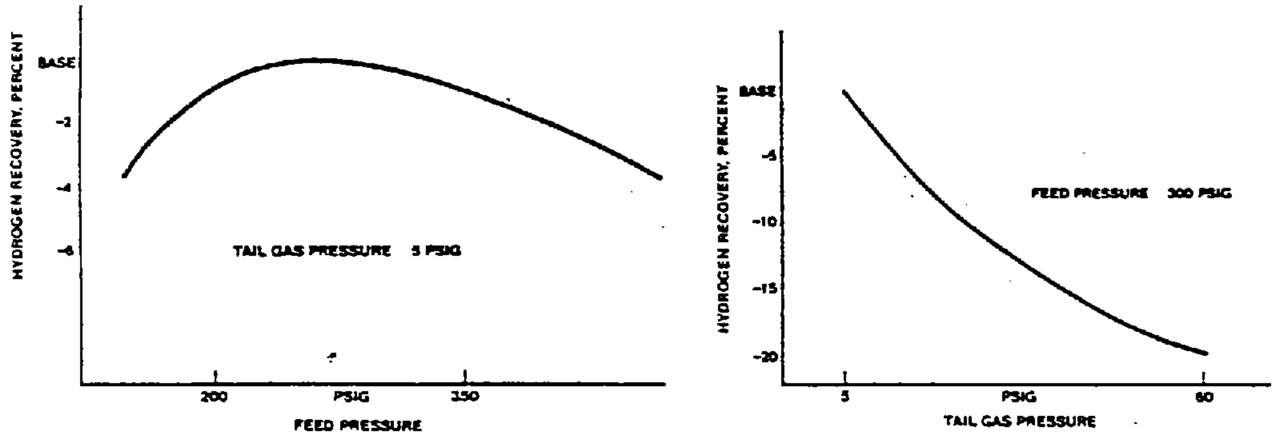
The PSA process is relatively insensitive to feed pressures. Optimum feed pressures depend on the type of system, but are normally in the range of 250 to 500. Commercial POLYBED PSA systems have been designed for pressures ranging from 85 to 1000 psig.

Typical impact of pressure level is contained in Figure 5.

SHB- 40

Figure 5

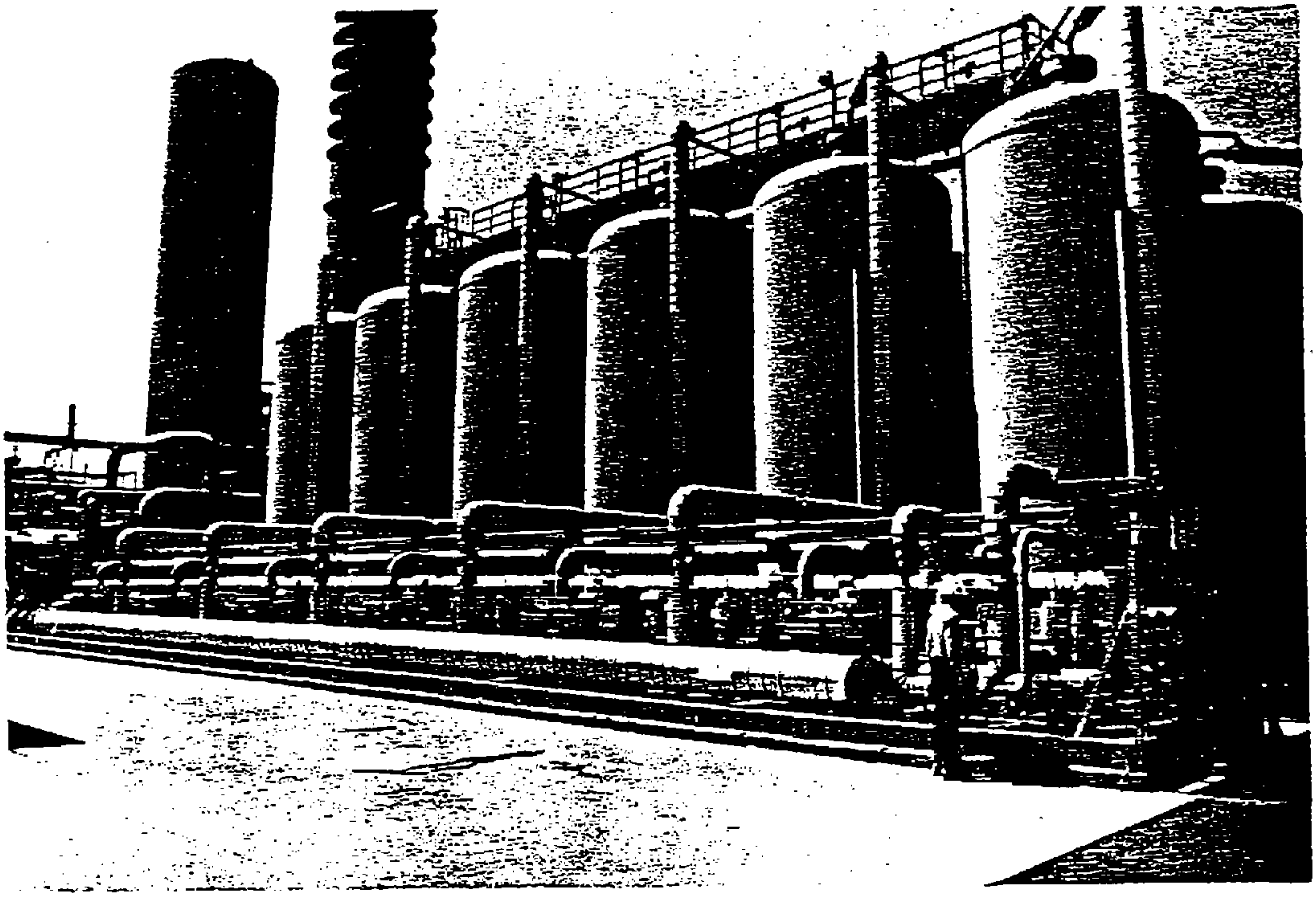
EFFECT OF PRESSURE LEVELS ON PSA SYSTEM RECOVERY



The PSA process requires little feed pretreatment. It is capable of removing many components which present difficulties to the other hydrogen separation processes, including aromatics, carbon oxides, water, hydrogen sulfide and ammonia. However, the feed to a PSA system must be entirely in the vapor phase. Liquids can permanently deactivate the adsorbent. If liquids are not present, the adsorbent lasts for the life of the equipment under normal operating conditions.

PSA process equipment consists of carbon steel adsorber vessels, valve and piping skids, adsorbents, low pressure carbon steel tail gas surge tanks and a computerized control system for valve sequencing and control. A photograph of a POLYBED® PSA system is shown in Figure 6.

Figure 6



This POLYBED PSA was put on-stream in 1988 in the FCC feed hydro-treating section of a major oil company in California. Its capacity is 76.0 million SCFD of 99.9+% H_2 from steam-reforming of natural gas and refinery gas.

- POLYBED is a UOP registered trademark

2.0 PROCESS UNIT DESCRIPTIONS

2.1 CRUDE OIL DISTILLATION UNIT

The crude oil distillation unit is normally the first refinery unit to process the crude oil. In this unit, distillation serves as the basic method for separating the crude petroleum into various fractions that can then be refined into final products.

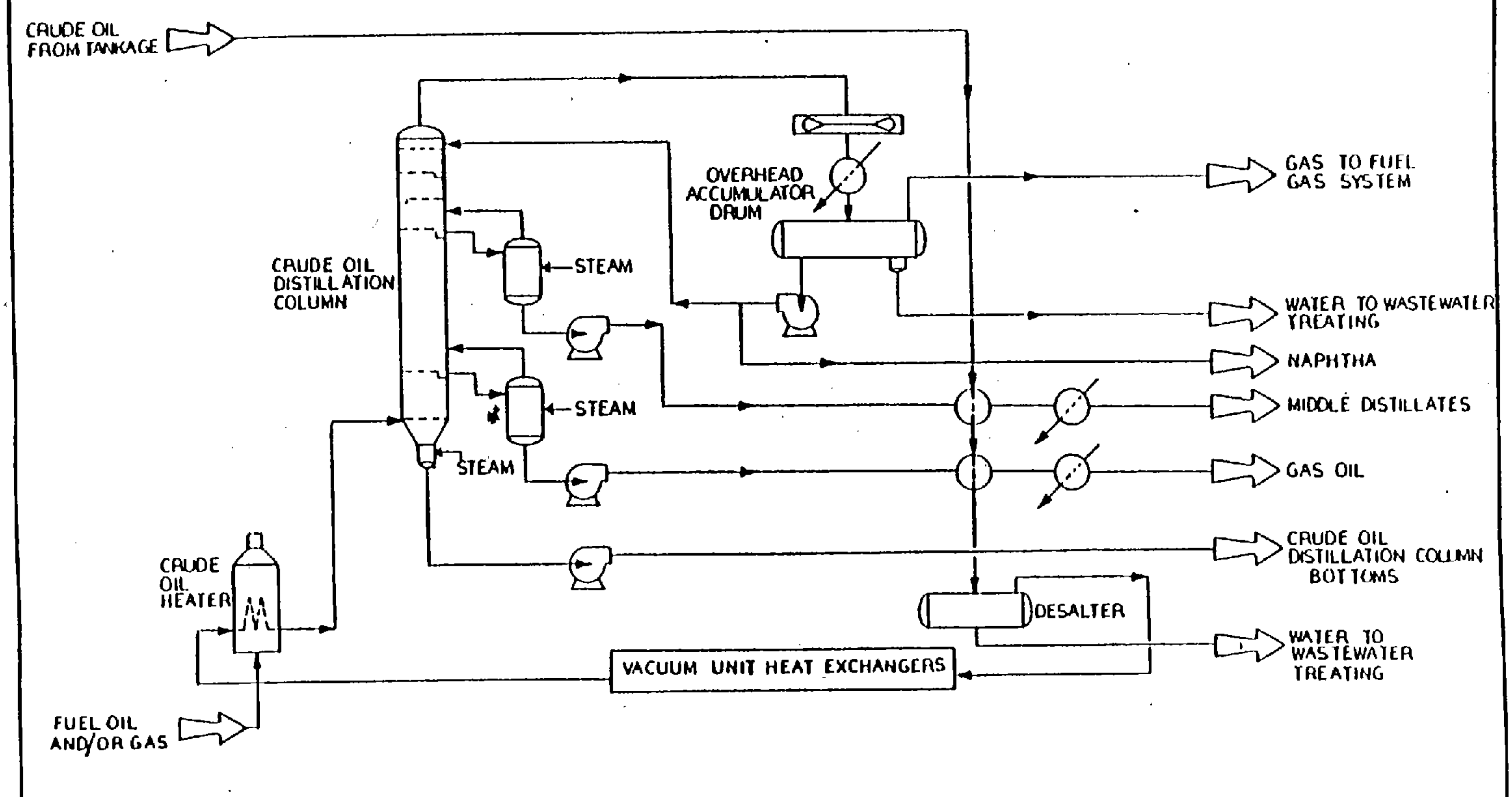
As shown in Figure 5, the crude oil is pumped from tankage, preheated by heat exchange with various product streams (fractions) to about 200-250°F and sent to the desalter. The purpose of desalting is to remove inorganic salts from crude oil so that these salts will not cause plugging of exchangers, coking of furnaces and corrosion. The process also removes the soluble trace metals present in the water phase which act as poisons to process catalysts. The most widely used desalting process is electrostatic desalting. In this process, chemicals and water are added to the crude oil and oil/water separation is carried out by gravity differential in the presence of a high voltage electrostatic field. The field helps to agglomerate the water droplets, which contain the salts, and thus separate the water from the oil. The oil is removed from the top of the desalter vessel, and the water from the bottom. The water is sent to the wastewater treatment plant.

The crude oil is then pumped through additional heat exchangers at the vacuum unit and then through the crude oil furnace where the oil is further heated to 650-700°F. The hot crude oil is then fed to the crude oil distillation column commonly known as the atmospheric distillation column. This column is typically a cylindrical tower 10 to 30 feet in diameter and can be up to 100 feet high and operates at 5 to 20 psig.

As shown in Figure 5, the column separates (distills) the crude oil into product streams having specific boiling point ranges. The higher the boiling point, the "heavier" the fraction. Depending upon the subsequent refinery process scheme, these streams commonly are light ends (lowest boiling points), naphthas, middle distillates, gas

SHB-43

FIGURE 5
CRUDE OIL DISTILLATION UNIT



oil, and crude oil unit residuum (highest boiling point). Some of the heavier streams are often individually steam stripped to further remove the light material that may still be present after distillation. The amount of each fraction depends upon initial composition of the crude oil and the operating conditions of the tower. (A lighter crude oil will produce a greater proportion of light fractions.)

Following distillation, the crude oil distillation unit product streams can be further processed by a number of schemes. For example, distillates can be separated by further distillation to make finished products such as diesel fuel, kerosene and jet fuel. Gas oils can be cracked to form lighter, lower boiling compounds which may be blended into gasolines or recovered directly as heating oil. The processing scheme chosen is dictated by the quality of the crude oil available and the demands of the geographical area where the products are to be marketed.

2.2 VACUUM DISTILLATION UNIT

A vacuum distillation unit is shown in Figure 6. The feed to this unit is the bottoms from the crude oil distillation column. The hot feed is first heated in a furnace to 700-750°F and then charged to the vacuum distillation column. This column operates at 735-660 mm Hg vacuum (760 mm Hg is atmospheric pressure).* The vacuum in the column can be produced by using steam ejectors or vacuum pumps. (Figure 6 shows steam ejectors.) The combination of high temperature and reduced pressure causes additional distillation to take place which cannot occur at atmospheric pressure.

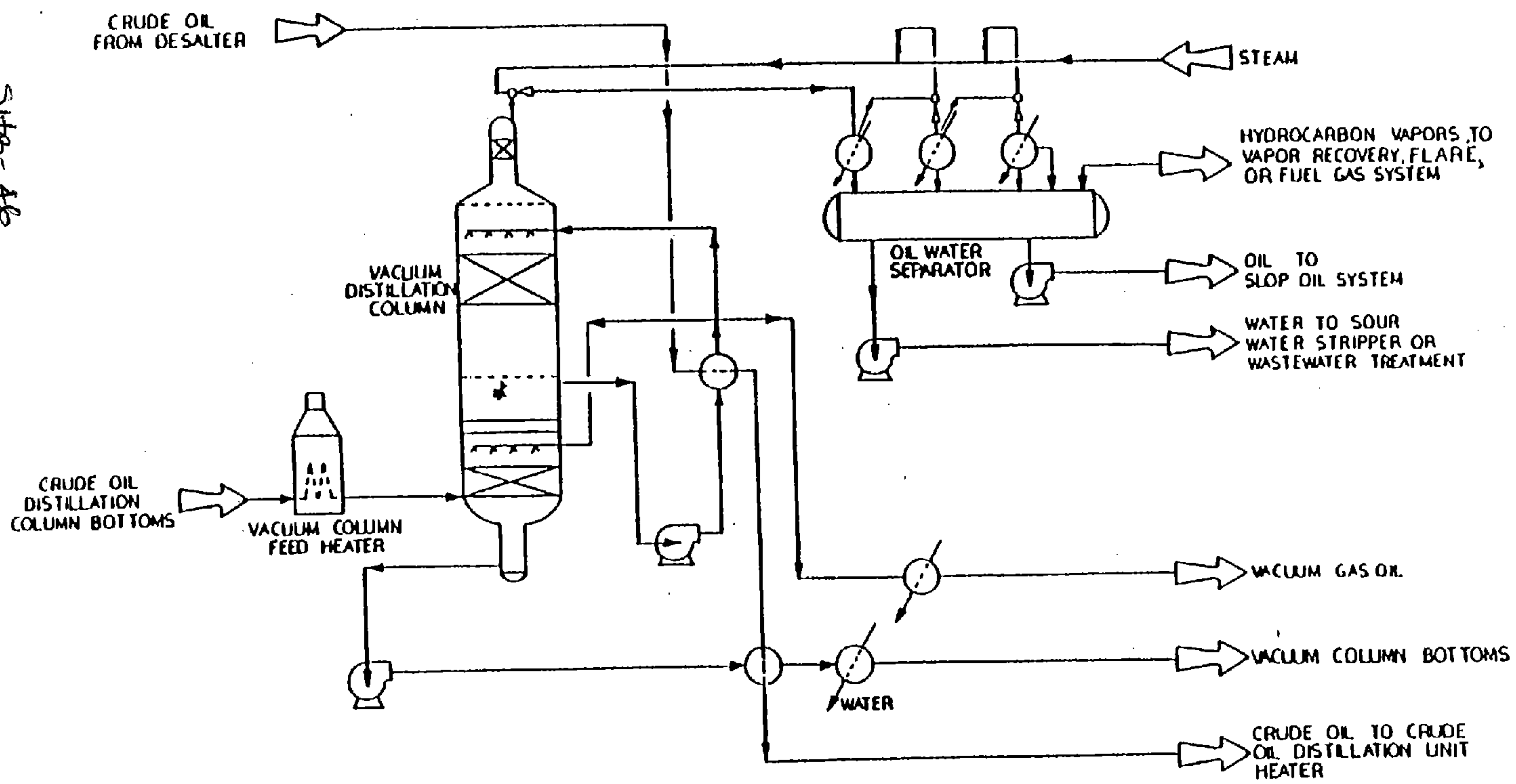
The product streams from the vacuum tower typically are light vacuum gas oil, heavy vacuum gas oil, and vacuum tower bottoms. The tower also produces a stream of lighter material which commonly is collected as an overhead product oil. This oil typically is sent to the "slop oil" collection system. This recovered "slop" oil can be reprocessed through the crude oil distllation unit or sent to other oil processing units.

---

*mm Hg = millimeters of mercury.

SHB-45

FIGURE 6
VACUUM DISTILLATION UNIT



SIHB-46

The product streams from the vacuum distillation unit can be further processed depending upon the desired products and the sulfur content of the crude. While the vacuum gas oil product can be sent to hydrocracking or catalytic cracking, it may be recovered directly as heating fuel oil and would not require further processing. The vacuum column bottoms, in addition to being sent to the coker, may also be sent to the fuel oil blending where it is recovered as bunker fuel oil. If a low sulfur bunker fuel oil is required, the vacuum bottoms may be desulfurized prior to blending.

2.3 HYDROTREATING UNIT

Hydrotreating (also known as hydrodesulfurization) is a catalytic process used to remove sulfur, nitrogen, olefins, arsenic and lead from liquid petroleum fractions. Typically, hydrotreating units are employed ahead of such processes as catalytic reforming since the catalyst used in reforming will be rendered inactive if the feed contains sulfur, nitrogen, olefins or metals. Hydrotreating may also be used prior to catalytic cracking to reduce the sulfur emissions from the regenerator and improve product yields. It may also be employed to upgrade petroleum fractions into finished products such as kerosene, diesel fuel and heating oil. Hydrotreating generally removes over 90% of the above contaminants.

Sulfur removal is accomplished by contacting the untreated petroleum fractions with hydrogen in the presence of a catalyst. The reaction converts the sulfur to hydrogen sulfide (H_2S) and the nitrogen to ammonia (NH_3). The H_2S and NH_3 are separated from the liquid fraction by vapor-liquid separation. In addition, there will be some saturation (removal) of olefins which also will consume hydrogen. The degree of olefin saturation will depend upon the severity of the hydrotreating.

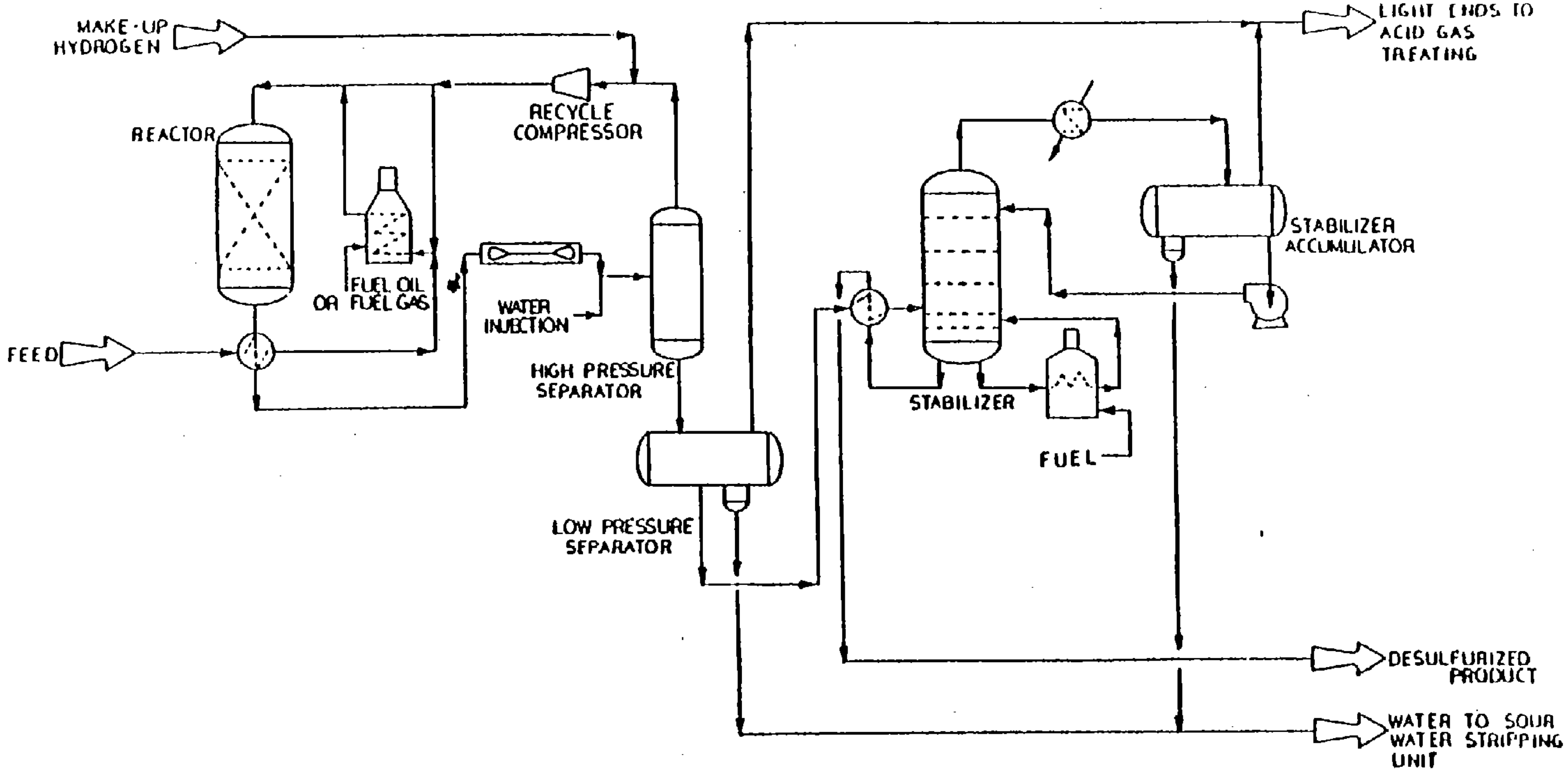
Hydrotreating processes are used on a wide range of feedstocks from naphthas to heavy residual oils (see Figures 1 and 2). In general, hydrotreating of process streams from sour crude oil requires greater quantities of hydrogen and more severe operating conditions (higher hydrogen pressures and lower space velocities) than does hydrotreating of sweet crude oil fractions. The hydrotreating of the heavier process streams (such as distillates or resid) consumes more hydrogen than does the treating of the lighter streams (such as naphtha).

Periodically, the hydrotreating unit catalyst loses activity due to the deposition of coke on the catalyst particles, and must be regenerated. Regeneration consists of burning off this coke under controlled conditions. Typically, regeneration is required when the cumulative amount of feedstock processed is equivalent to about 100-200 barrels of oil/lb of catalyst. This is dependent upon the amount of sulfur present, the characteristics of the feedstock, and the severity of the operating conditions. In many refineries hydrotreating catalysts are regenerated every one to three years.

Figure 7 shows a typical hydrotreating process. The feed is mixed with fresh makeup and recycled hydrogen, heated, and fed to the catalytic reactor where the sulfur and nitrogen are converted to H_2S and NH_3. The hydrogen required for the desulfurization is supplied by the catalytic reforming unit and (if required) a hydrogen plant.

The product then goes to the high pressure separator where the excess hydrogen is flashed off and recycled to the reactor. The liquid then passes to the low pressure separator where the H_2S, NH_3, noncondensible gases, and additional hydrogen are removed. The gas from the low pressure separator is treated to remove the H_2S, and the treated gas goes to the fuel gas treating system. The liquid product from the low pressure separator is then fed to a stabilizer where the remaining light material is stripped off and sent to the fuel gas system and the liquid product goes to further processing or storage. The product from naphtha hydrotreating is sent to a naphtha splitter (fractionation) where the light and heavy naphtha streams are separated. Heavier hydrotreated fractions (i.e., gas oils) can be sent to cracking operations for further processing, or recovered as final products.

FIGURE 7
HYDROTREATING UNIT



SHB-49

For catalyst regeneration, some refineries provide swing reactors that can be taken out of service for catalyst regeneration and therefore do not require a shutdown to regenerate the catalyst.

2.4 CATALYTIC REFORMING UNIT

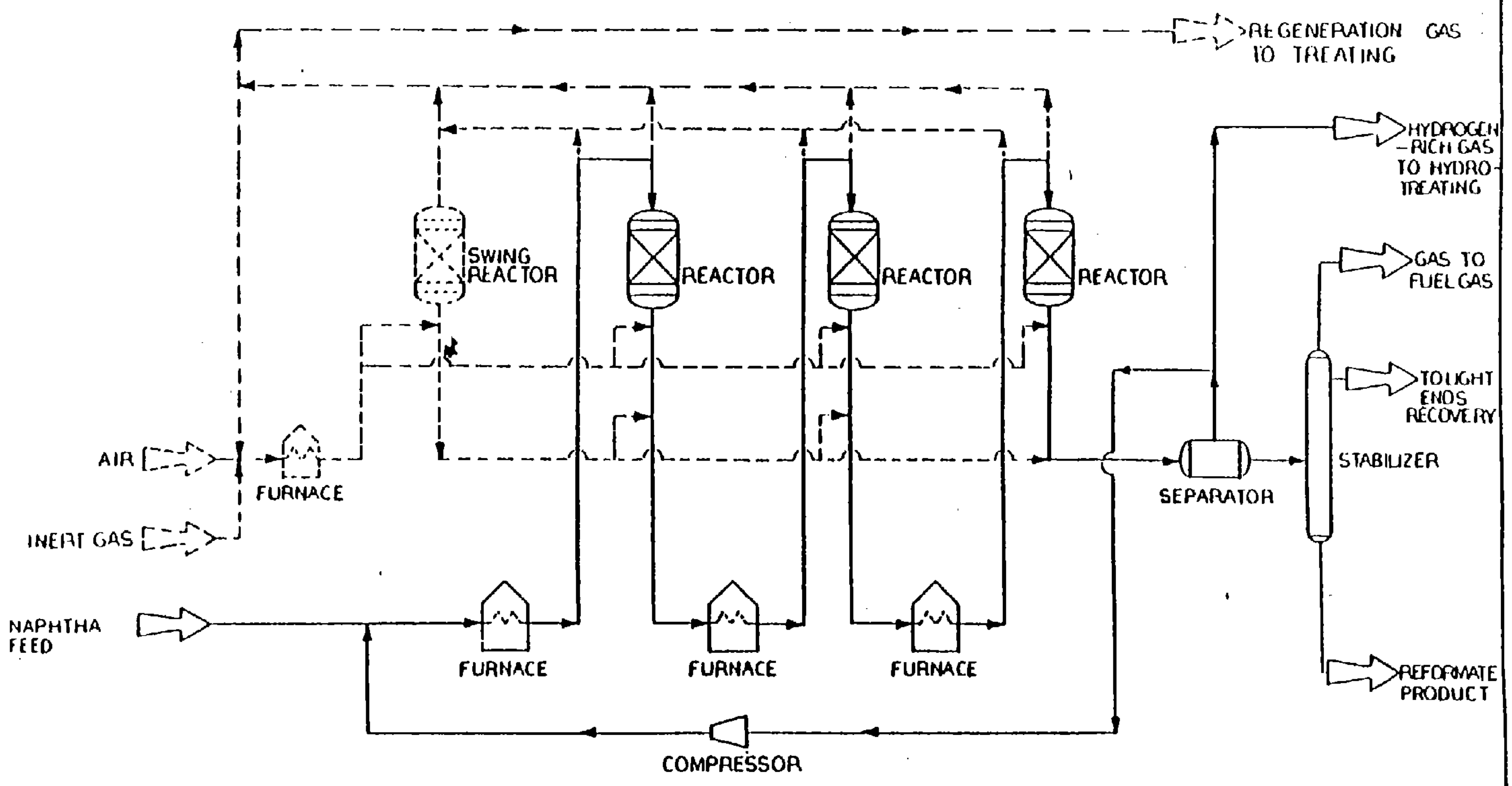
Catalytic reforming is a process used to upgrade low octane heavy naphthas to produce high octane gasoline blending stocks or high yields of aromatic hydrocarbons for petrochemical use (i.e., benzene). The final product will depend upon such variables as reactor temperature and pressure, the catalyst used, and hydrogen recycle rate. Reforming catalysts are readily deactivated (poisoned) by sulfur and the feed must be hydrotreated (desulfurized) prior to being charged to the reforming unit. Typical catalysts are platinum based, but other metals may be used.

Due to the process conditions, reformer catalysts must be regenerated more frequently than hydrotreating catalyst. In some refineries, spent catalyst is replaced rather than being regenerated, but this practice is usually economically prohibitive.

A typical catalytic reforming unit is shown in Figure 8. The naphtha feed is mixed with recycled hydrogen rich gas heated in a furnace and fed to the first reactor. Since the reforming reaction requires heat, (endothermic), the reactor product must be reheated before entering the next reactor. This process is repeated for three reactors. The liquid product then passes to a separator to remove the hydrogen rich gas and then to a stabilizer for final separation of light gases and product. The reformate product then goes to storage for blending into gasoline. The light gases, consisting of mostly propane and butane are sent to light ends recovery.

As shown in Figure 8, a swing reactor is provided to allow for catalyst regeneration without the need to shut the unit down or loss of capacity. As in hydrotreating, during the reforming process, coke is deposited upon the catalyst particles. The regeneration process consists

FIGURE 8
CATALYTIC REFORMING UNIT



of burning off this coke under controlled conditions. The gases (consisting primarily of CO_2) from regeneration are then sent to gas treating for particulate removal before being discharged to the atmosphere.

2.5 FLUID CATALYTIC CRACKING UNIT (FCCU)

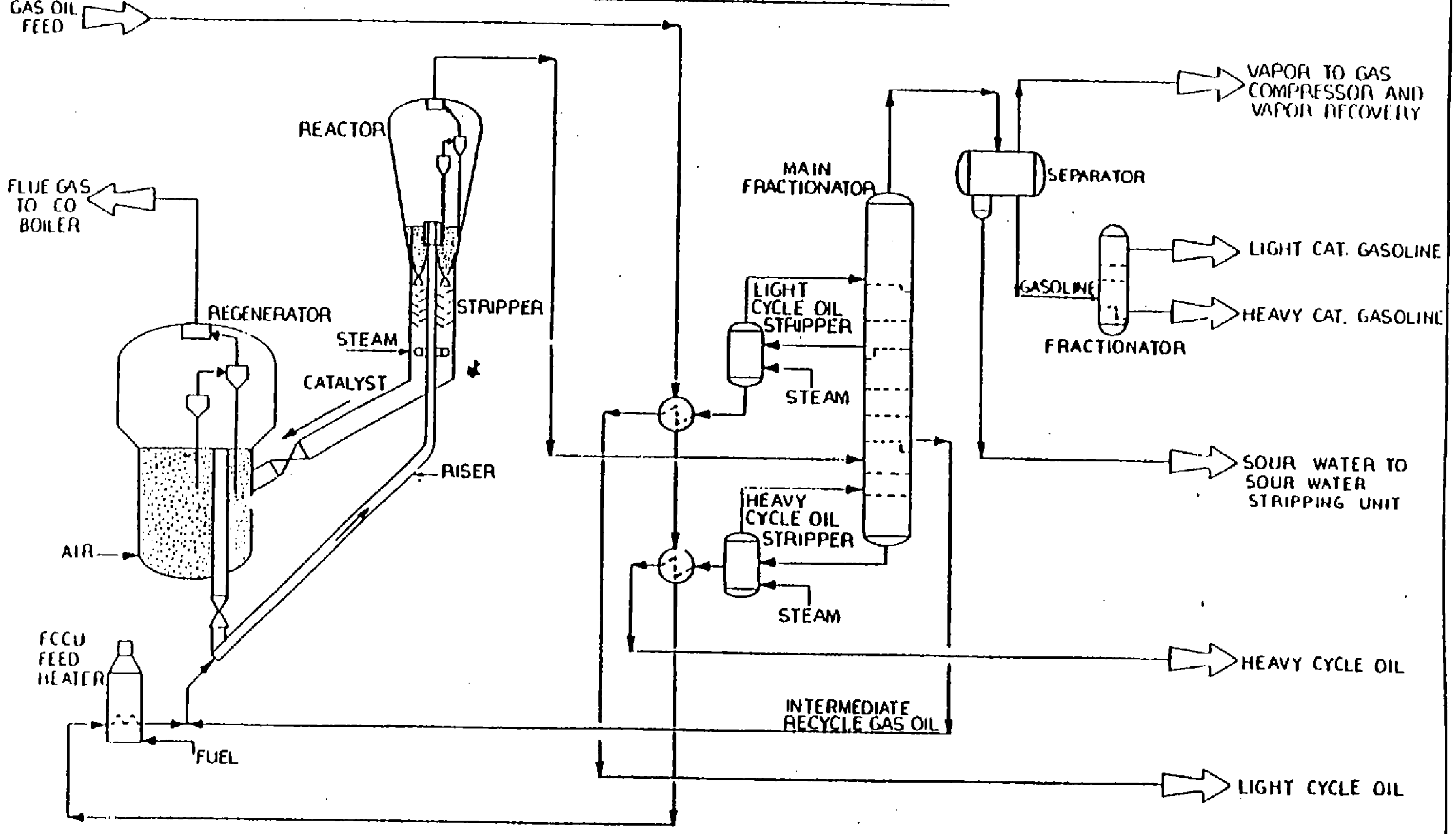
Fluid catalytic cracking is a low pressure process which uses high temperatures in the presence of a catalyst to break or crack heavier, higher boiling petroleum fractions into lighter more valuable materials. The process catalyst is continuously regenerated and depending upon the sulfur content, the unit feed may be desulfurized prior to processing.

A typical FCCU is shown in Figure 9. While there are numerous FCCU designs currently in use, they employ the similar operating principles. Fresh feed is preheated through heat exchange with the unit product streams. It is further heated to process temperature in a fired heater, mixed with regenerated catalyst and fed through the fresh feed riser to the reactor. The flow and temperature conditions in the riser and reactor are carefully controlled to vaporize the feed and achieve the desired degree of cracking. Since the majority of the cracking occurs in the riser, too short of a residence time in the riser will result in too little cracking; too long a residence time will overcrack the material. In the reactor, the cracking process is completed and the hydrocarbon vapors pass through cyclones to remove entrained catalyst and then to the fractionator. The fractionator separates the cracked product into the various streams. Reactor temperatures are typically 950 to 1400°F and pressures are 10 to 20 psig.

Due to the severity of the cracking operation conditions, catalyst must be continuously regenerated to remove coke which is formed on the catalyst as a by-product of the process. Spent catalyst is discharged from the reactor, steam stripped to remove entrained hydrocarbons, and fed to the regenerator. Air is fed to the regenerator and, due to the high catalyst temperature, the coke is burned off the catalyst and forms a mixture of CO and CO_2. The heat from coke combustion serves to maintain a hot catalyst bed. The regenerator flue gases

SHB-52

FIGURE 9
FLUID CATALYTIC CRACKING UNIT



are passed through cyclones to a CO boiler to burn the carbon monoxide to carbon dioxide and recover heat and generate steam. The regenerated catalyst is then returned to the feed riser. Operating conditions in the regenerator range from 1100 to 1300°F and 10 to 25 psig.

2.6 HYDROCRACKING UNIT

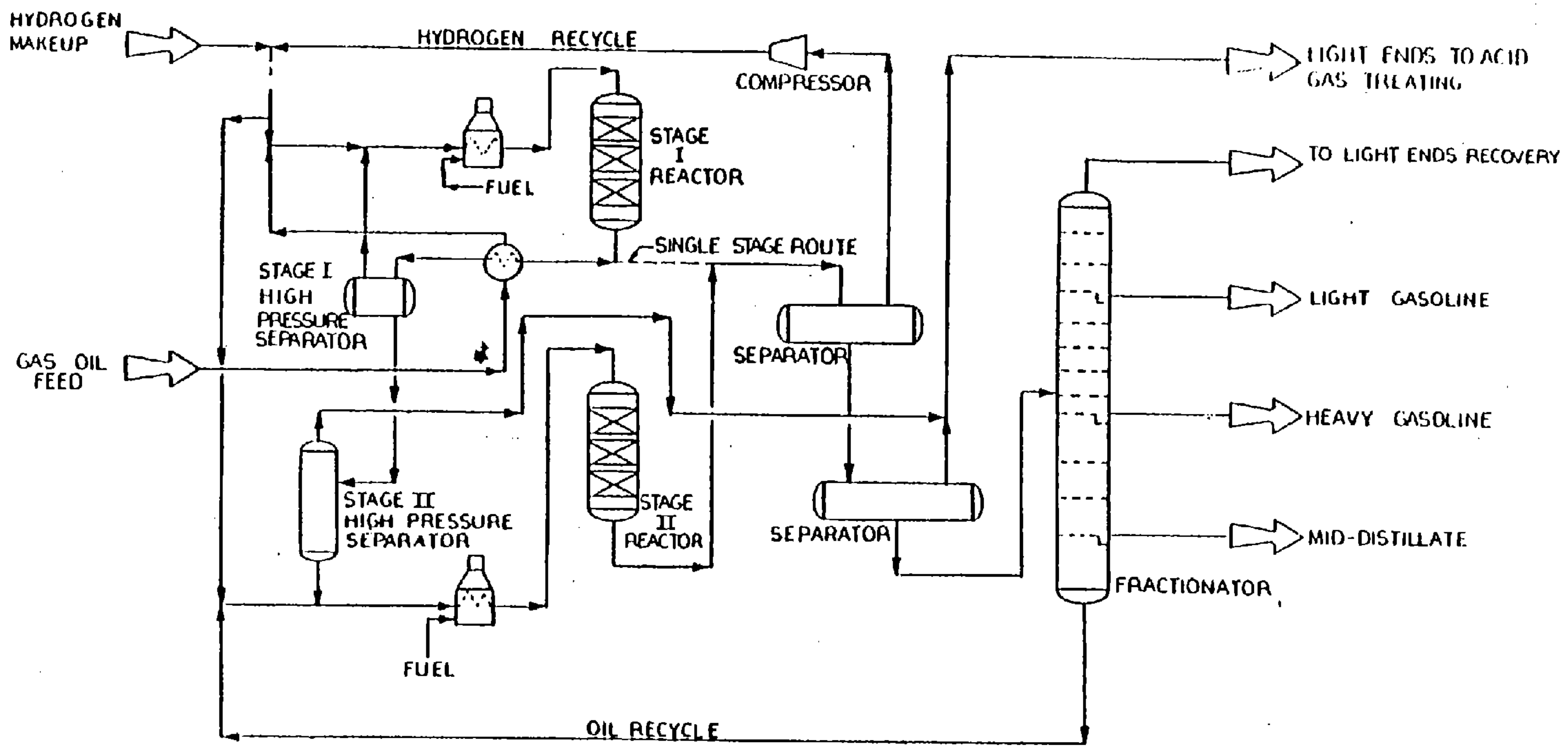
Hydrocracking differs from fluid catalytic cracking in that hydrogen is used in the cracking process and the process pressures are substantially higher (500-4500 psig). Temperatures are, however, somewhat lower (500-550°F) and a different type of catalyst is employed. This process is useful particularly for sour feedstocks in that a high degree of desulfurization is accomplished in the reactor and therefore hydrotreating of sour feeds ahead of the process may not be required. The process produces high quality gasoline and distillates and accepts a wide variety of feedstocks including naphthas, gas oils, and heavy aromatic feedstocks that could cause severe coking if fed to the FCCU.

A typical hydrocracking unit is shown in Figure 10. While Figure 10 shows a two-stage system, single stage processes are also used, primarily with sweet (low sulfur) feedstocks. Feed is mixed with hydrogen, heated, and fed to the first reactor. In this stage, depending upon conditions, some cracking of hydrocarbons occurs, but the principal reactions are the conversion of sulfur to H_2S and the nitrogen to NH_3. The first stage effluent is cooled and fed to the two stage, high pressure separator where the hydrogen-rich gases and light ends are removed. The product from the first reactor is then mixed with recycle fractionator bottoms and additional hydrogen and fed to the second stage reactor where the cracking reactions are completed.

The second stage reactor products then are fed to another two-stage separator where further removal of hydrogen and light ends is accomplished. The liquid product is then fed to the fractionator where the liquid product is separated into the various product streams.

SHB-54

FIGURE 10
HYDROCRACKING UNIT



SHB-55

2.7 DELAYED COKING UNIT

Delayed coking is another type of cracking process which does not employ a catalyst or hydrogen. The process is described as a thermal cracking process in that the cracking is accomplished at high temperature (900-950°F) and low pressures (20 to 60 psig). Feedstocks to coking units typically are heavy bottom products from the vacuum unit and heavy cycle oils from catalytic cracking.

A delayed coking unit is shown in Figure 11. The fresh charge is fed directly to the fractionator where the feed combines with the heavy recycle. The combined feed (fractionator bottoms) then is pumped to the coker furnace where it is heated to coking temperature. This heating produces partial vaporization and mild cracking. The liquid-vapor mixture then enters the coke drum where the liquid undergoes further cracking until it is converted to hydrocarbon vapor and coke. The vapor is further cracked as it passes upward through the coke bed.

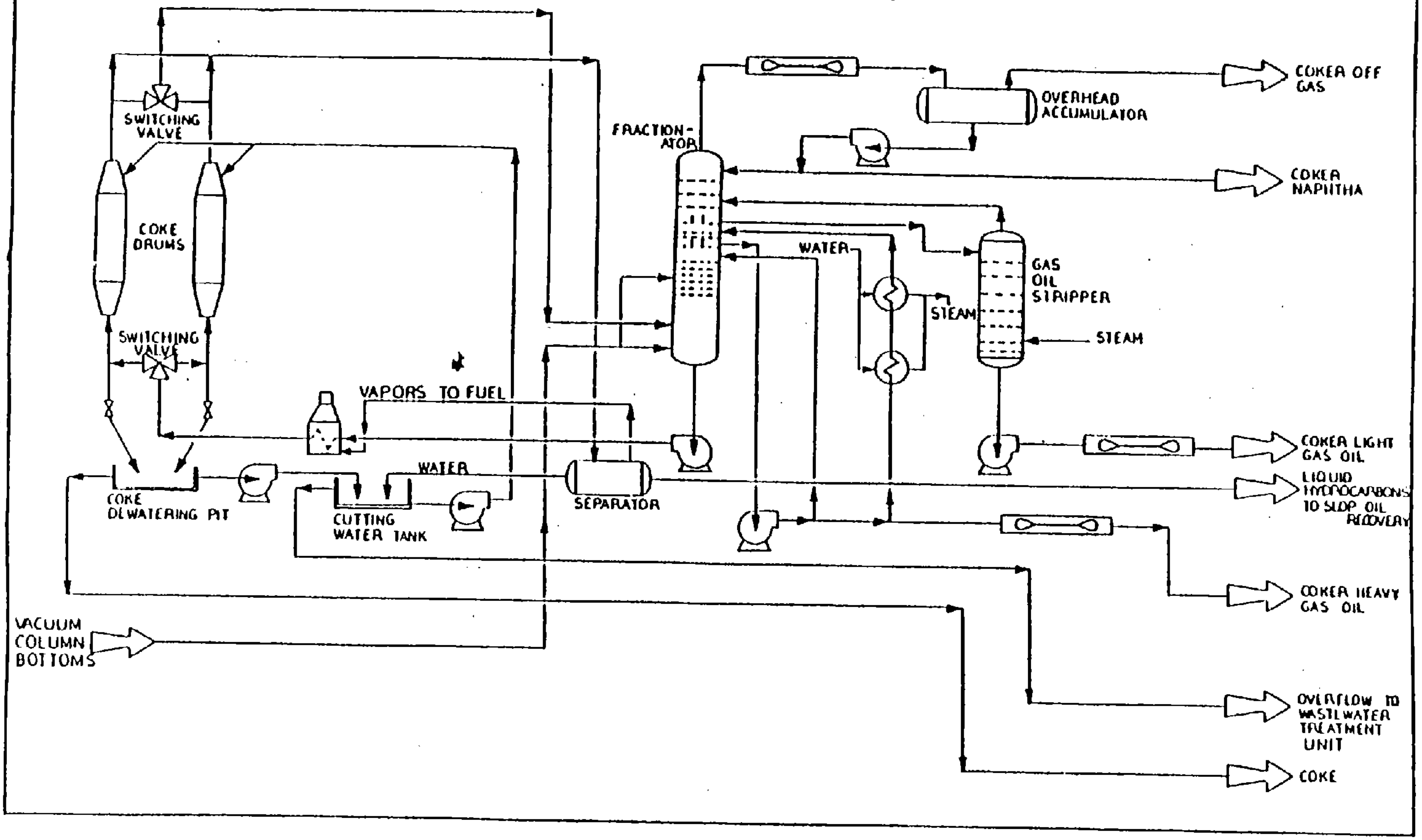
The coke drum overhead vapor then enters the fractionator and is separated into coker off gas, coker naphtha, and light and heavy coker gas oils, which are withdrawn as products. The unreacted material is recycled from the bottom of the fractionator and combined with fresh feed for another pass through the system. The unit recovers heat by generating steam in the fractionator side pumparound.

The coking unit typically has at least two coke drums but may have more to accommodate higher feedrates. In the normal operation of a two-drum system, one drum is in service while the other is being decoked.

Decoking is a two-step process in which the coke is first cooled and then removed from the drum. In the cooling step, saturated steam and water are injected into the bottom of the drum. This cools the coke and removes volatile hydrocarbon vapors. The water vapor-hydrocarbon vapor mixture passes to a separator where it is condensed. The separator discharges a vapor stream of non-condensible hydrocarbons which is used as heater fuel, a water stream which is used in the second

SHB-66

FIGURE II
DELAYED COKING UNIT



SHB-67

decoking step, and a liquid hydrocarbon stream which is recovered as slop oil.

When the coke is cool, the drumhead is removed and coke removal (decoking) begins. First, a high pressure water drill is used to bore a pilot hole in the coke bed. Upon completion of the pilot hole, the drill bit is changed to one with specially designed water sprays which loosen (cut) the coke from the drum. The coke and water drop from the drum into a pit where the coke dewaters and the cutting water is recovered for reuse. Excess water is discharged to the wastewater treatment plant. The coke is then removed from the pit by heavy loading equipment either to storage piles or directly onto hauling equipment.

2.8 HYDROFLUORIC ACID (HF) ALKYLATION UNIT

The purpose of the alkylation unit is to convert unsaturated propylene, butylene and isobutane, in the presence of a hydrofluoric acid catalyst,* into a material called alkylate which is blended into gasoline. Propylene and butylene are produced by the fluid catalytic cracking unit and isobutane is recovered from the light ends recovery unit. The alkylate product, when blended into gasoline, will offer a good octane rating which is especially important in the production of unleaded gasoline. Unit operating conditions are typically 100 to 125 psig, and 90 to 120°F, in the reactor, 40 to 100 psig, and 280°F, in the fractionator, and 300 to 390 psig, and 400°F, in the HF stripper. A typical HF alkylation unit is shown in Figure 12.

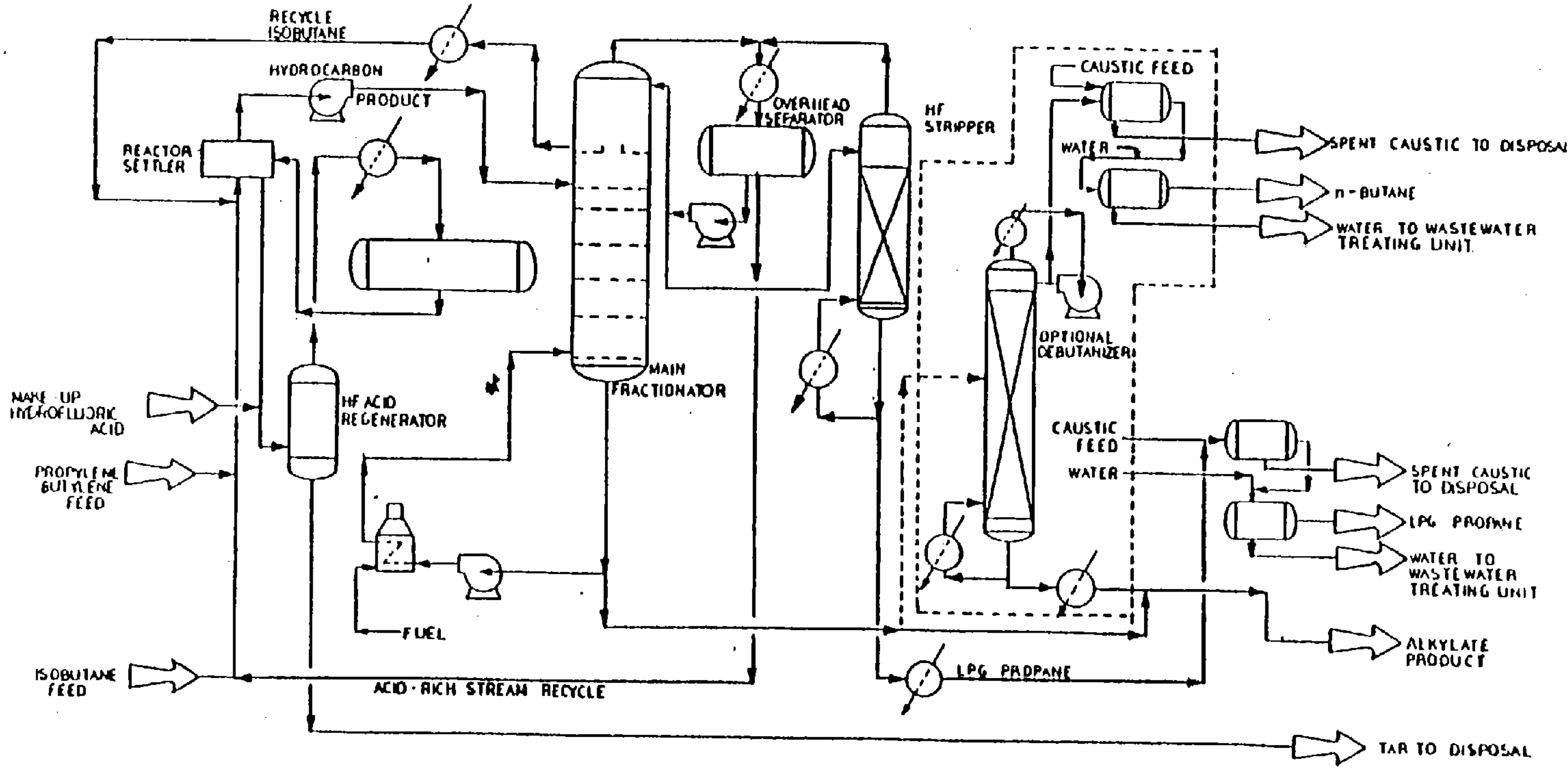
The unit feed containing principally propylene and butylene is mixed with recycled acid and isobutane and fed to a reactor-settler where alkylation reaction takes place. The hydrocarbon phase is withdrawn to a fractionator where the alkylate product is separated from the unreacted feed, entrained catalyst, and the propane and n-butane that are formed by the reaction. The product alkylate may first be debutanized if necessary, or be pumped directly to storage or gasoline blending.

---

*Alternative processes may use sulfuric acid rather than HF.

SHB-58

FIGURE 12
HYDROFLUORIC ACID ALKYLATION UNIT



The fractionator overhead product is condensed and collected in an overhead separator where propane-rich and acid-rich fractions are formed. A portion of the propane-rich material is recycled directly to the fractionator, and the remainder is fed to the HF stripper to separate the HF and the liquefied petroleum gas (LPG) product. The LPG is usually sent to a caustic wash to neutralize any acid that may be present and then to storage. The acid-rich fraction from the overhead separator is recycled and mixed with the incoming feed.

The alkylation unit usually also includes an HF regenerator which continuously purifies a small side stream of acid. The tar that is formed in the regenerator may be disposed of by incineration or neutralized with lime and handled as a solid waste.

2.9 LIGHT NAPHTHA ISOMERIZATION

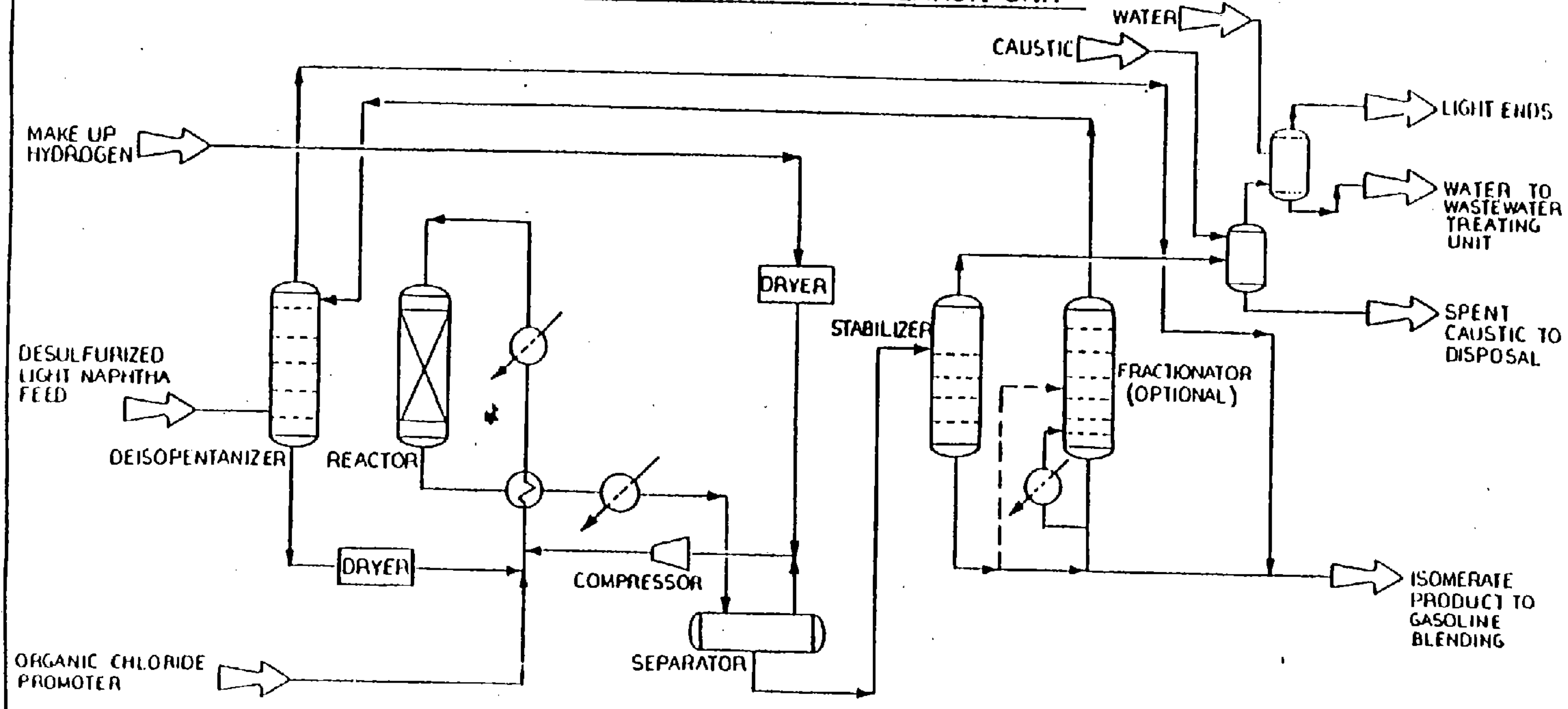
The light naphtha isomerization unit is used to convert light naphtha into a motor fuel blending stock called isomerates. The components of the light naphtha fraction are primarily normal pentane and normal hexane. Isomerization is employed to increase the octane rating of pentane and hexane by converting them from the straight chain hydrocarbons form to their branched chain isomers. The process uses a platinum containing catalyst in the presence of hydrogen to affect the isomerization reaction. Operating pressures in the reactor range from 300 to 400 psig and temperatures are typically 250-400°F. Figure 13 shows a typical light naphtha isomerization unit.

In this process, desulfurized pentane-hexane mixtures are fed to the deisopentanizers to remove any isopentane present in the feed. The isopentane is removed overhead and combined directly with the product isomerate. The n-pentane and n-hexane mixture is then dried, mixed with an organic chloride catalyst promoter and hydrogen, and fed to the reactor.* The hydrogen assists in maintaining reactor pressure and helps

---

*The purpose of the promoter is to increase the activity of the catalyst and increase the rate of reaction.

FIGURE 13
LIGHT NAPHTHA ISOMERIZATION UNIT



to saturate any olefins or aromatics that may be present. The product is cooled and fed to a separator where excess hydrogen is removed to be recycled. The product is then fed to a stabilizer to remove light ends. The light ends are scrubbed with caustic to remove any hydrochloric acid (HCl) that may have been formed by the reaction. The stabilizer bottom product can then be sent directly into gasoline blending or may be further fractionated to remove unreacted normal pentane and normal hexane for recycle.

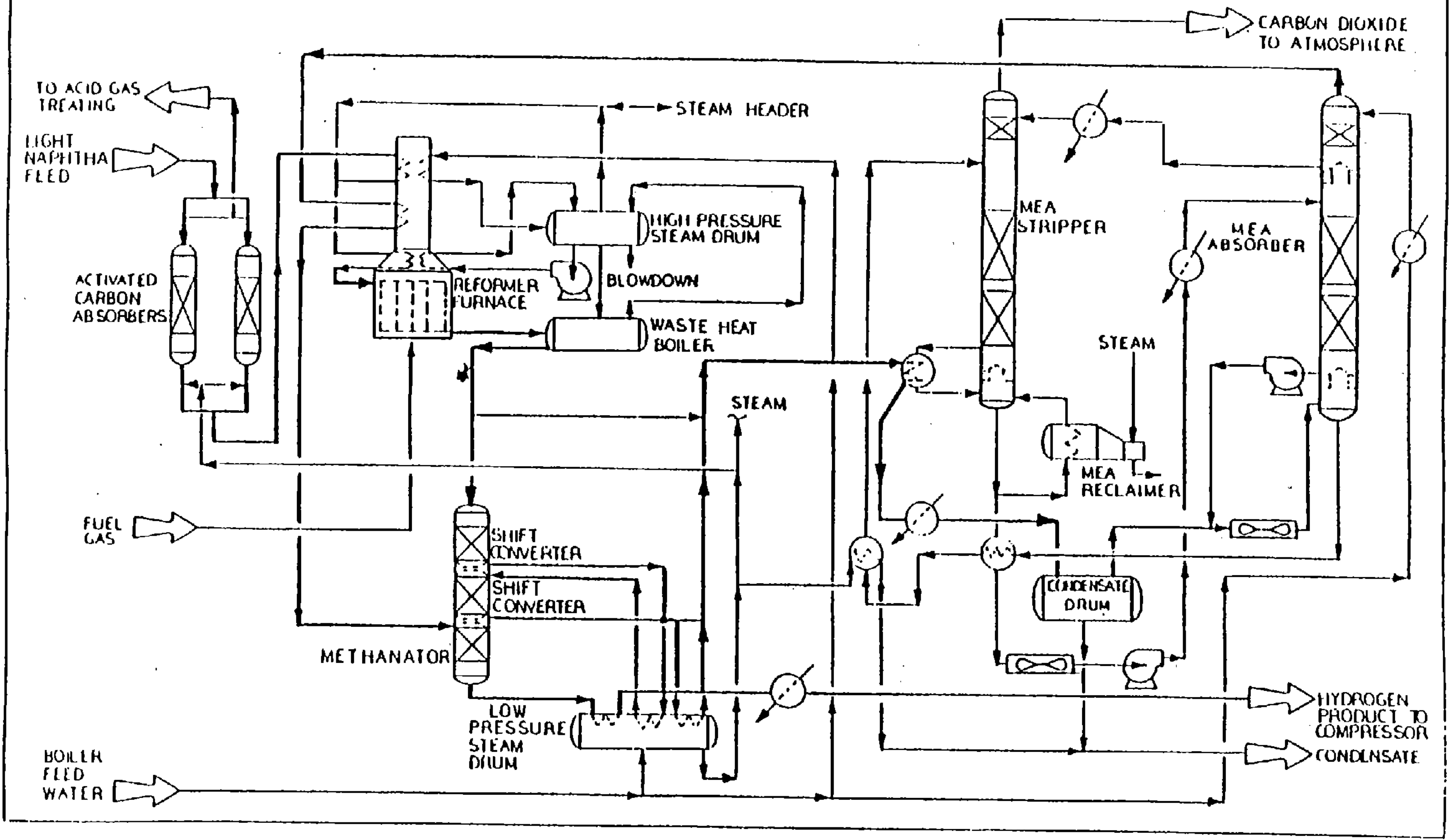
2.10 HYDROGEN PRODUCTION UNIT

Hydrogen is used as a reactant in numerous refinery units including hydrotreating, isomerization and hydrocracking. The most widely used method for producing hydrogen is steam reforming of available hydrocarbons such as natural gas, refinery fuel gas, propane, butane, or desulfurized light naphtha. Hydrogen is also produced in the refinery as a by-product in the catalytic reforming process. However, when processing sour crudes, reforming processes will probably not produce sufficient quantities of hydrogen to meet the refinery needs, and, therefore, additional hydrogen production is required.

The sequence of processing steps for hydrogen production by steam reforming is sulfur removal, reforming, shift conversion, carbon dioxide absorption and methanation. In addition, the hydrogen generation process produces sufficient high-pressure and low-pressure by-product steam to satisfy all the needs of the process. A typical flow diagram is shown in Figure 14. The feed to the plant normally contains traces of sulfur which are removed by adsorption on activated carbon. Sulfur removal is required because the process catalyst is poisoned (deactivated) by sulfur. Two carbon beds are used, normally operating in parallel flow. During regeneration, one bed is valved out of the normal flow for regeneration, while the other bed remains onstream. Upon completion of regeneration, the sequence is reversed. Carbon regeneration is accomplished by heating the carbon with steam to remove the absorbed sulfur. The steam is then condensed and sent to the sour water stripper.

SHB-62

FIGURE 14
HYDROGEN PRODUCTION UNIT



SHB-63

The sulfur-free gas is preheated in the upper (convection) section of the reformer furnace and then mixed with high pressure steam. The mixed gas flows downward through catalyst-filled tubes in the lower (radian) where the steam reacts with methane and other hydrocarbons to produce hydrogen, carbon monoxide, and carbon dioxide. The high-temperature effluent gas from the reformer furnace flows through a waste heat boiler which produces high-pressure steam that is mixed with fresh feed. Additional high-pressure steam is generated in the convection section of the furnace. About three-quarters of the total hydrogen product is produced in the forming reaction. The mixture then passes to the two-stage shift conversion reactors. In these reactors the carbon monoxide and water are catalytically reacted to form CO_2 and hydrogen.

The reaction is highly exothermic (heat producing) and the first stage reactor catalyst is a high temperature catalyst. Excess heat is a hinderance to the reaction and is removed from the product between the stages by generating low pressure steam. The second-stage shift converter employs a low temperature catalyst. The lower temperature conditions allow the reaction to go to completion.

The crude hydrogen gas from the shift converter is further cooled and passed through a condensate knockout drum. From here it is sent to the CO_2 absorption system to remove any remaining CO_2. The system shown is a typical CO_2 absorption system using MEA (monoethanol amine) as the absorbent. Many other absorbents are, however, available.

The crude hydrogen is first mixed with a portion of the regenerated MEA, cooled and fed to the center of the tower. The remaining MEA is pumped to the top of the absorption tower. In the tower the remaining carbon dioxide is removed from the gas stream. The hydrogen is then passed from the top of the absorption tower through the convection section of the reforming furnaces to the methanator. The carbon dioxide-rich MEA passes from the absorber to the MEA stripper where the solution is heated and the carbon dioxide is driven off. The stripped MEA is then returned to the absorption system and the carbon dioxide is vented to the atmosphere.

Methanation is a high temperature (600°F) catalytic process which converts any remaining carbon monoxide and carbon dioxide to methane by the reaction with a portion of the hydrogen. Following methanation, the hydrogen is compressed and pressures may range from 200 psig for naphtha hydrotreating to 3500 psig for hydrotreating residuum.

Another catalytic process that is currently being used for hydrogen production is the partial oxidation of residual oils. Feed to these units typically are bottom products from the vacuum tower or heavy coker gas oil, which avoids the necessity of using naphtha or other more valuable hydrocarbons as hydrogen plant feedstock.

In the partial oxidation process, the residual oil is fed to a combustion chamber where it is partially burned in the presence of steam and oxygen. Gases leaving the combustion chamber are composed primarily of hydrogen and carbon monoxide and have a temperature of 2000 to 2800°F. The gases are then quenched with water and steam and fed to a shift converter for further conversion of the CO and steam to hydrogen. The gases are then purified by absorption and the hydrogen product is sent to storage or process units.

2.11 GASOLINE SWEETENING UNIT

Gasoline is said to be sour if it contains noticeable amounts (>0.1 ppm) of sulfur compounds, particularly the odoriferous mercaptans. A process that removes these compounds or converts them to less objectionable forms is called "sweetening." Gasoline sweetening is usually accomplished by converting the mercaptans to a disulfide. The use of sweetening is dependent primarily on the sulfur content of the crude oil mercaptan, sulfur specifications of the gasoline product, and if the original feedstock had been hydrotreated prior to catalytic cracking.

SHB-65

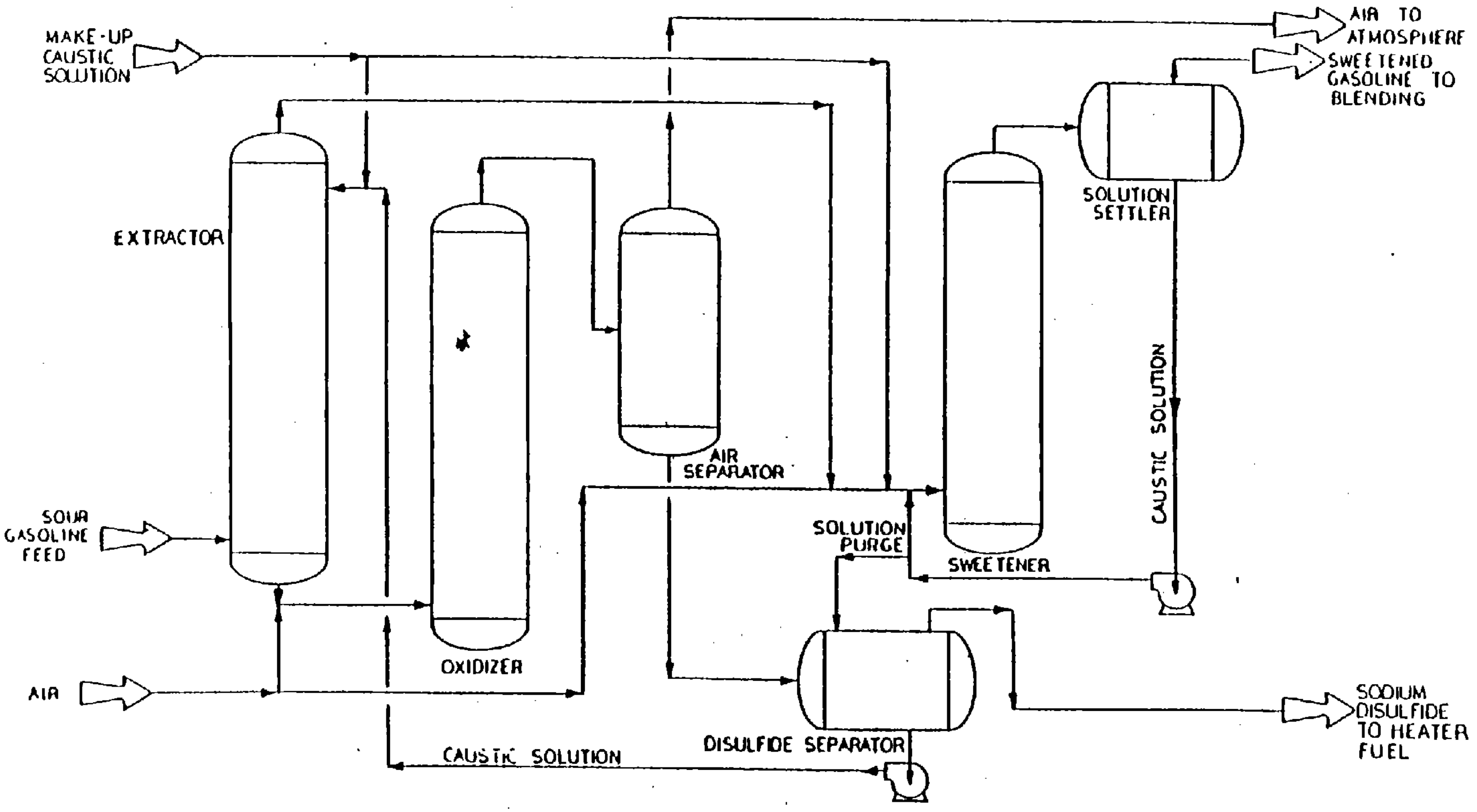
There is a variety of sweetening processes available including treatment with sulfuric acid or absorption of the mercaptan by molecular sieves. However, the most widely used processes usually employ sodium hydroxide (NaOH) with added catalysts or promoters. Most frequently a caustic solution containing the dissolved catalyst or promoter is employed, but a fixed bed catalyst system may also be used.

Figure 15 shows a typical gasoline-sweetening process that employs a sodium hydroxide solution (caustic) containing a dissolved catalyst. This process is conducted at ambient temperature (90-100°F) and low pressure (5-25 psig). Sour gasoline is fed to the extractor, where it is brought into contact with recycled, regenerated caustic solution. The two streams are immissible and the mercaptans are removed through liquid-liquid extraction. However, only a portion of the mercaptan is removed in the extractor and the partially sweetened gasoline flows from the top of the extractor to the sweetener where it is contacted with additional recycled caustic solution and air. In the sweetener, the remaining mercaptan is oxidized to disulfide. This disulfide remains with the treated gasoline. Caustic solution is separated from the treated gasoline in the solution settler and is recycled to the sweetener.

Caustic solution from the extractor, containing dissolved mercaptan in the form of sodium mercaptan is mixed with air and sent to the oxidizer. In the oxidizer, the mercaptan is oxidized to disulfide and the sodium ion is restored to NaOH. The mixture then flows to the air separator. Excess air is vented from the air separator to the atmosphere and the caustic solution and disulfide flow to the disulfide separator. The insoluble disulfide layer separates and is withdrawn from the system, and the regenerated caustic is recycled to the extractor.

SHB-66

FIGURE 15
GASOLINE SWEETENING UNIT



SHB-67

2.12 ACID GAS TREATING UNIT

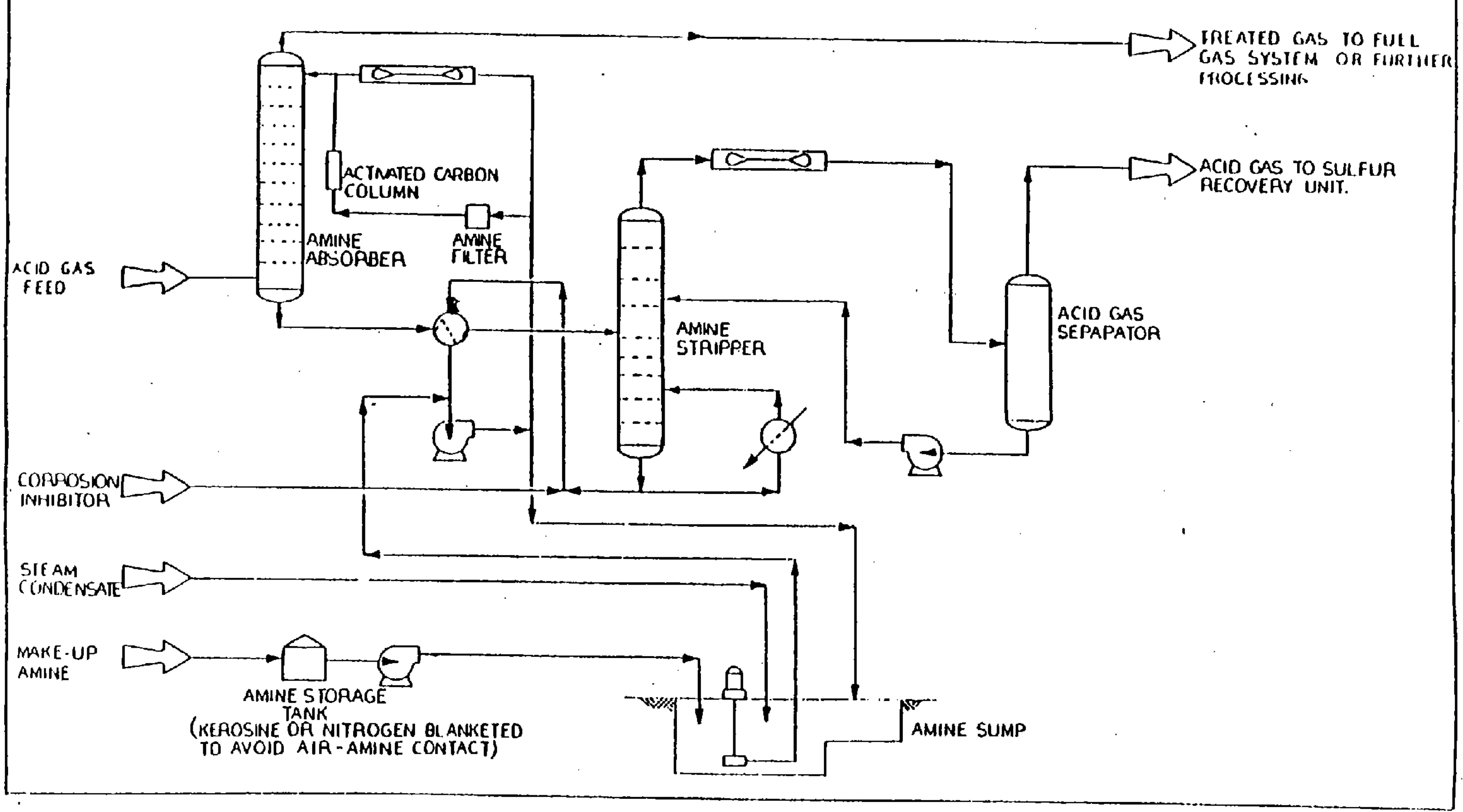
Hydrogen sulfide (H_2S) and carbon dioxide (CO_2) are termed acid gases, and a gas stream containing these compounds is called sour gas. Sour gas is produced in a number of refinery units including cracking and hydrotreating. Refinery-produced fuel gas can be expected to be sour and it is necessary to treat the gas to remove hydrogen sulfide before it can be used as refinery fuel.

Acid gases are typically removed by absorption in alkaline solution. The alkaline material is chosen so that the chemical bond formed during absorption can be broken by heating to regenerate the solution. Absorbent solutions containing acid gas are termed "rich" and the regenerated solutions are termed "lean." Several acid gas treating processes are available but the differences are primarily in the choice of alkaline absorbent. The most widely used absorbents are monoethanol amine (MEA) and diethanol amine (DEA). The processes are exactly the same except for the absorbent used.

A typical acid gas absorption system is shown in Figure 16. The absorbing medium is a 10 to 20 weight percent solution of amine and water. Sour gas enters the bottom of the column and cool, lean amine enters at the top. Treated gas leaves the top of the absorber and goes to the refinery fuel gas system. Rich amine, containing the absorbed acid gas, is heat exchanged with the lean amine and fed to the top of the stripper. The steam used for stripping the rich amine is generated by boiling the water fraction of a portion of the amine solution in the stripper bottoms reboiler. This eliminates the need for additional stripping steam which would dilute the amine solution. Acid gas and steam leave the top of the column and steam is condensed. The condensate and acid gas are separated in the acid gas separator and the condensate is returned to the stripper as reflux. This practice of condensate recovery reduces the possibility of the amine being concentrated due

SH6-68

FIGURE 16
ACID GAS TREATING UNIT



SHB-69

to water loss. The acid gas goes to the sulfur recovery plant and the hot, lean amine from the stripper reboiler is cooled and returned to the absorber.

In some systems, a portion of the return lean amine is filtered before it enters the absorption tower. The purpose of the filter is to control the amount of particulate matter present in the system. These particulates, typically iron/sulfide, are corrosion products caused by the formation of acids in the system. These acids are formed when the regenerator temperature is too high and amine decomposition occurs. In addition, the presence of oxygen in the system will also cause decomposition of the amine and subsequent acid formation. Therefore, care is taken to avoid contaminating the amine with air. These corrosion products can cause severe foaming and a subsequent carryover of amine from the absorber to the fuel gas system. In addition, the filter may be followed by activated carbon treatment to remove trace organics that may be present, which can also cause absorber foaming and amine carryover.

2.13 SOUR WATER STRIPPING UNIT

Water containing sulfides is termed sour water or sour condensate. Refinery operations produce sour water from processes such as hydrotreating and catalytic cracking and whenever steam is condensed in the presence of gases containing hydrogen sulfide. Sour water usually also contains ammonia, and small amounts of phenol and other hydrocarbons. These contaminants are odorous and may cause wastewater treatment plant upsets and wastewater discharge violations if they were discharged without treatment. Sour water stripping is used by refineries to reduce the level of the contaminants in sour condensate to allow further use of this condensate.

There are many different stripping methods, but most of them involve the downward flow of sour water through a trayed or packed tower while an ascending flow of stripping stream or gas removes the H_2S and NH_3. Operating conditions vary from 1 to 50 psig and 100 to 270°F.

SHB-70

Typical stripping mediums are steam, flue gas or fuel gas, with steam being most commonly used.

Sour water stripping will remove both hydrogen sulfide and ammonia from the water. A typical sour water stripping unit is shown in Figure 17. Sour water is fed to the feed drum which acts as a surge drum for the stripping column. The sour water is then pumped through a preheat exchanger and into the top of the stripper column. Steam is fed into the bottom of the column. Sour gas, containing steam and contaminants, leaves the top of the stripper and is partially condensed. Condensate and sour gas are separated in the surge tank and the condensate is recycled to the stripper. The sour gas is removed to the sulfur recovery unit and the stripper bottoms are fed to the crude oil desalters or discharged directly to the wastewater treatment system. If steam consumption is a concern and maximization of H_2S removal is desired, acid may be added to the sour water feed. This lowers the pH of the feedwater and essentially "fixes" the NH_3 in solution. Since the ammonia is not removed, less steam is required to affect a high degree of H_2S removal.

Sour water stripping will also remove varying amounts of phenols, mercaptans and other contaminants present in the feedwater. The actual amount of these materials removed is dependent upon the unit operating conditions and feedwater characteristics.

2.14 LIGHT ENDS RECOVERY UNIT*

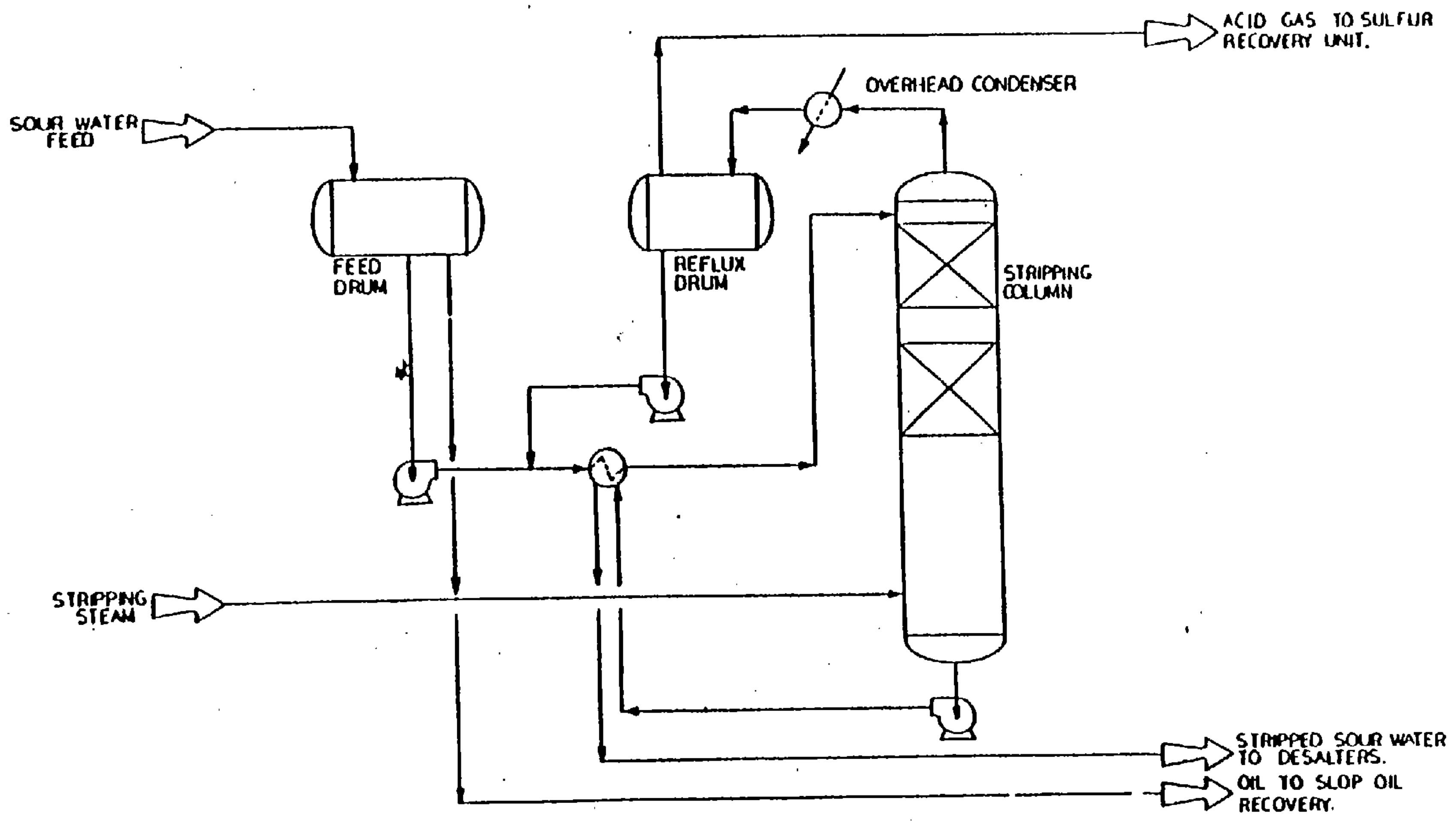
The term light ends typically refers to light hydrocarbon gases having four or less carbon atoms. These include methane, ethane, propane, and butane. Also included are C_3 and C_4 olefins and such materials as isobutane. The purpose of the light ends recovery unit is to separate these gases for further use.

A typical light ends recovery unit is shown in Figure 18. The feed to the unit is desulfurized light ends which have been collected from various process units in the refinery. The gases are first liquefied by compression and cooling in order to affect separation by

SHB-71

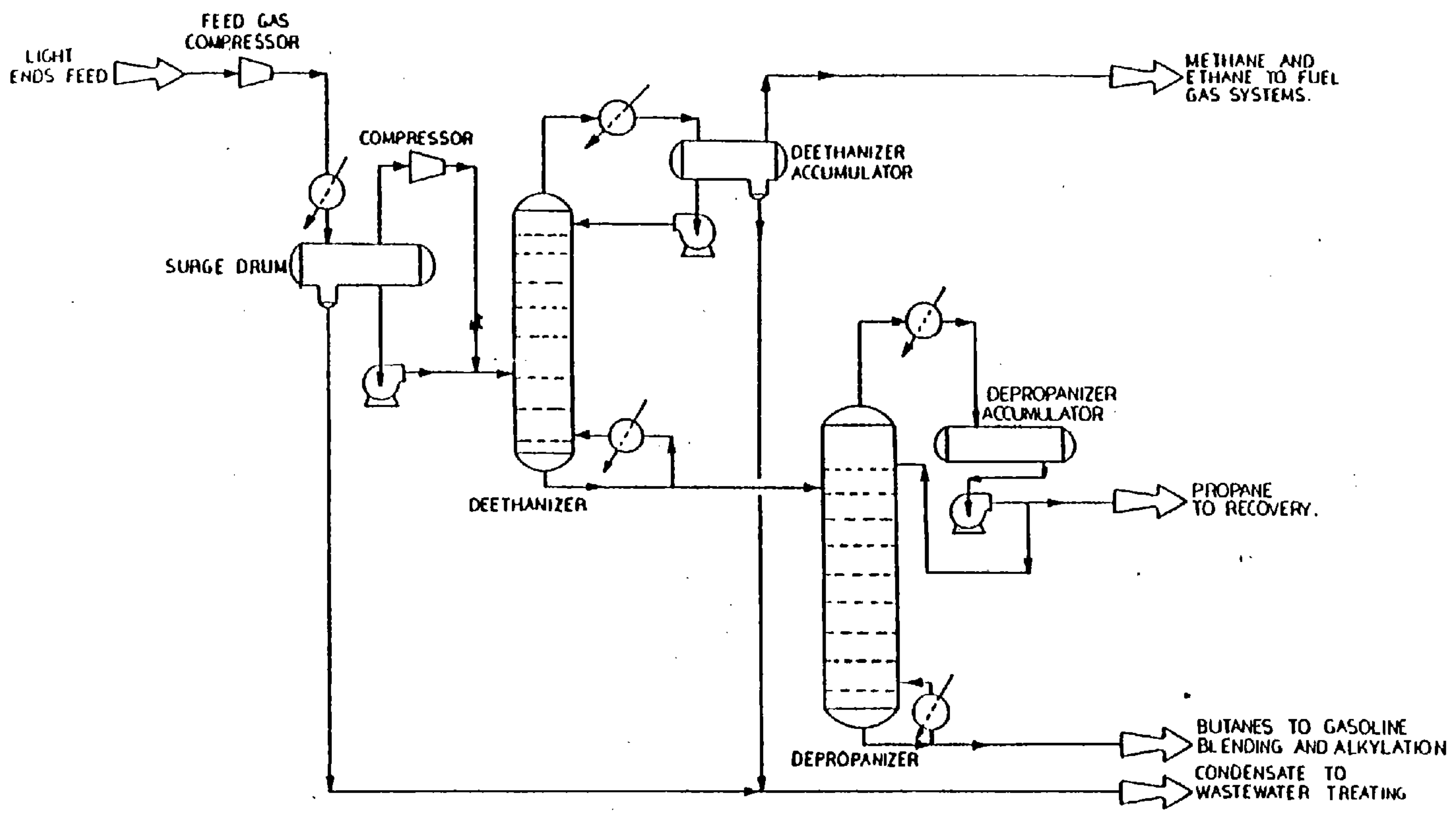
FIGURE 17

Sour Water Stripping Unit



SHB-72

FIGURE 18
LIGHT ENDS RECOVERY UNIT



distillation, and sent to a surge drum to remove any condensed moisture. The mixture is then pumped to the de-ethanizer column where methane and ethane are separated from the mixture and recovered for fuel gas. The de-ethanizer bottoms are then sent to the depropanizer where the C_3 and C_4 compounds are separated. These streams may then be further processed to separate the normal butane and propane from the C_3 and C_4 olefins and isobutanes that may be present. The olefinic and iso-compounds are used as feedstock for the alkylation unit. The n-butane is sent to gasoline blending and the n-propane is recovered as liquefied petroleum gas (LPG).

2.15 SULFUR RECOVERY UNIT

The sulfur recovery unit is used to convert hydrogen sulfide (H_2S) to elemental sulfur. The most widely used sulfur recovery system in refineries is the Claus process which uses both thermal and catalytic conversion reactions. The feed stream contains acid gases (CO_2 and H_2S) from the acid gas recovery plant, along with small amounts of hydrocarbon impurities. The Claus unit is normally designed to convert 95% or more of the H_2S to elemental sulfur. The majority of the remaining sulfur is removed by the tail gas treating unit.

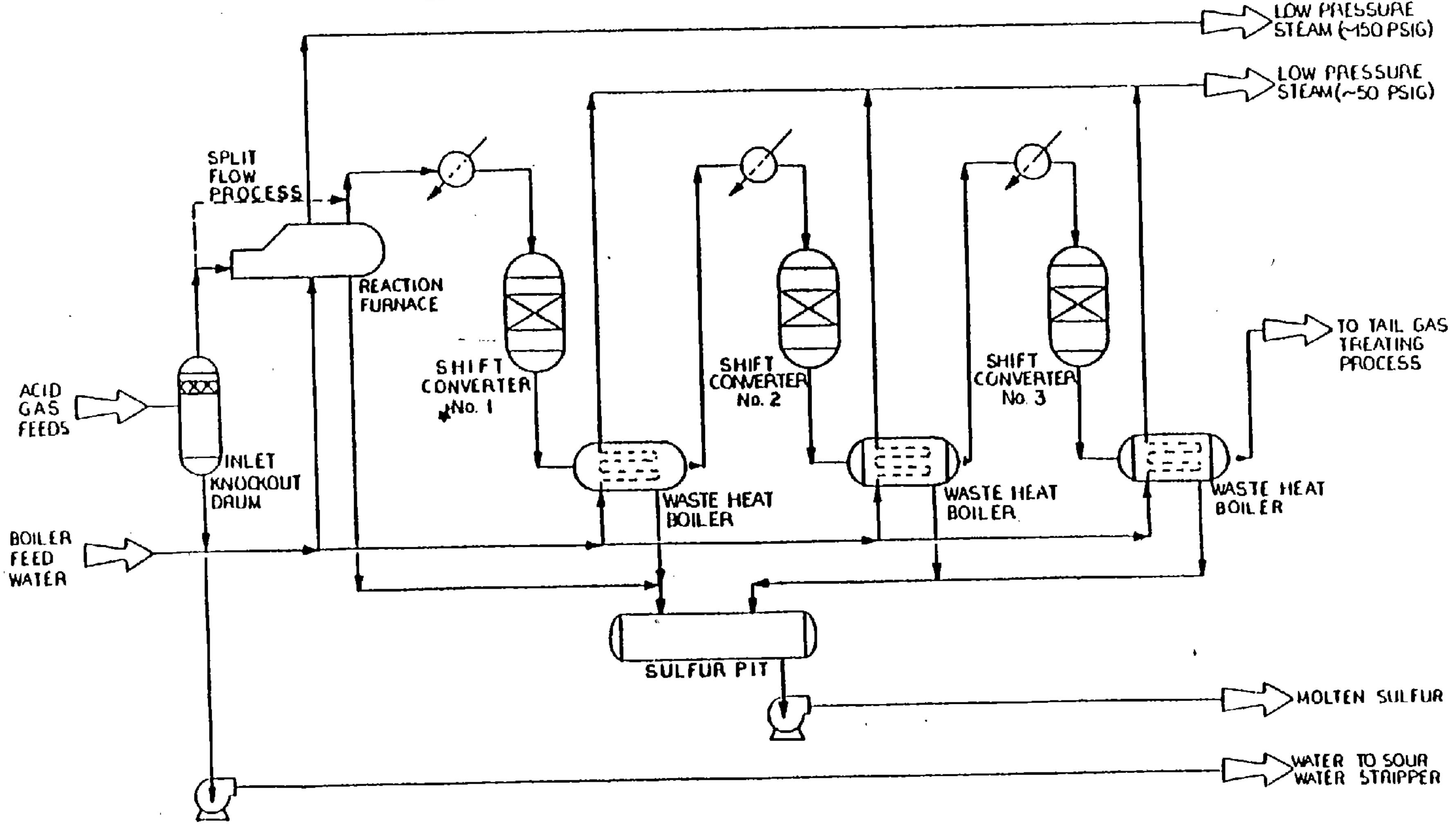
In the Claus process, hydrogen sulfide is converted to elemental sulfur in two steps. In the first step (thermal), H_2S is partially burned with air in a boiler to SO_2. Low pressure steam is generated as a by-product. The H_2S/SO_2 mixture is then reacted over a catalyst to produce sulfur and water by a shift conversion reaction. The shift conversion is carried out usually in three stages with sulfur removal after each stage. The use of the shift conversion reactors allows for more complete sulfur removal and lower operating temperatures would be possible with thermal conversion alone. The design of a sulfur recovery unit depends upon the acid-gas composition. If the concentration of H_2S in the feed is high (more than 40% by volume), a "straight-through" process is used. In the "straight-through" configuration, all of the acid-gas and air are fed to the burner. If the H_2S concentration in the feed is low (less than 40% by volume), a "split-flow" process is used. In the "split-flow" process, a portion of the feed is burned completely to SO_2 and combined with the remainder of the feed to provide the proper H_2S/SO_2 ratio for the shift conversion.

A typical three-stage Claus sulfur recovery unit is shown in Figure 19. The acid-gas stream containing H_2S, CO_2, water and minor amounts of hydrocarbons is fed to an inlet knockout drum to remove any entrained liquid and then fed to the reaction furnace. The furnace consists of two stages. The first is a reaction furnace followed by a waste heat boiler. In the furnace, a portion of the H_2S (~30%) is burned to SO_2. Due to the high temperatures present, the remaining H_2S and the newly formed SO_2 react to form elemental sulfur. The hot gases and sulfur vapor then pass to the boiler to generate low pressure steam, and thereby condensing the sulfur vapors. The molten sulfur is removed and the remaining H_2S/SO_2 gas mixture is reheated, and fed to the first-stage shift converter. In the converter, H_2S and SO_2 react in the presence of a catalyst to form elemental sulfur. The gases and sulfur vapors are fed to a boiler to generate steam, again condensing the sulfur. The sulfur is removed and the cycle is repeated for two additional stages. The tail gas containing unreacted H_2S and SO_2 is then sent to the tail gas treating unit. The recovered sulfur is then sold as elemental sulfur or used on-site to manufacture sulfuric acid.

2.16 TAIL GAS TREATING UNIT

There are numerous processes available to treat Claus unit tail gas and they are generally divided into reduction and oxidation processes. Both types have been successfully used in refinery applications and the choice of unit will depend upon the tail gas composition and process economics.

FIGURE 19
CLAUS SULFUR RECOVERY UNIT



SHB - 76

2.16.1 Reduction Processes

Reduction processes for treating tail gas typically convert all the sulfur compounds in the feed to H_2S. The H_2S is then removed from the gas. The most commonly used reduction processes are the Beavon and SCOT processes.

Beavon Process

The Beavon Process is shown in Figure 20. In this process, the tail gas is first heated to the temperature required for the catalytic reaction to convert all sulfur compounds to hydrogen sulfide by mixing it with a hot stream of gas resulting from partial combustion of hydrocarbon gas in an in-line burner. This gas not only supplies the necessary heat but also sufficient hydrogen to satisfy the requirements of the hydrogenation reactions. After passing through the reactor, the gas is cooled by direct contact with water. The cooled gas, which contains primarily nitrogen, carbon dioxide, and hydrogen sulfide, is then sent to the Stretford column for hydrogen sulfide removal. The water condensed from the gas in the direct contact cooler is sent to the sour water stripper.

The H_2S-rich gas enters the Stretford absorption/reaction column where it is contacted counter-currently with a solution of sodium salts. The treated gas has very low concentrations of sulfur compounds and is released to the atmosphere. Should any unreacted H_2S be present in the tail gas, incineration may be required depending on the H_2S concentration.

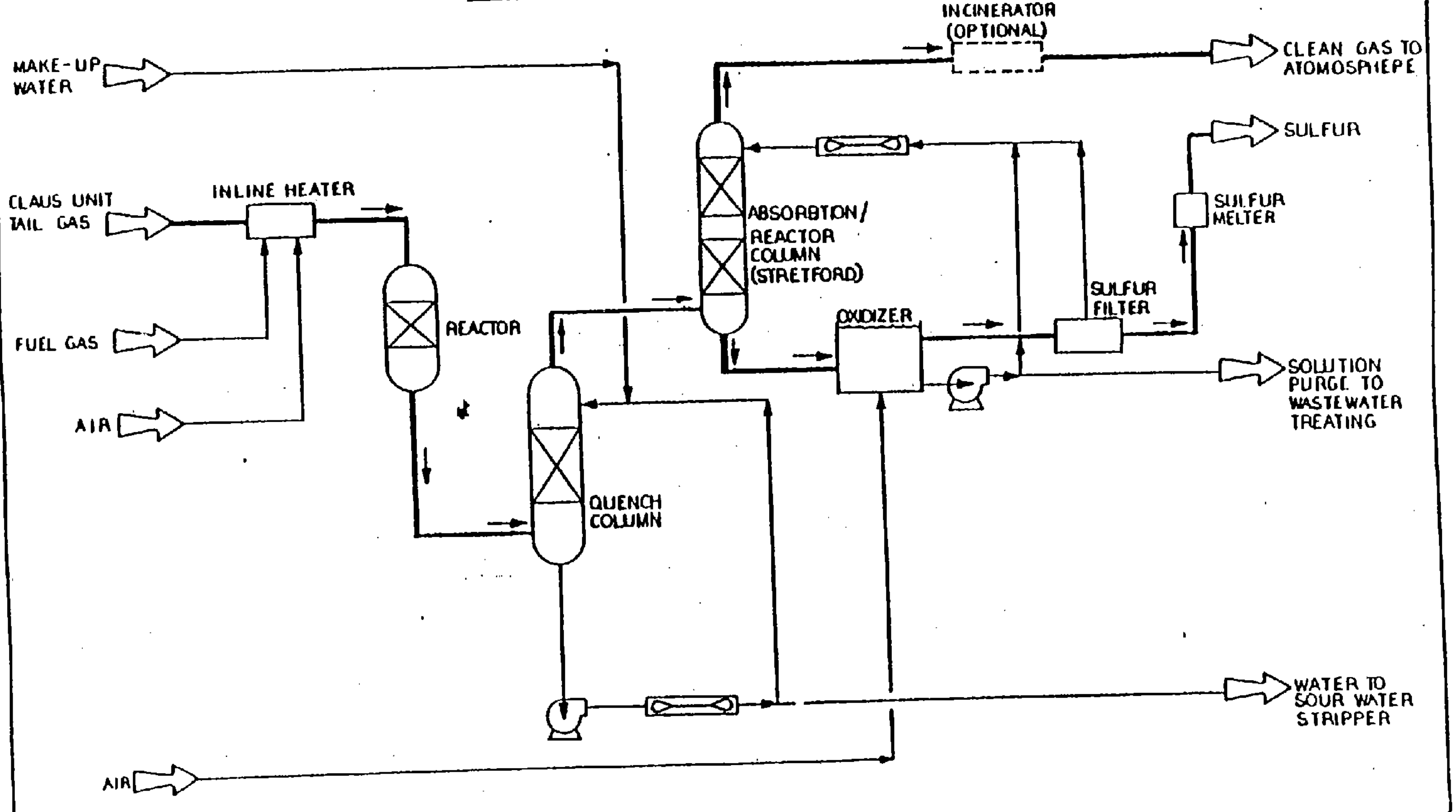
The solution then passes to the reaction section of the column where the conversion of H_2S to elemental sulfur takes place. The sulfur solution then is fed to the oxidizer where it is contacted with air. The air serves to separate the sulfur as a froth (±10%) solids and regenerate the absorption solution. The froth is then fed to a filter or centrifuge for recovery of the solids and the regenerated solution is returned to the absorption column.

SCOT Process

A typical flow diagram for the SCOT Process is shown in Figure 21. Like the Beavon Process, the first step is to catalytically convert all sulfur compounds to H_2S, and the method employed is similar to that used in the Beavon Process.

SHB-77

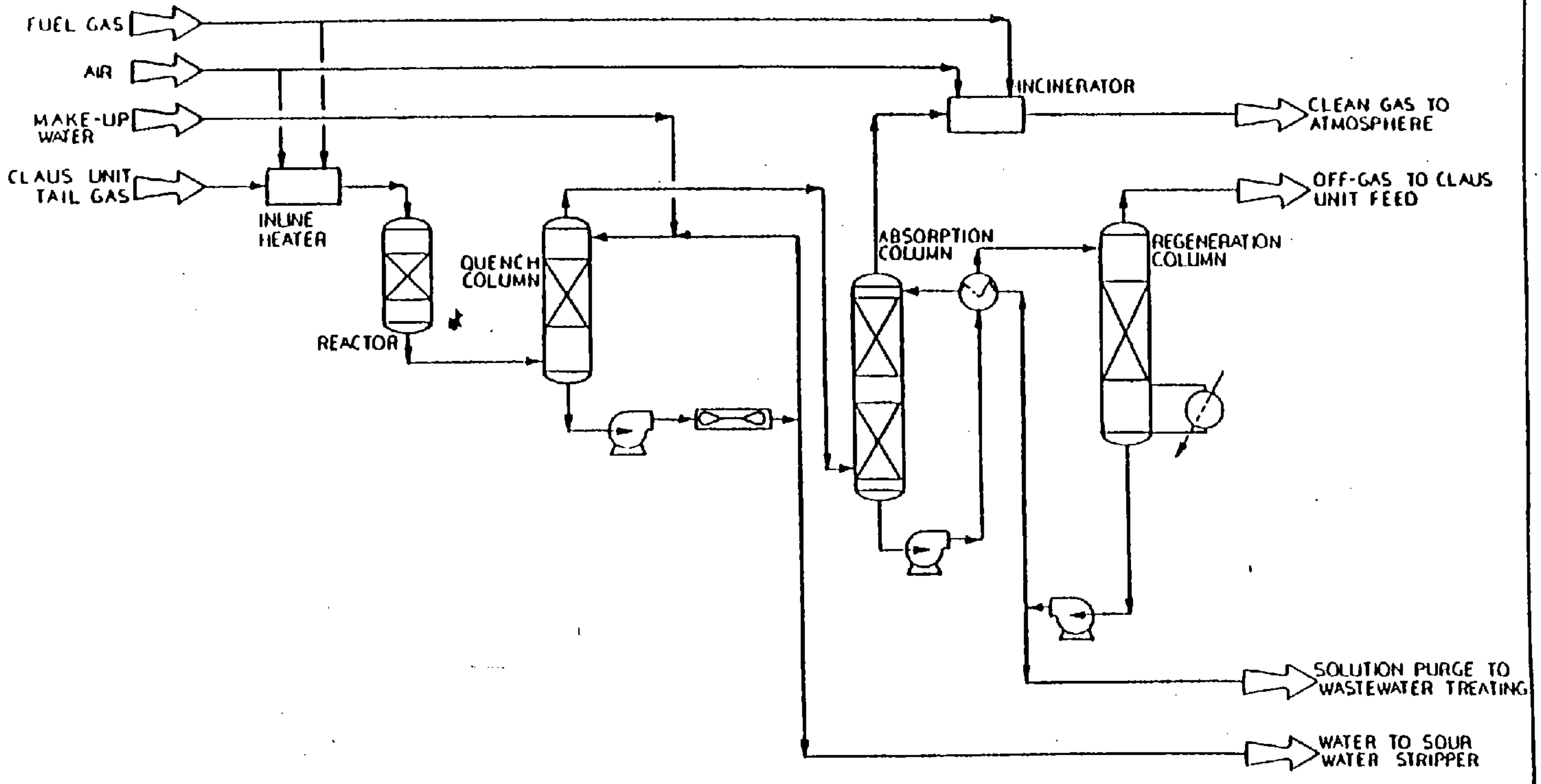
FIGURE 20
BEAVON TAIL GAS TREATING UNIT



SHB-78

FIGURE 21

SCOT TAIL GAS TREATING UNIT



SHB-79

Following the H_2S conversion, the H_2S-rich gas is quenched with water and fed to the absorber. In the absorber, the H_2S is absorbed from the gas stream by an amine solution (usually di-isopropanol amine). However, unlike the Beavon Process, there is no conversion of the H_2S to elemental sulfur. The treated gas is virtually free of sulfur compounds and is incinerated and released to the atmosphere.

The rich amine solution (containing H_2S) then goes to the regenerator where the H_2S and CO_2 are stripped from the amine in a method similar to that used in the acid gas treating unit.* The gases are returned to the Claus unit and the lean amine is recycled to the absorber.

2.16.2 Oxidation Process

The only oxidation process that is currently being used in refineries to treat Claus plant tail gas is the Wellman-Lord Process.

- Wellman-Lord Process

A typical Wellman-Lord unit is shown in Figure 22. The Claus unit tail gas is first incinerated to convert all sulfur compounds to sulfur dioxide. The hot flue gas is then quenched, cooled, and sent to an absorber. The sulfur dioxide is absorbed from the flue gas with a solution of sodium sulfite. The clean gas contains very low concentrations of sulfur compounds, and can be released to the atmosphere. The solution leaving the bottom of the absorber, now rich in sodium bisulfite with some sodium sulfate, is discharged to a surge tank and then to the evaporator.

Low pressure steam heats the solution in the evaporator to drive off sulfur dioxide and water vapor. The evaporator overhead is partially condensed to remove the water. The condensate is recycled to a dissolving tank and the sulfur dioxide containing gas is returned to the Claus unit feed.

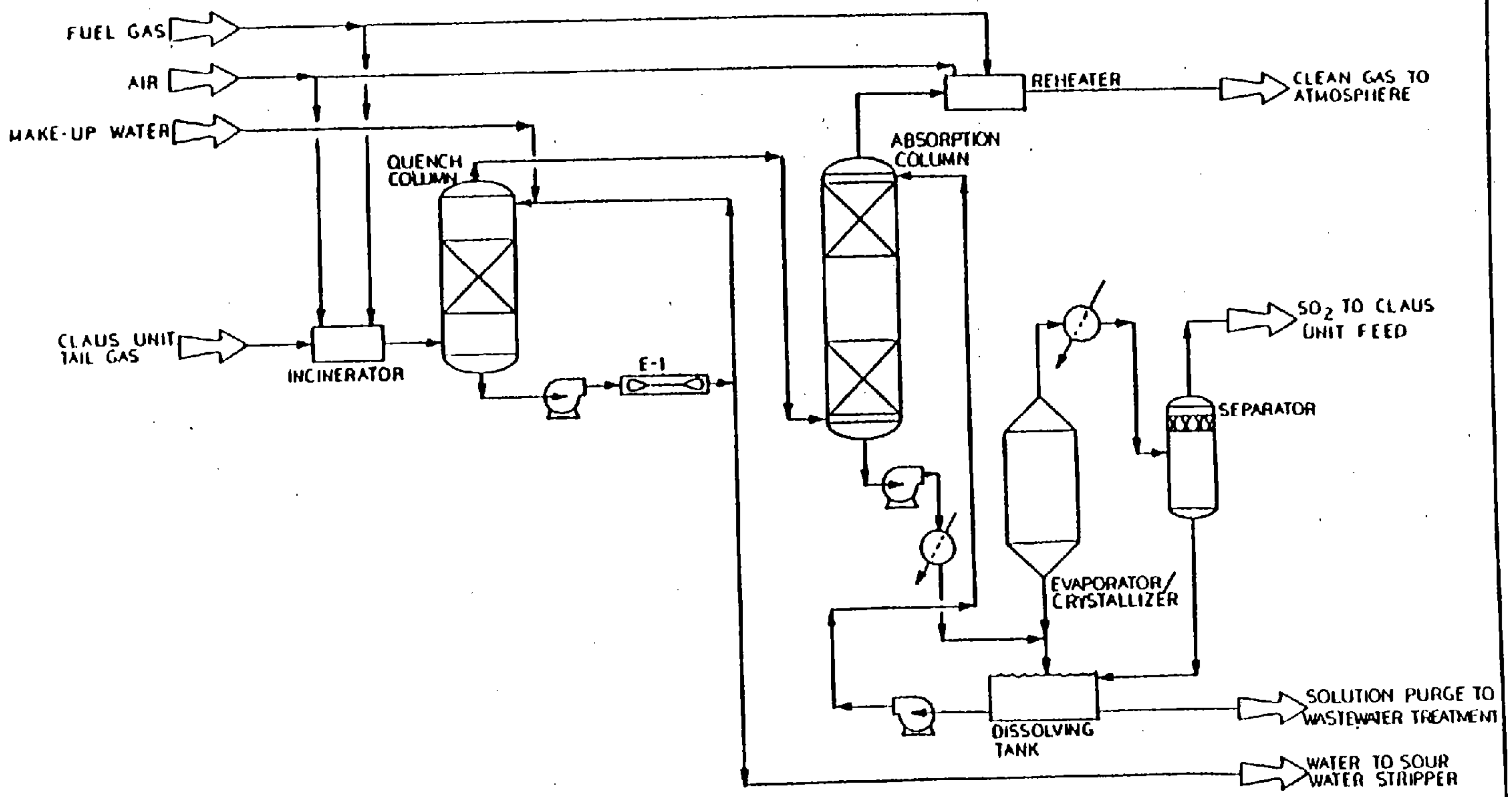
The sodium sulfate that is formed in the evaporator when the sulfur dioxide is driven off, precipitates and builds up a dense slurry of crystals. The crystals are redissolved by the overhead condensate and the solution is returned to the absorber.

---

*See Section 2.12.

SHB-80

FIGURE 22
WELLMAN-LORD TAIL GAS TREATING UNIT



SAB-81

The sodium sulfate which is formed is not regenerable and must be purged from the system. This is generally equivalent to 10 percent of the absorbed sulfur.

2.17 WASTEWATER TREATMENT UNIT

Treatment of refinery wastewater to remove dissolved organic contaminants typically involves both physio-chemical and biological treatment processes, integrated into a single system. This treatment combined with in-plant source control of wastewater produces a high quality effluent suitable for discharge to surface waters.

A typical wastewater treatment unit is shown in Figure 23. This unit represents a system which treats wastewater for discharge to a receiving stream. If the refinery discharges to a publicly owned treatment works (POTW), it may not include the biological treatment section (aeration tanks) and the final clarifiers and filters. Therefore, the actual wastewater treating system will depend upon the decision between stream or municipal discharge.

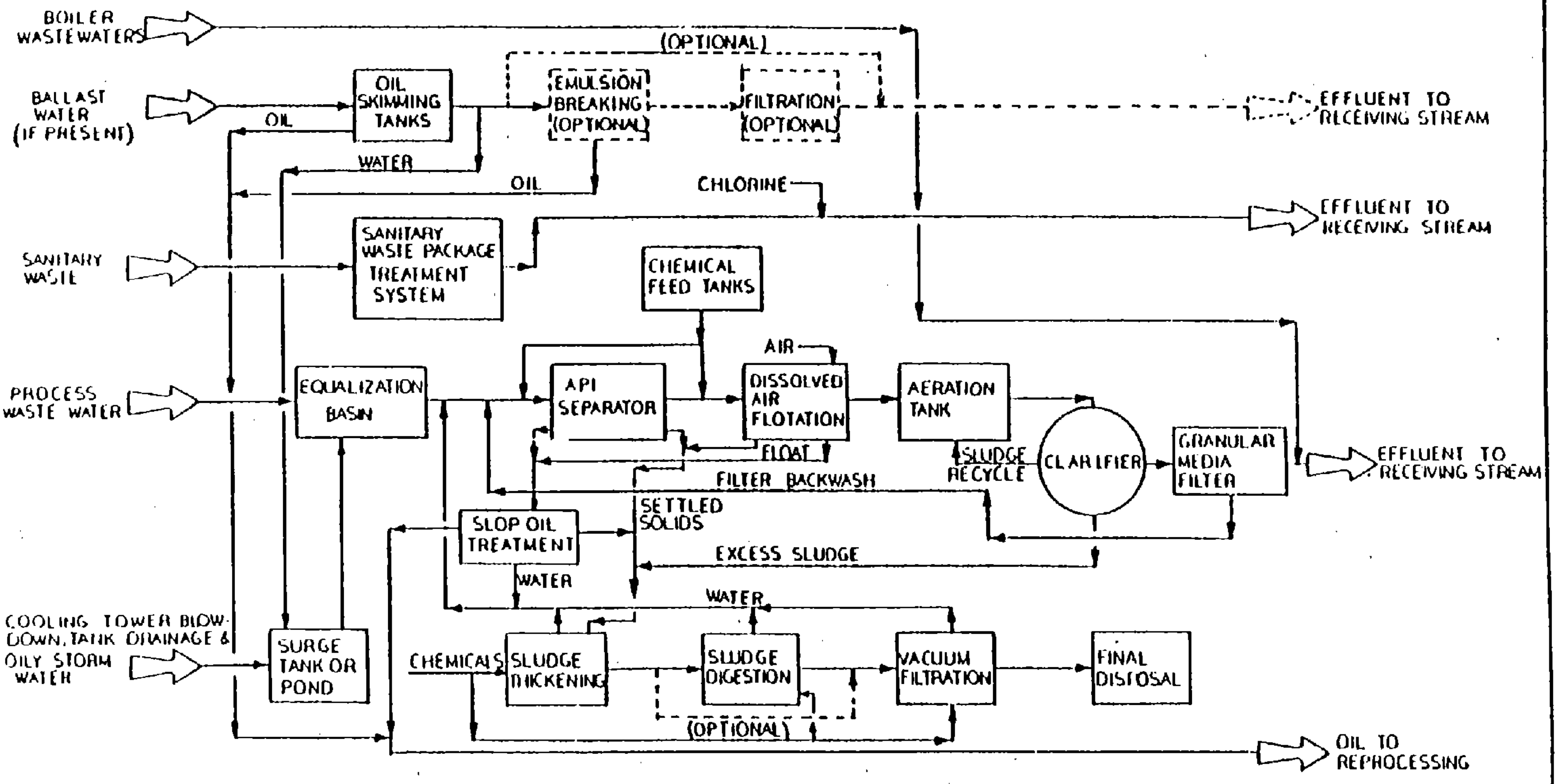
The wastewater and contaminated storm water enters the equalization basin which serves as a surge tank for the process. From the equalization basin, the flow is pumped to the API separator for the removal of suspended solids and free (floating) oil. The oil collected by the API separator is pumped to the "slop" oil treatment system. This is normally a series of holding tanks in which the oil and water is separated by gravity. The oil is returned to the refinery for reprocessing and the water is returned to the treatment system.

The wastewater stream is then fed to the dissolved air flotation unit (DAF). The purpose of the DAF unit is to remove colloidal solids and oil which cannot be removed from the water by conventional gravity separation. A portion of the DAF effluent is saturated with air and mixed with the unit influent. The air bubbles mix with the oil and solids and cause them to float to the surface of the tank. The float

5HB-82

FIGURE 23

WASTEWATER TREATMENT UNIT



is then skimmed off and returned to the slop oil treating system. Any solids that settle in the DAF tank are handled with the other settled solids. Chemical treatment may be added ahead of the DAF unit which will assist in the removal of emulsified oil.

The flow then passes to the aeration basin where the water is biologically treated to remove contaminants such as dissolved organic constituents (BOD_5) and ammonia. Biological treatment is the removal of the dissolved organic material by microorganisms in an oxygen-rich environment. The flow then enters the final clarifier to remove the biological solids. The clarifier overflow is then passed through granular media filters to remove entrained suspended solids. The filtrate is then discharged to the receiving stream.

Numerous alternatives exist for disposing of the solids generated by the wastewater treating system. The method chosen will depend upon economic and site considerations. In the system shown in Figure 23, a portion of the settled solids (underflow) from the final clarifier is mixed with the settled solids collected in the API separator, DAF unit, and slop oil treatment system, and sent to a gravity sludge thickener. From the thickener, the sludge can be processed by digestion, dewatered by vacuum filtration, and then finally disposed of by land disposal or incineration. Water collected in the sludge processing operations is returned to the head of the waste treatment unit.

The wastewater treating system shown in Figure 23 represents the treatment technology required to meet the Best Practical Control Technology (BPCT) refinery wastewater discharge regulations.* To meet the 1984 regulations, additional treatment such as the application of powdered activated carbon in the aeration basin for the removal of residual dissolved organic materials and processes such as reverse osmosis to remove dissolved inorganic solids from the effluent may be required. These processes can be added to existing treatment facilities. The wastewater treatment system for new refineries in addition to the

---

*Reference 16

activated carbon and dissolved solids removal systems may also include segregated treatment of specific waste streams and two-stage biological treatment as part of the initial plant design.

Boiler blowdown, sanitary wastes and ballast water may be treated separately from the main process wastes. Sanitary wastes are collected separately and treated in a package biological treatment plant designed specifically to treat domestic waste. This practice avoids the costly requirement of chlorinating the entire refinery discharge due to the presence of sanitary wastes as well as the possible formation of chlorinated hydrocarbons in the receiving water. Boiler blowdown and other boiler wastewaters usually do not require treatment and can be discharged directly.

In the case of coastal refineries or refineries served by tanker, ballast water from tankers must also be collected and treated, primarily for oil removal. The ballast water is first pumped to holding tanks where free oil and suspended solids are allowed to separate by gravity. The tanks are typically equipped with skimmers to remove the separated oil which is sent to the refinery for processing. The water can then be discharged directly with the plant effluent, sent to the wastewater treatment plant for further treatment, or can be pumped to a second series of tanks for removal of emulsified oil before being discharged. The actual ballast water treatment system employed will depend upon the characteristics of the waste.

2.18 REFINERY OFF-SITES

Refinery off-sites are a general category of equipment, systems and facilities that are used in support of the refining unit operations. In addition to the major off-sites discussed in this section, off-sites include such facilities as garages, machine shops, storehouses and necessary offices.

5HB-85

GLOSSARY OF TERMS USED IN PETROLEUM REFINING

A

ABSORPTION	A process whereby a liquid dissolves a gas, such as amine which absorbs hydrogen sulfide (H_2S) from fuel gas.
ACCUMULATOR	A vessel which serves as a collection point for condensed products, such as tower overhead material.
ACID	A member of an important and fundamental category of chemical substances characterized by having an available reactive hydrogen and requiring an alkali to neutralize them. Acid solutions usually have a sour, biting, and tart taste, like vinegar. (See also specific acids under alphabetical listing.)
ACID GAS	A gas containing hydrogen sulfide and carbon dioxide.
ACID GAS TREATING	Process where acid gases are removed from hydrocarbon gases by absorption in amine solution.
ACTIVATED CARBON	A form of carbon which has a high adsorptive capacity for chemical species contained in gases, vapors and liquids.
ADDITIVES	Chemicals added to petroleum products to improve performance or obtain desired product characteristics.
ADSORPTION	A process in which chemical species contained gases, vapors or liquids physically adhere to the surface of a solid, such as activated carbon.
ALGAE	Plants of the group comprising practically all seaweeds and allied freshwater or nonaquatic forms, such as pond scums, stoneworts, etc.
ALKYLATION	A catalytic process for combining isoparaffins and olefins such as isobutane and butylene, to form alkylate, a gasoline component. Extremely important in the production of unleaded gasoline.
AMINE	Organic chemical used to absorb acid gases from hydrocarbon gases in the acid-gas treating unit.
ANALYSIS	The process of determining the composition of a substance by chemical or physical methods. (See also specific types of analysis under alphabetical listing.)
ANODE	The positive pole or electrode of an electrolytic cell, vacuum tube, etc.
ANTI-KNOCK COMPOUNDS	An additive to gasoline, such as tetraethyl, lead, for improving combustion characteristics in internal combustion engines.
API GRAVITY	An index for measuring the density of crude oil and petroleum products. The higher the gravity, the lighter (less dense) the material.

API SEPARATOR	A device for separating oil from water by gravity differential.
AROMATIC HYDROCARBONS	Hydrocarbons with an unsaturated closed ring structure, such as benzene, toluene and xylene.
ASH	A non-volatile, incombustible component of fuels which remains after combustion.
ASPHALT	Black to dark-brown solid or semisolid cementitious material which gradually liquefies when heated and in which the predominating constituents are bitumens. These occur in the solid or semisolid form in nature; are obtained by refining petroleum; or are combinations with one another or with petroleum or derivatives thereof. (See also specific asphalts under alphabetical listing.)
ASTM DISTILLATION	Any distillation made in accordance with an ASTM distillation procedure; and, especially, a distillation test made on such products as gasoline and kerosene to determine the initial and final boiling points and the boiling range (ASTM Method D 86.)
ATMOSPHERIC PRESSURE	1. The pressure of air. 2. More specifically, the pressure of the air at sea level. 3. As a standard, the pressure at which the mercury barometer stands at 760 mm, or 30 in. (equivalent to approximately 14.7 psi).
ATOM	The smallest complete particle of an element which can be obtained, yet retain all physical and chemical properties of the element. According to present theory, the atom consists of a nucleus of protons and neutrons positively charged, surrounded by negatively charged particles called electrons.

B

BACK PRESSURE	1. The pressure on the outlet or downstream side of a flowing system. 2. In an engine, the pressure which acts adversely against the piston, causing loss of power.
BACT	Refers to level of air and wastewater control technology defined as Best Available Control Technology.
BAFFLE	A partial restriction, generally a plate, located so as to change direction, guide the flow, or promote mixing within the equipment in which it is installed.
BALLAST	The flow of waters from a ship which is treated at the refinery.
BARREL	A volume unit used in the petroleum industry consisting of 42 U. S. standard gallons.

BASELINE	Present and future conditions as they would exist in the absence of a proposed action.
BASIC SEDIMENT AND WATER	The heavy material which collects in the bottom of storage tanks, usually composed of oil, water and foreign matter. Also called bottoms, bottom settlings, etc.
BICYCLIC	An organic compound containing two rings, e.g. naphthalene.
BLEND	Any mixture prepared for a special purpose; e.g., the products of a refinery are blended to suit market requirements.
BLENDING STOCK	Any of the stocks used to make commercial gasoline. These include: natural gasoline, straight-run gasoline, cracked gasoline, polymer gasoline, alkylate, and aromatics.
BLIND	A solid plate inserted in a flanged joint to seal one side of the joint from the other side.
BLOCK VALVE	A valve used for isolation of equipment.
BLOWDOWN	Material purged from refining processes during startups, shutdowns, and pressure relieving. Aqueous blowdowns also occur from cooling water and boiler systems as a part of normal operation.
BOILING POINT	The temperature at which a substance boils, or is converted into vapor by bubbles forming within the liquid; it varies with pressure. (See also specific boiling points under alphabetical listing.)
BOILING RANGE	The range of temperature, usually determined at atmospheric pressure in standard laboratory apparatus, over which the boiling or distillation of an oil commences, proceeds, and finishes.
BOMB	A steel cylinder used as a device for conducting oil tests under high pressure, e.g., in gum, sulfur, and Reid vapor pressure tests.
BOTTOMS	The liquid which collects in the bottom of a vessel (tower bottoms, tank bottoms), either during a fractionating process or while in storage. (See also "basic sediment and water; residue".)
BRINE	Water which is nearly saturated with salts.
BUBBLE CAP	An inverted cup with a notched or slotted periphery to disperse the vapor in small bubbles beneath the surface of the liquid on the bubble plate in a distillation column.

BUBBLE TOWER	A fractionating tower so constructed that the vapors rising pass up through layers of condensate on a series of plates or trays. The vapor passes from one plate to the next above by bubbling under one or more caps and out through the liquid on the plate. The less volatile portions of vapor condense in bubbling through the liquid on the plate, overflow to the next lower plate, and ultimately back into the reboiler. Fractionation is thereby effected.
BUBBLE TRAY	One of the circular, perforated plates having the internal diameter of a tower, set at specified distances in a tower to collect the various fractions produced in fractional distillation.
BUNKER FUEL OIL	A heavy residual fuel oil used mainly by ocean-going vessels.
BUTANE	Either of two isomeric, flammable, gaseous hydrocarbons, C_4H_{10}, of the paraffin series: n-butane or isobutane.

C

CARBON	A nonmetallic element existing in diamonds, graphite, and numerous amorphous forms; combined as carbon dioxide, carbonates, and in all living things. Carbon is unique in forming an almost infinite number of compounds (it is present in all organic compounds).
CARBON DIOXIDE	A heavy, colorless gas, CO_2, which will not support combustion. Dissolved in water, it forms carbonic acid. It is exhaled by lung-possessing animals as a waste gas, but is inhaled by certain plants which absorb its carbon and release its oxygen as a waste gas.
CARBON MONOXIDE	A colorless, odorless gas, CO; a product resulting from the incomplete combustion of carbon.
CARBON RESIDUE (CONRADSON; RAMSBOTTOM)	The carbonaceous residue formed after evaporation and pyrolysis of a petroleum product. The residue is not entirely composed of carbon, but is a coke which can be further changed by pyrolysis. Tests for the determination of carbon residue are intended to provide some indication of the relative coke-forming propensities of an oil (ASTM Methods D 189 and D 524).
CATALYST	A substance used to increase the rate of chemical reactions but which is not directly involved in the reaction. Solid refinery catalysts are usually made from platinum or other heavy metal. Liquid catalysts are acids such as Hydrofluoric Acid (HF).
CATHODE	The negative pole or electrode of an electrolytic cell, vacuum tube, etc.

SHB-89

CAUSTIC	A term used for solutions of sodium hydroxide used in various treating and sweetening processes. A very strong alkali.
CELL	1. The smallest cooling tower subdivision which can function as an independent unit with regard to air and water flow; it is bounded by exterior walls or partition walls. Each cell may have one or more fans or stacks and one or more distribution systems. 2. A location providing isolation of an engine stand to reduce noise, hazard, etc.
CETANE NUMBER	An obsolete designation for the starting and running quality of diesel fuel, using cetane as a reference fuel. It has been succeeded by the cetane number.
CHECK VALVE	An automatic valve which permits fluids to pass in one direction but closes when the fluids attempt to pass in the opposite direction.
CHEMICAL TREATMENT	Refining effected by chemical reagents to remove (or modify) certain constituents that have an unfavorable effect on finished oils.
CHLORIDE	Any of the salts or esters of hydrochloric acid, e.g., sodium chloride. (See also specific chlorides under alphabetical listing.)
CLAUS PROCESS	A sulfur recovery process in which hydrogen sulfide is converted to elemental sulfur.
COIL	Any of a number of turns of piping, or one of a series of connected pipes in rows or layers, for the purpose of radiating or absorbing heat. (See also "cracking coil".)
COKE	Solid carbonaceous residue obtained from coking residual crude oil. Calcined coke is coke that has been heat treated to remove volatile materials.
COKING	Thermal cracking process in which vacuum distillation unit residuum is converted to lower boiling range material and coke.
COMPOUND	A substance formed by the combination of two or more ingredients in definite proportions by weight, and possessing physical and chemical properties entirely different from those of the ingredients. (See also specific compounds under alphabetical listing.)
COMPRESSOR	A machine which draws in air or other gas, compresses it, and discharges it at a higher pressure. (See also "centrifugal compressor".)
CONDENSATE	1. The liquid product coming from a condenser. 2. A light hydrocarbon mixture produced as a liquid product in a gas-recycling plant through expansion and cooling of the gas.

SHB-90

CONDENSER	Ordinarily, a water-cooled heat exchanger used for cooling and liquefying oil vapors. Where the cooling medium used is air, the condenser is called an air condenser. (See also specific condensers under alphabetical listing.)
CONDENSER BOX	A large box-shaped structure in which the condenser, which may consist of coils or "worms", is submerged in a heat-absorbing medium, usually water.
CONVECTION	The flow of heat through liquid or gas by actual mixing of the fluids (physical turbulence).
CONVECTION SECTION	That portion of the furnace in which tubes receive heat by convection from the flue gases.
COOLER	A heat exchanger whose primary purpose is to reduce the temperature of one of the passing fluids.
COOLING TOWER	A unit or structure, usually built of wood, for the purpose of cooling water by evaporation.
CRACKED GASOLINE	Gasoline obtained by cracking heavier petroleum fractions.
CRACKING	A process in which large hydrocarbon molecules are divided into smaller molecules. Processes may be catalytic or thermal types.
CRUDE OIL	Raw material used for refinery feedstock.
CRUDE STILL	Distillation equipment in which crude oil is separated into various products.
CYLINDER	The tubular barrel portion of a piston engine within which the piston moves.

D

DEAERATOR	A divide used to remove dissolved oxygen from boiler feed water.
DEBUTANIZATION	Distillation to separate butane and lighter components of the feed from pentane and heavier components.
DE-ETHANIZER	A distillation column which removes ethane and lighter hydrocarbons from propane and heavier hydrocarbons. The terms depropanizer and debutanizer are also used for similar operations.
DEPROPANIZATION	Distillation in which lighter components are separated from C_4's and heavier material. Also called depropanation.
DESALTING	A process in which salts are removed from crude oil by washing with water. In some cases desalting may take place in the presence of an electrostatic charge to and in oil-water separation.

DIESEL FUEL	Fuel used for internal combustion in diesel engines; usually that fraction which distills after kerosene; similar to gas oil.
DISTILLATE	That portion of a liquid which is removed as a vapor and condensed during a distillation process. (See also specific distillates under alphabetical listing.)
DISTILLATION	A process in which a hydrocarbon feed is separated in various components of different boiling points.
DISTILLATION RANGE	The difference between the temperature at the initial boiling point and at the end point, as obtained by the distillation test.
DOWNCOMER	A means of conveying liquid from one tray to the next below in a bubble tray column.
DRAWOFF	A connection which allows liquid to flow from the side or bottom of a vessel.
DRY GAS	A hydrocarbon gas which does not condense easily or contain water vapor. Usually contains mostly light hydrocarbons, such as methane and ethane.

E

ECONOMETRIC MODEL	A model of the economy that emphasizes the relationship of production to income, and of income to demand. These models are usually estimated statistically from time series data.
ELECTRIC DESALTING	A continuous process to remove inorganic salts and other impurities from crude oil by settling out in an electrostatic field.
ENDOTHERMIC	Reaction or process which requires heat to take place.
ENTRAINMENT	Liquid droplets or mist contained in vapors leading a boiling liquid.
ETHANE	A gaseous paraffinic hydrocarbon, CH_3CH_3, occurring in natural gas.
EXOTHERMIC	Reaction or process which produces heat as it proceeds.
EXTRACTION	Process in which a substance is removed from a liquid stream by contacting with a second, immisible liquid (liquid-liquid extraction). Can also have gas-liquid extraction where one stream is a gas.

SHB-92

F

FEEDSTOCK	Crude oil or a fraction thereof to be charged to any process equipment.
FIXED ROOF	A tank roof which is rigidly fixed to the tank regardless of the tank liquid level.
FLARE	A device used for burning waste gases and is usually part of the relief valve system.
FLASH DRUM	A vessel used to separate vapors and liquids after a pressure reduction.
FLASH POINT	The minimum temperature at which vapors above a petroleum fraction or product will ignite in the presence of a flame.
FLASH TOWER	The vessel used for the separation of oil fractions in a flash distillation process.
FLOATING ROOF	A roof which floats on surface of liquid in a storage tank to reduce evaporation losses.
FLUE GAS	Gas from the combustion of fuel, the heating value of which has been substantially spent and which is, therefore, discarded to the flue or stack.
FLUID CATALYTIC CRACKING	High temperature, low pressure catalytic process which converts (cracks) higher boiling range fractions into lower boiling range materials.
FRACTIONAL DISTILLATION	The separation of the components of a liquid mixture by vaporizing and collecting the fractions, or cuts, which condense in different temperature ranges.
FRACTIONATING COLUMN	A column arranged to separate various fractions of petroleum by a single distillation. The column may be tapped at different points along its length to separate various fractions in the order of their condensing temperatures (boiling points). (See also "bubble tower"; "tower".)
FRACTIONATION	Separation in successive stages, each removing from a mixture some proportion of one of the substances. The operation may be precipitation, crystallization, distillation, etc. (See also specific fractionation processes under alphabetical listing.)
FUEL GAS	Light hydrocarbon gases consisting mainly of methane and ethane, generated by the refining processes and used for firing process heaters and furnaces.
FUEL OIL	Any liquid or liquefiable petroleum product burned for the generation of heat in a furnace or firebox, or for the generation of power in an engine, exclusive of oils with a flash point below 100 F. (Tag closed-cup tester) and oils burned in cotton- or wool-wick burners. (See also specific fuel oils under alphabetical listing.)

FURNACE	That portion of the refinery heater in which the combustion of fuel and air takes place.
FURNACE OIL	Distillate fuel oil used for residential and commercial heating. Also known as No. 2 Fuel Oil.

G

GAGE GLASS	A glass tube with one or more pet cocks, called gage cocks, affixed to the boiler (still or other vessel) to furnish a visual indication of the level of the liquid in the vessel. In the case of a boiler, it is also called a water gage.
GALLON	A unit measure of volume. A U. S. gallon contains 231 cu. in. or 3.785 liters; it is 0.83268 times the imperial gallon. One U. S. gallon of water weighs 8.3374 lb. at 60 F.
GAS DETECTOR	An instrument for determining the explosibility of a gas-air mixture. It is used as a safety device in refinery operations and is also known as an explosimeter.
GAS OIL	A petroleum distillate with a viscosity and boiling range between those of kerosene and lubricating oil.
GASOLINE	A refined petroleum product which, by its composition, is suitable for use as a fuel in internal-combustion engines.
GLAND	The outer portion of a stuffing box, consisting of a tubular projection which embraces the rod and extends into the bore of the box, thus bearing against the packing.
GRAVITY	1. The ratio of the weight of a volume of any liquid to the weight of an equal volume of distilled water at 60 F. (See also API gravity; "specific gravity".) 2. The downward force which the earth exerts upon all objects.

H

HEADER	A common manifold in which a number of pipelines are united. Usually refers to the U-bend connection between two consecutive tubes in the coil.
HEAT EXCHANGER	Apparatus for transferring heat from one fluid to another. Specifically, a piece of equipment having a tubular piping arrangement which effects the transfer of heat from a hot to a relatively cool material by conduction through the tube walls.
HEAT MEDIUM	A medium used for the transfer of heat at temperature levels above that of steam. Probably the most widely used medium is a high-boiling petroleum fraction, usually in the gas oil range.

SHB-94

I

IMMISCIBLE	Two materials are immiscible if they will not dissolve in each other, such as oil and water.
INDUCED DRAFT	Air drawn, rather than forced, into a furnace.
INHIBITOR	A substance, the presence of which, in small amounts, in a petroleum product prevents or retards undesirable chemical changes from taking place in the product, or in the condition of the equipment in which the product is used. In general, the essential function of inhibitors is to prevent or retard oxidation or corrosion.
INORGANIC	Pertaining to substances not organic, nonliving, i.e., which are not carbon compounds, with the possible exception of the oxides and sulfides of carbon. (See also "organic".)
ISO-	With respect to hydrocarbons, a prefix denoting branching on a straight chain.
ISOBUTANE	A colorless paraffinic gas (2-methylpropane, trimethylmethane), C_4H_{10}, with characteristic natural gas odor; boiling point, -117 C (10.6 F). An important component of natural gasoline, refinery gases, and wet natural gas.
ISOMERIZATION	A process in which normal hydrocarbons are converted to their isomers by rearranging the molecular structure. The final product called isomerate is used as a blending component in gasoline.

J

JET FUEL	A kerosene-based fuel for use in gas turbine powered aircraft. JP-4 and JP-5 are common grades of jet fuel.

K

KEROSENE	A petroleum distillate boiling between naphtha and gas oil. Used in jet fuels and heating oils.
KNOCKOUT	A drum or vessel, constructed with baffles, through which a mixture of gas and liquid is passed to disengage one from the other. As the mixture comes in contact with the baffles, the impact frees the gases and allows them to pass overhead; the heavier substance falls to the bottom of the drum.
KNOCKOUT DRUM	A process vessel used to remove entrained liquid from gases.

L

LATENT HEAT	1. The latent heat of fusion, or the amount of heat necessary to change a unit mass of solid into a liquid without change of temperature. 2. The latent heat of vaporization, or the amount of heat necessary to change a unit mass of liquid into vapor without change of temperature.

SHB-96

HEAT OF VAPORIZATION	The quantity of heat required to convert a definite amount of a liquid at its boiling point into the gaseous state.
HEATER	The furnace-and-tube arrangement which furnishes the principal heating element in a processing unit.
HEAVY CRUDE OIL	Viscous crude oils with API gravities less than 16.
HEAVY ENDS	The highest boiling portion of a petroleum fraction.
HEPTANE	Any of nine isomeric hydrocarbons of the paraffin series, C_7H_{16}; specifically, normal heptane, with boiling point at 95 C (203 F).
HOLDUP	Any time period during which a certain proportion of the liquid introduced into the distillation apparatus is actually in the column or tower as a reflux and rising vapor.
HYDROCRACKING	A high temperature, high pressure catalytic process which cracks petroleum fractions in the presence of hydrogen. Also will perform some degree of hydrodesulfurization and hydrogenate unsaturated compounds.
HYDRODESULFURIZATION	A process in which sulfur, nitrogen and metals are removed from petroleum in the presence of a catalyst by combining the sulfur with hydrogen.
HYDROGEN	The lightest of all gases, occurring chiefly in combination with oxygen in water; also in acids, bases, alcohols, petroleum and other hydrocarbons.
HYDROGEN SULFIDE	A compound of hydrogen and sulfur, specifically the monosulfide; a colorless, flammable, poisonous gas, H_2S, having a disagreeable odor; called also sulfureted hydrogen.
HYDROMETER	A graduated instrument for determining the gravity of liquids, usually made of hollow glass and weighted at one end so as to float upright. On immersion, the lighter the liquid, the lower the instrument sinks because the buoyant force is less. Some hydrometers are marked to read percentage of constituent, or some other property related to gravity. The instruments used in measuring petroleum products usually read degrees API or specific gravity directly (see "API gravity"; "specific gravity".)
HYDROTREATING	A process in which petroleum is reacted with hydrogen in the presence of a catalyst to remove sulfur or to hydrogenate unsaturated compounds. Often used interchangeably with hydrodesulfurization.

LEAD	Industry parlance for the motor fuel antiknock additive compound tetraethyllead, or for other organometallic lead antiknock compounds.
LIGHT	A relative term applied to petroleum fractions to denote the lower boiling material, such as light naphtha and light gas oil.
LIGHT ENDS	Light liquid hydrocarbons, typically ethane, propane and butane.
LINEAR RELATIONSHIP	Of the first degree with respect to one or more variables; involving measurement in one dimension only.
LIQUID PHASE	The term describing a product or substance when in the form of a liquid.
LOADING RACK	A structure used to load petroleum products into seagoing vessels, tank trucks, rail tank cars, or barges.
LOOK BOX	A box with glass windows built in the rundown lines from stills, so arranged that the stream of oil coming from the condenser coils may be watched at all times and samples for tests drawn as desired.
LUBRICATING OIL	A fluid lubricant used to reduce friction between bearing surfaces. Petroleum lubricating oils may be produced either from distillates or residues; amounts of other substances, known as additives, may be added to impart or improve certain required properties.
LUBRICATION	The state of being lubricated, or the act of applying lubricating substances which are capable of reducing friction between moving mechanical parts. (See specific types of lubrication under alphabetical listing.)

M

MANHEAD	An access opening into a tower, drum, or tank to allow entry of a man during shutdowns for inspection, cleaning or repair. Also called manhole.
MANOMETER	An instrument for measuring the expansion or the expansive power of gases or vapors; a pressure gage or vacuum gage.
MERCAPTAN	An organic compound present in "sour" crude oils or gasolines. Mercaptan compounds contain sulfur and have a strong odor.
METHANATION	A process in which carbon monoxide is converted to methane by reaction with hydrogen.

SH9-97

METHANE	A light, odorless, flammable gas, CH_4; the first member of the paraffin series (which see); boiling point, -151.4 C. It is the chief constituent of natural gas. It is also often produced by the partial decay of plants in swamps, so that its occurrence is not uncommonly misinterpreted as an indication of the presence of petroleum.
METHODOLOGIES	Systems of practices or procedures. The procedures deal with the components of an environmental impact assessment.
MID-BOILING POINT	The temperature at which approximately 50 percent of a material has distilled. There are, however, several specific definitions of the mid-boiling point, and the term should be used only with a clear understanding of its meaning in the context.
MISCIBLE	Two materials are miscible if they will dissolve in each other, such as salt and water.
MITIGATION	To lessen or reduce. Used in the context of environmental assessments to refer to an action designed to reduce adverse impacts.
MOTOR GASOLINE	A complex mixture of relatively volatile hydrocarbons, with or without small quantities of additives, which have been blended to form a fuel suitable for use in automotive internal-combustion engines.
MOTOR VALVE	A valve incorporated in automatic control systems to regulate the rate of flow of material through a section of pipe. It is actuated either mechanically, electrically, or by gas pressure from a control instrument.

N

NAPHTHA	A petroleum fraction boiling in the gasoline range.
NAPHTHALENE	A solid aromatic hydrocarbon containing a double benzene nucleus, $C_{10}H_8$; a constituent of coal tar. Obtained from crude oil and cracked petroleum products; used as a chemical intermediate and as an insecticide; melting point, 80.2 C (176.3 F).
NAPHTHENES	A group of hydrocarbons having a saturated ring structure such as cyclohexane found in naphthenic crude oils.
NAPHTHENIC ACID	A generic term applied to organic acids which occur in crude oil. ASTM Method D 288 defines them as carboxylic derivatives of cycloalkane hydrocarbons (naphthenes). The monobasic acids have the general formula $C_nH_{2n-2x}O_2$, where "X" is the number of rings in the molecule. Their salts are called naphthenates.

ORGANIC ACID	Any of the acids formed in organic matter, e.g., the fatty acids; one of the organic acids which occur in small quantities in petroleum (see "naphthenic acid"). (Editor's Note: Any acid containing the carboxyl group (COOH)).
ORIFICE	A device for restricting the flow through a pipe. The difference in pressure on the two sides of an orifice plate can be used to measure the volume of flow through the pipes.
ORIFICE METER	An instrument which measures the flow through a pipe by use of the difference in pressure on the upstream and downstream sides of an orifice plate.
OVERHEAD	The vapors which are boiled off the top of a distillation tower or the lightest product obtained in the distillation process.

P

PARAFFIN	A series of linear and branched hydrocarbons fully saturated in hydrogen, such as methane, propane. Also known as alkanes. High molecular weight paraffin in solid form is known as paraffin wax.
PARAFFIN-BASE CRUDE	Crude oil which contains paraffin hydrocarbons but no asphalt.
PARAFFIN SERIES	A homologous series of open-chain saturated hydrocarbons of the general formula C_nH_{2n+2}, of which methane (CH_4) is the first member; sometimes referred to as the methane series.
PARTIAL PRESSURE	The fraction of the total pressure exerted by each constituent of a gas mixture. The sum of the partial pressures is equal to the total pressure. The partial pressures are proportional to the concentrations of the individual gases in the mixture.
PENTANE	Any of three isomeric hydrocarbons, C_5H_{12}, of the paraffin series; specifically, the one of normal structure, $CH_3(CH_2)_3CH_3$. The others are 2,2-dimethylpropane, $CH_3C(CH_3)_2CH_3$; isopentane, $(CH_3)_2CHCH_2CH_3$. All three occur in petroleum.
PETROLEUM	A material occurring naturally in the earth, predominantly composed of mixtures of chemical compounds of carbon and hydrogen with or without other nonmetallic elements such as sulfur, oxygen, nitrogen, etc. Petroleum may contain, or be composed of, such compounds in the gaseous, liquid, and/or solid state, depending on the nature of these compounds and the existent conditions of temperature and pressure.
pH VALUE	The logarithm of the reciprocal of the hydrogenion concentration. This indicates the acid or alkaline condition of a substance, pure water and neutral solutions having a pH of 7. Acid solutions have a pH less than 7; alkaline solutions, a pH greather than 7.

NAPHTHENIC CRUDE	Crude oil containing a relatively large percentage of naphthenes. An oil obtained from a naphthenic crude is said to be a naphthene-base oil. Lubricating oils made from such crudes are normally distinguished from similar oils made from paraffinic crudes (both oils equally well refined) by lower gravity, lower carbon content and pour point, and lower rating viscosity index.
NITROGEN	Element of atomic number 7, of group V of the periodic system; colorless, odorless, tasteless diatomic gas constituting approximately four-fifths of the air; chemically rather inert; soluble in water. Derived from liquid air by fractional distillation.
NITROGEN BASE	A compound, such as amine, which may be considered a substitution product of ammonia; a compound containing trivalent nitrogen, capable, like ammonia, of combining with acids in the formation of salts containing pentavalent nitrogen.
NORMAL SOLUTION	A solution containing one gram molecular weight of the dissolved substance divided by the hydrogen equivalent of the substance per liter of solution.

O

OCTANE	Any of the group of isomeric hydrocarbons, C_8H_{18}, of the paraffin series; specifically, normal octane, a colorless liquid boiling at 124.6 C (256.1 F), found in petroleum.
OCTANE NUMBER	An index used to measure the anti-knock properties of gasoline. Research, Motor and Road Octane Numbers are three different octane ratings.
ODORANT	A material added to fuel gas to impart a distinctive odor and permit human detection.
OFFSETS	An amount of pollution reduced from existing sources which exceed projected amount of pollution from a new source (nonattainment areas).
OLEFINS	A class of hydrocarbons which are "unsaturated" or deficient in hydrogen, such as ethylene, butylene.
ON STREAM	A term to denote that a refinery or process unit is in normal operation.
ORGANIC	Designation for a branch of chemistry treating, in general, of the compounds produced in plants and animals, or of carbon-hydrogen compounds of synthetic origin; contrasted with inorganic (which see).

SHB-100

PIPE STILL	A still in which heat is applied to the oil while being pumped through a coil or pipe arranged in a suitable firebox. After leaving the heating zone, the pipe runs to a fractionator; a portion of oil is taken off overhead as vapor, and the liquid portion is removed continuously.
PREHEAT	To heat, previous to some treatment, as an oil to be subsequently distilled, or as a body of gas or oil to be used as fuel.
PRESSURE	The force or thrust exerted on a surface, normally expressed as force per unit area. Pressure is exerted in all directions in a system. Common examples: air pressure in a tire, or water pressure at some depth in the ocean. (See also specific types of pressure under alphabetical listing.)
PRESSURE DROP	The decrease in pressure due to friction, which occurs when a liquid or gas passes through a pipe, vessel, or other piece of equipment.
PRESSURE VESSEL	An enclosed container in which greater than atmospheric pressure is maintained.
PRIMARY AIR	The air required for combustion in a furnace which is mixed with the fuel (gas, oil, pulverized coal, etc.) in and through the burner.
PROPANE	A gaseous paraffin hydrocarbon, C_3H_8, occurring in crude oil, natural gas, and refinery cracking gas. It is used as a fuel, a solvent, and a refrigerant.
psia, psig	Pressure designations in pounds per square inch. Psig is the actual reading of a pressure gauge and psia is psig plus atmospheric pressure.
PUBLIC OWNED TREATMENT WORKS	A treatment works which is owned by a state or municipality.
PUKING	In a still or bubble tower, the foaming and rising of oil to the extent that part of the liquid is driven out of the vessel through the vapor line. (See also "surge".)
PUMP	A machine for raising or transferring liquids or gases by suction, pressure, or both. (See also specific pumps under alphabetical listing.)
PUMPAROUND	A system on a distillation tower for withdrawing a liquid from a plate, cooling it, and returning it to another plate for the purpose of inducing the condensation of vapors.
PURGING	The displacement of one material with another in process equipment; frequently, displacement of hydrocarbon vapor with steam or inert gas.

SHB-161

R

REBOILER	A heat exchanger used to boil liquid to provide vapors to the bottom of a process column.
RECYCLE	1. A type of operation in which part of the product is continuously fed back for reprocessing, in contrast to once-through operation. 2. That portion of the product which is fed back.
REDUCED CRUDE OIL	The crude oil remaining after distillate products have been removed in the crude distillation process. Typically is the feed-stock to the vacuum distillation unit.
REFINERY GAS	Any form or mixture of gas gathered in a refinery from the various stills.
REFLUX	In fractional distillation, that part of the distillate which may be returned to the column to assist in making a better separation into desired fractions. This operation is called refluxing. Reflux may be either circulating or induced. Circulating reflux is liquid which is withdrawn hot, cooled, and pumped back to the tower. Induced reflux is liquid formed within a fractionation tower by condensation of vapors by means of an internal cooling coil.
REFLUX CONDENSER	A condenser which constantly condenses vapors and returns liquid to the original distilling unit or to lower levels of a fractionating tower.
REFORMING	A process in which the octane rating of naphtha is increased by catalytic reaction or mild thermal cracking. The product is termed reformate and used as a blending component in gasoline.
RESIDUAL FUEL OIL	Fuel oils containing reduced crude oil.
RISER	That portion of the bubble plate assembly which channels the vapor and causes it to flow downward to escape through the liquid.

S

SAFETY VALVE	A valve on a still, vapor line, or other pressure vessel, set so that it will permit the emission of gases when the maximum safe working pressure is reached.
SALT	A compound in which a metal or other positive ion exists in place of the hydrogen of an acid (e.g., potassium bromide, in which potassium replaces the hydrogen of hydrobromic acid), formed: 1, by direct replacement of the acid hydrogen with a metal; 2, by neutralization of the acid with an appropriate base; or, 3, by double decomposition.

SATURATED HYDROCARBON	Hydrocarbons that have no deficiency of hydrogen such as methane and ethane.
SAYBOLT-FUROL, SAYBOLT-UNIVERSAL	Measures of viscosity used in petroleum industry.
SCRUBBING	Purifying a gas by washing with water or chemical; less frequently, the removal of entrainment. The equipment used to give intimate contacting of the material to be purified is called a scrubber.
SECONDARY AIR	The air which provides the oxygen necessary for the complete combustion of fuel (gas, oil, powdered coal, etc.), and which was not provided by the burner in the form of primary air.
SETTLER	A separator; a tub, pan, vat, or tank in which the partial separation of a mixture is made due to difference in density. The operation may be continuous or batch. The separation may be solids from liquid or gas, liquid from liquid, liquid from gas.
SHIFT CONVERTER	A reactor used to convert two compounds to two different compounds, such as are used in sulfur plants and hydrogen plants.
SIDESTREAM	A liquid stream taken from any one of the intermediate plates of a bubble tower.
SIDESTREAM STRIPPER	A device used to perform further distillation on a liquid stream from any one of the plates of a bubble tower, usually by the use of steam.
SIEVE PLATE	A fractionating tower tray which is perforated so that the vapor emerges vertically through the tray, making no turns. Some sieve trays are designed with no exit weirs. Sieve trays with perforation 1/8-inch and 3/16-inch diameter have overall efficiencies equal to, or approximately 10 percent higher than, those of bubble trays.
SIGHT FEED LUBRICATOR	A lubricant feeder which permits the oil to pass visibly, drop by drop, through a section of a glass tube so that its rate of supply may be observed.
SKIMMING	Distillation of crude oil to remove light fractions only. Also known as topping.
SLOP	A term loosely used to denote odds and ends of oil produced in the plant, which must be rerun or further processed in order to make them suitable for use. Also called slop oil.
SOUR	Containing sulfur compounds such as hydrogen sulfide, as in sour gas or sour crude oil. Sour crude oil is defined as having more than 0.5% (wt) of total sulfur.
SPLITTER	A fractionating tower with an overhead stream and a bottoms stream only.

STABILIZATION	The process of separating light gases from petroleum or gasoline, thus leaving the liquid stable in the sense that it can be handled or stored with less liability to change in composition.
STABILIZED GASOLINE	Gasoline from which "wild" or low-boiling hydrocarbons (which have high vapor pressure) have been removed by stabilization.
STABILIZER	A distillation process which removes light ends from petroleum liquids, generally butanes, from naphthas.
STANDARD PRESSURE	Pressure under which the mercury barometer stands at 760 mm, or 30 inches (equivalent to approximately 14.7 psi).
STEAM	1. Water in the vapor state. 2. To remove the last traces of naphtha from a bed of filter clay or activated earth by the injection of steam into the filter.
STEAM DISTILLATION	A distillation in which vaporization of the volatile constituents is effected at a lower temperature by introduction of steam directly into the charge. Steam used in this manner is termed open steam.
STRAIGHT-RUN PRODUCT	A product produced by the primary distillation of crude oil.
STRAPPING	The procedure whereby storage tanks are strapped (measured) on their outside with steel measuring tapes, and the measurements used to calculate the volumetric capacity of the tank for given increments in its height. Deductions are made for plates and interior fittings to determine the actual volume of the tank.
STRIPPING	Removal of the lightest fractions from a mixture. The process is usually carried out by passing the hot liquid from a flash drum or tower into a stripping vessel-or section (stripper), through which open steam or inert gas is passed to remove the more volatile components of the cut.
STUFFING BOX	A device affording the passage and the lengthwise and rotary motion of a piston rod, shaft, or some similar moving piece while maintaining a fluid-tight joint about the moving part.
SULFIDE	Any of the compounds resulting from the combination of sulfur ions (S =) with metallic or other positive ions, or organic radicals.
SURGE	An upheaval of fluid in a system frequently causing a carryover of liquid through the vapor lines.
SWEET	Containing little sulfur or sulfur compounds, such as hydrogen sulfides and mercaptans.

T

TAIL GAS	Sulfurous gases unreacted in sulfur recovery process.
TAIL GAS TREATING	Processes which remove the residual sulfur compounds present in sulfur recovery unit tail gas.
TAR	Highly viscous polymerized residue produced in a vacuum distillation, cracking coils. By-product of the cracking process.
TEMPERATURE	An arbitrary measurement of the amount of molecular energy of a body, or the degree of heat possessed by it. It should be distinguished from heat itself. Heat is a form of energy; temperature is a measurement of its intensity.
TOPPED CRUDE	Residual crude oil obtained in topping plant.
TOPPING	See Skimming
TOWER	A vertical vessel in which petroleum is distilled, or gases are absorbed, etc.
TRANSFER LINE	A pipe through which material being processed flows from one piece of equipment to another. Generally, the pipeline carrying the heated stock from the furnace to a tower or reaction vessel.
TRAP	A device or piece of equipment for separating one phase from another, as liquid from a gas or water from steam.
TREATING	A process in which petroleum is contacted with chemicals to improve product quality.
TUBE BUNDLE	A group of fixed, parallel tubes, such as is used in a heat exchanger; includes the tube headers with the tubes, baffles, and spacer rods.
TURNAROUND	A maintenance operation in which a refinery or process unit is shut down and repaired.

U

UNDECANE	Colorless liquid paraffinic hydrocarbon, $C_{11}H_{24}$; specific gravity, 0.745; boiling point, 195.8 C (384.4 deg. F.); melting point, 26.5 C (79.7 F.)

V

VACUUM DISTILLATION	Separation of crude oil by distillation at pressures below atmospheric.

VALENCE	The combining power of an element, as exhibited by the number of atomic weights of hydrogen with which one atomic weight of the element will combine. Certain atoms are capable of combining with others in different proportions; they are said to have a number of valences, or combining factors.
VAPOR PRESSURE	Pressure exerted by a liquid at a given temperature in a closed vessel in the absence of air or other compounds.
VAPOR RECOVERY	A system used to collect hydrocarbon vapors from vents and relief devices for reuse in the refinery.
VIRGIN STOCK	See Straight Run
VISCOSITY	A measure of resistance to flow, often determined by the time for liquid to pass through standard orifice.

W

WASH	In petroleum refining, to cleanse or purify by intimate contact with water or chemicals. (See also "scrubbing"; specific washes under alphabetical listing.)
WEEP HOLE	A small hole in the bubble plate which serves to drain liquid from the plate when the column is not in use.
WEIR	A wall or partition for maintaining a level of liquid; used in bubble trays and reboilers.
WET GAS	Fuel gas containing condensable hydrocarbon vapors.

Y

YIELD	The amount of a desired product or products obtained in a given process, expressed as a percentage of the feedstock. There are many yields, each of which should be specifically defined when used.

SHB-106

ABBREVIATIONS

AQCR	Air Quality Control Regions
BACT	Best Available Control Technology
BAT or BATEA	Best Available Technology Economically Achievable
BCT	Best Conventional Technology
BMP	Best Management Practices
BCD_5	Five-day Biological Oxidation Demand
BPCT	Best Available Control Technology
BS&W	Bottom Sediment and Water
BTU	British Thermal Unit
CAA	Clean Air Act
CAA§110	Section 110 of the Clean Air Act
CFR	Code of Federal Register
COD	Chemical Oxygen Demand
CWA	Clean Water Act
CWA§110	Section 110 of the Clean Water Act
EPA	United States Environmental Protection Agency
FCC	Fluid Catalytic Cracking Unit
LAER	Lowest Achievable Emission Rate
LPG	Liquefied Petroleum Gas
ug/m^3	Micrograms Per Cubic Meter
NAAQS	National Ambient Air Quality Standards
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standard
POTW	Public Owned Treatment Works
PSD	Prevention of Significant Deterioration
SIP	State Implementation Plan
SPCC	Spill Prevention Control and Countermeasure Plan
TEL	Tetraethyl Lead
TSS	Total Suspended Solids

SUMMARY OF REFINERY PROCESSES

5

CLASSIFICATION OF PETROLEUM REFINERY PROCESSES

1.0 STRAIGHTFORWARD SEPARATION PROCESSES. No chemical or molecular changes; i.e., fractional distillation, solvent dewaxing, solvent deasphalting, Udex.

2.0 CHANGE PROCESSES. Chemical transformation occurs.

- 2.1 BREAKUP PROCESS. Large molecules broken down into smaller ones; change in carbon number, molecular weight; i.e., catalytic or thermal cracking.
- 2.2 PROPERTY CHANGE PROCESS. Chemical character of molecule but not molecular weight altered; rearrangement in geometry of naturally-occurring molecules to change quality; i.e., reforming, paraffin isomerization.
- 2.3 BUILDUP PROCESS. Synthesize useful, larger molecules from smaller building blocks (which are commonly refinery degradation products; i.e., paraffin alkylation, polymerization.
- 2.4 CLEANUP PROCESS. Remove small amounts of naturally-occurring impurities such as sulfur, oxygen, nitrogen and metals.
  - 2.41 **FEEDSTOCK PREPARATION.** Remove contaminants which impair refinery process performance; i.e., catalyst poisons such as sulfur and lead (PtR) or nickel and vanadium (FCC).
  - 2.42 PRODUCT STREAM CLEANUP OR FINISHING. Remove impurities still remaining after processing to meet performance, marketing, or pollution spec; i.e., catalytic hydrodesulfurization.

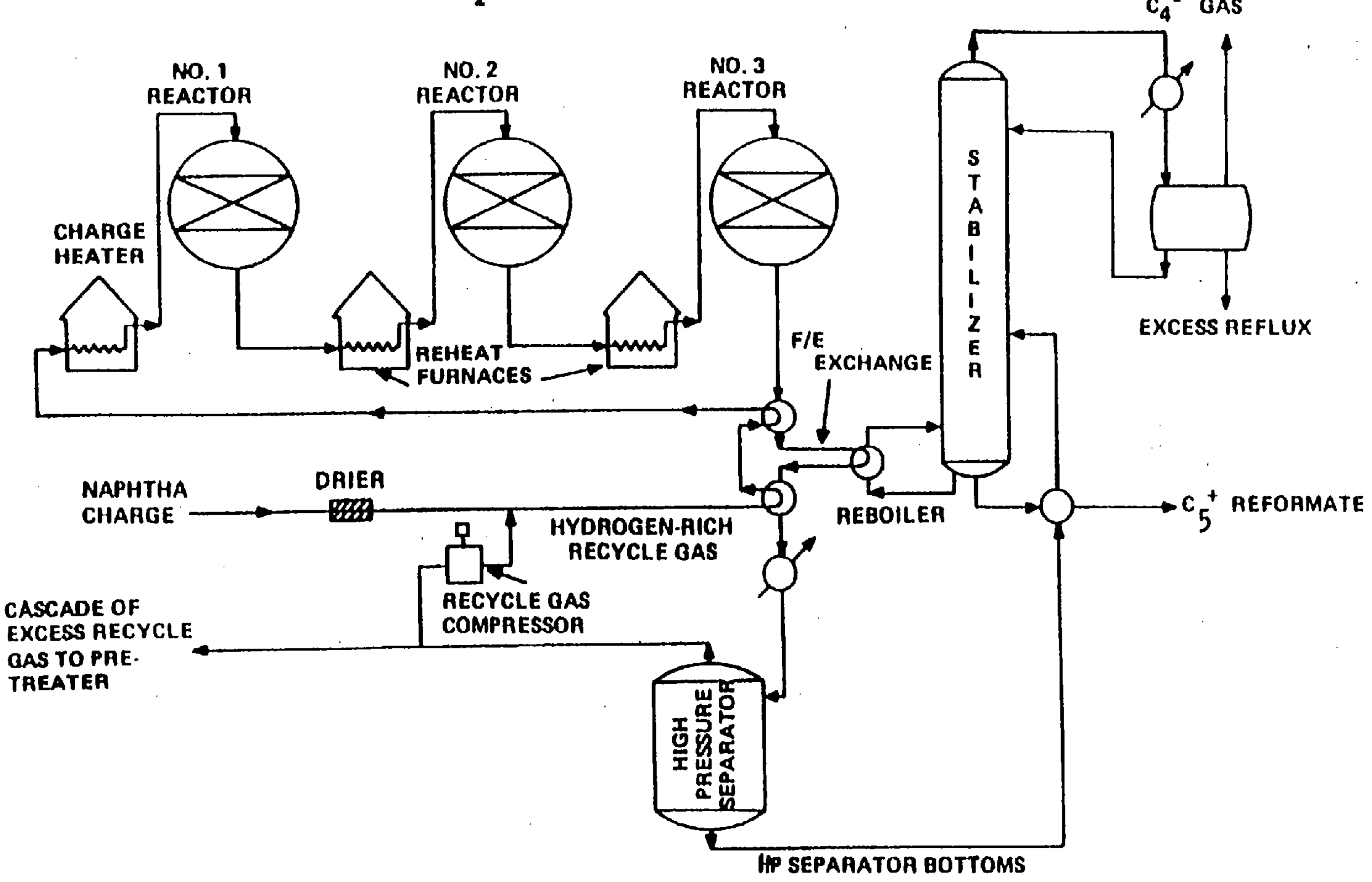
SHB - 110

PROCESS:	SEMIREGENERATIVE CATALYTIC REFORMING
OBJECTIVE:	Convert low octane naphtha to higher octane reformate with maximum conservation of C_5+ liquid yield and minimum degradation of liquid to gas and coke (catalyst life); reforming is major "octane flywheel" of refinery.
FEEDSTOCK:	Straight-run naphtha: ~C_6-C_{12}, b.p.~150-390°F, largely paraffins, naphthenes, few aromatics; relative proportions of P, N, A greatly influence yields.
PRODUCTS AND YIELD STRUCTURE:	Major: C_5+ high octane gasoline; minor: C_1-C_4 paraffins and H_2 gas; generally higher octanes are produced at expense of liquid yield.
CATALYST:	Pt or Pt/Re (~0.3-0.6 wt %) supported on high surface area, porous, slightly acidic Al_2O_3; sensitive to poisons: sulfur, lead, arsenic, and to high levels of water.
PROCESS ENGINEERING:	Unit/Hardware: 3 or 4 adiabatic reactors in series with interstage heating, H_2-recycle, compression and naphtha-drying. Operating Conditions: ~900-950°F, 200-600 psig, 6-10/1 H_2/HC ratio, 1-2 LHSV. Auxiliaries: Feed/effluent heat exchange, stabilizer (debutanizer). Mechanism: Pt strips H_2 out of naphthenes to form aromatics, and converts paraffins to aromatic rings; straight chain paraffins are isomerized.
SPECIAL EFFECTS:	H_2 produced in PtR is cascaded to naphtha pretreater and CHD; reforming involves complex interplay of kinetics and thermodynamics and is sensitive to pressure and temperature.
ALTERNATIVES:	C_6's or C_5/C_6 mixtures can be isomerized.

StB-114

TYPICAL SEMI-REGENERATIVE REFORMING PROCESS

200-600 PSIG
H_2/HC RECYCLE RATIO 6 — 10/1



SHB-112

PROCESS:	SELECTOFORMING
OBJECTIVE:	Upgrade naphthas and reformates to high octane gasoline components and manufacture of propane LPG; reduce reforming precious metal requirements.
FEEDSTOCK:	Any naphtha boiling range (C_5-C_{12}) fraction containing straight chain paraffins.
PRODUCTS AND YIELD STRUCTURE:	Major: C_5+ gasoline with clear octanes up to 8 numbers higher, higher DON, lower front end volatility; minor: significant yields of LPG (mainly propane, some C_4's) small amounts of H_2, C_1, C_2.
CATALYST:	Dual-functional, containing both a non-noble metal function and a shape-selective acid cracking function (zeolite).
PROCESS ENGINEERING:	Unit/Hardware: Fixed bed single pass adiabatic reactor with feed preheat. Operating Conditions: ~600-850°F, 200-600 psig, 2-4/1 H_2/HC ratio, 1-10 LHSV; H_2 can be cascaded from PtR, and separator off-gas can be recycled if necessary. Auxiliaries: Cooling, high pressure separation into refinery gas and liquid, and stabilization (to give LP gas and C_5+ Selectoformate). Mechanism: Selectoforming is a mild, post-reforming hydrocracking process, where n-paraffins are seletively adsorbed and cracked (mainly to propane), while branched paraffins, naphthenes, and aromatics (with higher octane numbers) are preserved.
SPECIAL EFFECTS:	At same product octane, reformer severity can be reduced and its cycle lengthened.
ALTERNATIVES:	Higher severity reforming of C_6+ naphthas or reformate; isomerization of C_5's.

SHB-113

SHB-114

PROCESS: HYDROPROCESSING

OBJECTIVE: Major general objective is to remove small amounts of naturally occurring impurities - sulfur, nitrogen, oxygen, metals - under relatively mild conditions, either to prepare a feedstock for catalytic processing of as final cleanup or finishing of a product stream; another objective sometimes is to add H_2 by catalytic hydrogenation of unsaturates to improve product quality or fuels performance.

FEEDSTOCK: These include all boiling ranges: naphthas (~C_5-C_{12}, b.p. ~120-390°F), middle distillates (~C_{12}-C_{20}, b.p. ~400-650°F), heavy gas oils (~C_{18}-C_{30}, b.p. ~550-800°F) and atmospheric resids (~C_{20}+, b.p. ~650°F+); most of these fractions contain P, N, A; cracked fractions may contain olefins.

PRODUCTS AND YIELD STRUCTURE: Major product from any boiling range fraction is always of comparable boiling range; some lighter products are generally made, however: some C_4- gas from naphtha, and some C_4- gas and naphtha from heavier fractions, because a small amount of cracking cannot be avoided.

CATALYST: Generally contains ~10% MoO_3 with ~3% CoO supported on high surface area, porous Al_2O_3; catalyst is rugged and can tolerate large accumulations of impurities without losing its hydrotreating capability; nickel or tungsten are used in some systems.

PROCESS ENGINEERING: Unit/Hardware: Generally fixed bed single pass adiabatic reactor with feed preheat, H_2-recycle/compression and cooling quench capabilities, and feed effluent heat exchange capacity.

Operating Conditions: ~700-800°F, 350-3000 psig H_2, ~0.5-5 LHSV; severity, particularly H_2 pressure, depends on how heavy feedstock is (see Figure 14 for breakdown).

Auxiliaries: High and low pressure separators, fractionators, and access to amine scrubbers to remove H_2S and mercaptans are required; supply of H_2 cascaded from PtR will generally be adequate for pretreater (naphtha) and CHD (kerosene, jet, light distillates), but for HOD (heavy gas oils and atmospheric residua), high H_2-consumption dictates construction of H_2 plant.

Mechanism: Sulfur is removed catalytically by hydrogenation of heterocyclic aromatic rings in which it is located; in lighter fractions, mild conditions suffice for desulfurization; with heavier oils, the sulfur is deeply buried in the hydrocarbon, and a mild catalytic cracking is required to extract it; hydrogenation of polynuclear aromatics consumes much H_2 but improves quality.

SPECIAL EFFECTS: Processing residua for fuels is especially difficult if large amounts of asphaltenes are present; these high molecular weight, often colloidal aggregates, are highly aromatic and tend to coke up catalysts; their sulfur and metals are difficult to remove, and much H_2 is consumed in their processing; both engineering and catalytic problems are encountered in their conversion.

ALTERNATIVES: There is no simple alternative to these basic hydrogenative cleanup processes. Also, some hydrogen must be added simply to meet the C and H stoichiometric requirements of a premium product slate; with heavy fractions, the only alternative to hydrogen addition is carbon rejection, i. e., by coking, solvent deasphalting, etc.

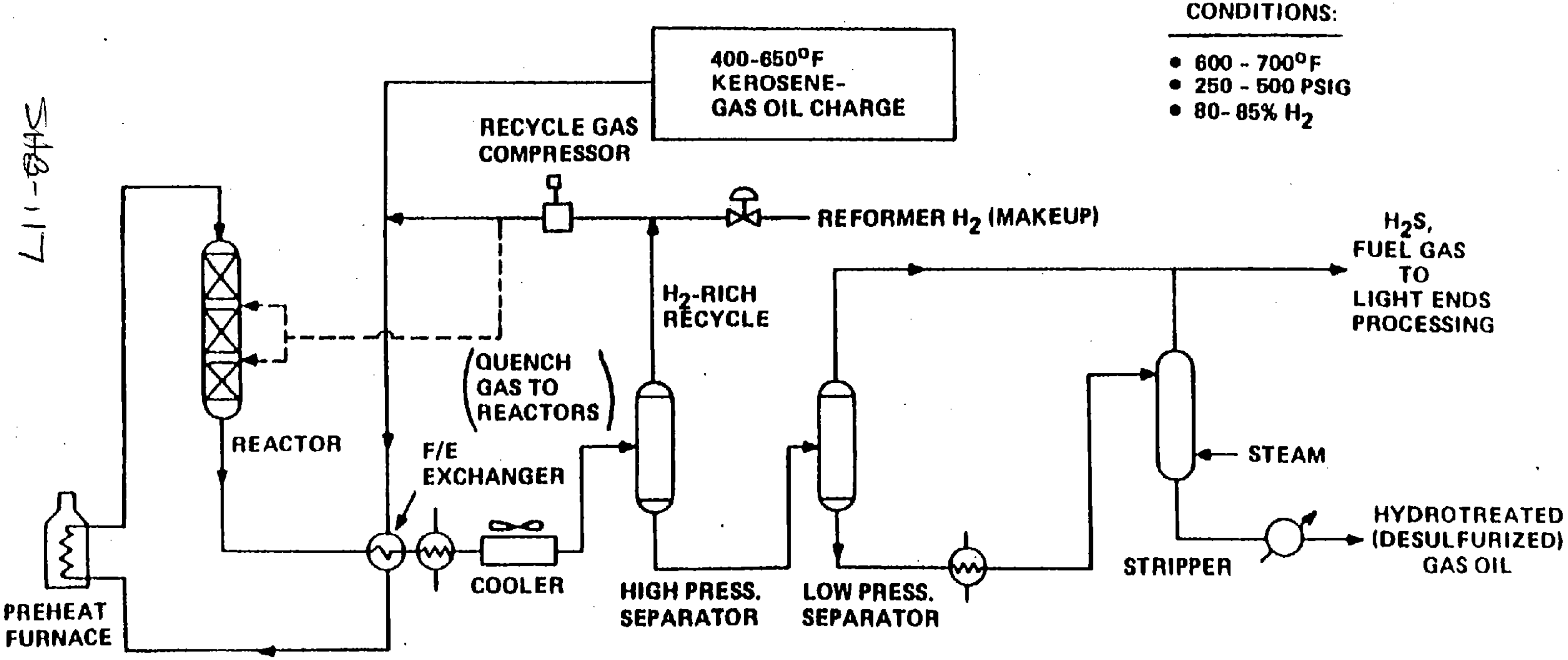
RELATIONSHIP BETWEEN FEEDSTOCK AND HYDRODESULFURIZATION SEVERITY

Stock	C # Range	T, °F	P_{H_2}, psig	Relative Cost (Approx.)
Naphtha	$C_5 - C_{12}$	700	350 - 450	1
Middle Dist.	$C_{12} - C_{20}$	650 - 700	500 - 650	~ 1.5 - 2
Heavy G.O.	$C_{20} \sim C_{35}$	700 - 750	1000	~ 3
Atm. Resid. *	C_{20}^{+}	700 - 800	1500 - 3000	~ 6 - 9

* Contains Asphaltenes

CATALYTIC HYDRODESULFURIZATION OF KEROSENE/DISTILLATES

SHB-117



PROCESS: CATALYTIC CRACKING

OBJECTIVE: Make available liquid fuels in the gasoline and light distillate boiling range by reducing molecular weight (cracking) of heavy petroleum fractions with minimum degradation of feed to coke and C_4-gas.

FEEDSTOCK: Any petroleum-type fraction can be cracked to a range of lighter products; generally ~C_{12}+ (~400°F) or more commonly, C_{20}+ (~650°F+) straight run or vacuum gas oils are processed, although very high molecular weight (no well-defined end point) atm. residua can be cracked (HOC); coker stocks, shale oil, coal-derived oils, etc., may also be cracked.

PRODUCTS AND YIELD STRUCTURE: Cracking a high molecular weight stock of any (P,O,N.A) composition yields a broad spectrum of products, both in terms of molecular weight and chemical class; a heavy gas oil will yield C_5- ~400°F gasoline as major product, light fuel oil, perhaps heavy fuel oil, C_4's, C_3- gas, and coke.

CATALYST: Over 95% of modern U.S. cracking units employ zeolite catalysts -- which contain a minor proportion (5-15%) of crystalline zeolite incorporated in a porous, amorphous inorganic matrix; such catalysts are thermally stable, have high internal surface area, and are best employed in fluid form (~.002 inch diameter); zeolite catalysts are more active and selective than the older amorphous silica-alumina catalysts, and are very strong acids; they are, however, susceptible to poisoning by excess nitrogen and contaminant poisons such as nickel or vanadium.

PROCESS ENGINEERING: Unit/Hardware: Modern fluid catalytic cracking units include reactor, regenerator and fractionation sections: hot, burned-clean regenerated catalyst is mixed with oil feed at the base of a tubular riser, where reaction occurs; in the reactor section, hot product vapors are separated and sent to fractionation, while spent catalyst is steam-stripped, and sent to a fluidized bed regenerator, where coke is burned off with air; the burned clean catalyst then begins a new cycle, while the flue gas (CO,CO_2), after separation of fines and CO-removal, is vented in the stack.

Operating Conditions: ~900-1000°F, 30-40 psig, 10-20 sec. residence time, 7-8 ratio catalyst circulation rate/oil circulation rate; up to 50% recycle of heavy, unreacted oil may be employed if desired.

Auxiliaries: A main distillation column with gasoline and lighter as overhead and take-offs for naphtha, light fuel oil, heavy fuel oil, etc., is always present; a debutanizer and unsaturated gas plant may also be within the battery limits.

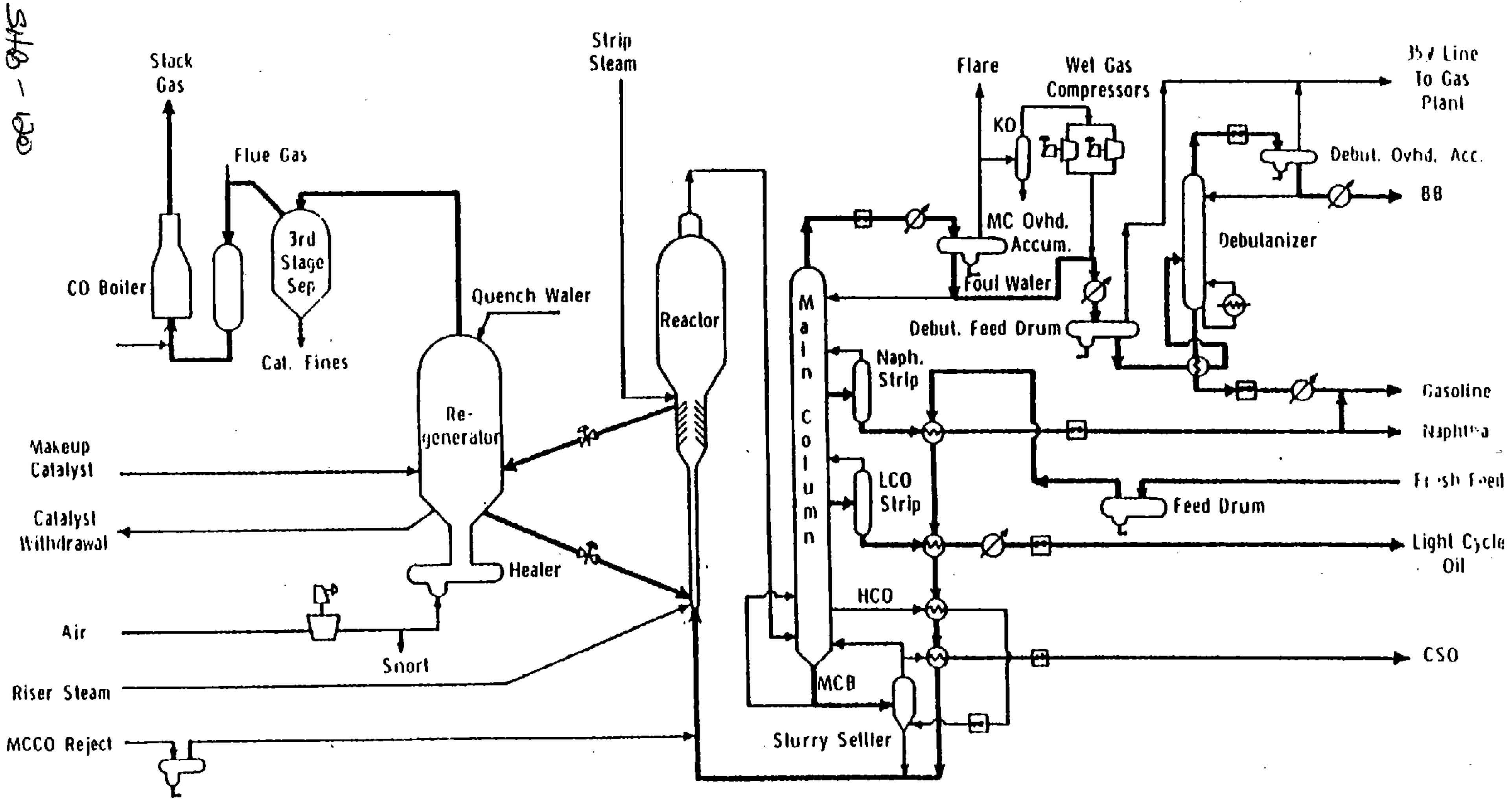
Mechanism: The high internal surface area, acidic zeolite catalyst cracks or fragments the high molecular weight hydrocarbons in such a manner that selective formation of gasoline and good quality distillate occurs, with minimum formation of dry gas and coke; thermal cracking, on the other hand, produces poorer quality gasoline, fewer valuable branched paraffins and aromatics, and more gum-forming diolefins.

SPECIAL EFFECTS: It is desirable to effect substantial removal of asphaltenes from residua cracking feedstocks, as these will coke up the catalyst and deposit metal poisons on the cracking catalyst; the metals, in turn, will degrade more feed into coke and gas, causing engineering problems.

ALTERNATIVES: At this time, catalytic cracking appears to be the only practical method of molecular weight reduction.

SHB - 120

[redacted] F C C - 1



PROCESS: HYDROCRACKING

OBJECTIVE: Conversion of wide range of hydrocarbon feedstocks to lower molecular weight, cleaner, more valuable products.

FEEDSTOCK: Like catalytic cracking, the feedstocks for this highly flexible process include naphtha, light and heavy gas oils, vacuum gas oils, cracked and coker gas oils, deasphalted residuum, topped crude, and shale oil.

PRODUCTS AND YIELD STRUCTURE: Variations in feedstock, catalyst and process can result in optimum product yields over a wide range, including slates that can emphasize high octane gasoline, jet fuel, low-pour, low-sulfur diesel, LPG, low sulfur fuel oils, or high VI lube stocks. Essentially no coke is formed.

CATALYST: Hydrocracking owes its flexibility in large part to the flexibility of its dual functional catalyst system, consisting of an acid component (i.e., zeolite or silica-alumina) and a hydrogenation component (i.e., Pd, Ni, Mo, W, etc.); hydrocracking catalysts are sensitive to nitrogen poisons; catalyst lifetimes may be up to 2 years.

PROCESS ENGINEERING:

Unit/Hardware: Hydrocrackers commonly operate as 2-stage, series, fixed-bed reactors with intermediate fractionation and recycle of H_2-gas and heavy bottoms; most of the sulfur and basic nitrogen is removed in the first stage (which functions as a hydrotreater); the second stage involves major molecular weight reduction by hydrocracking, with extinction recycle; because the reactions are highly exothermic, tight process control with external gas quench is required.

Operating Conditions: ~500-800°F, 1500-3000 psig H_2, 0.5-2 LHSV, 5000-9000 SCF/bbl H_2 circulation rate, 2000-3000 SCF/bbl H_2 consumption.

Auxiliaries: Because of the high H_2 consumption, it is necessary to build an H_2 plant; reforming of hydrocracked naphtha is often required to meet gasoline octane requirements.

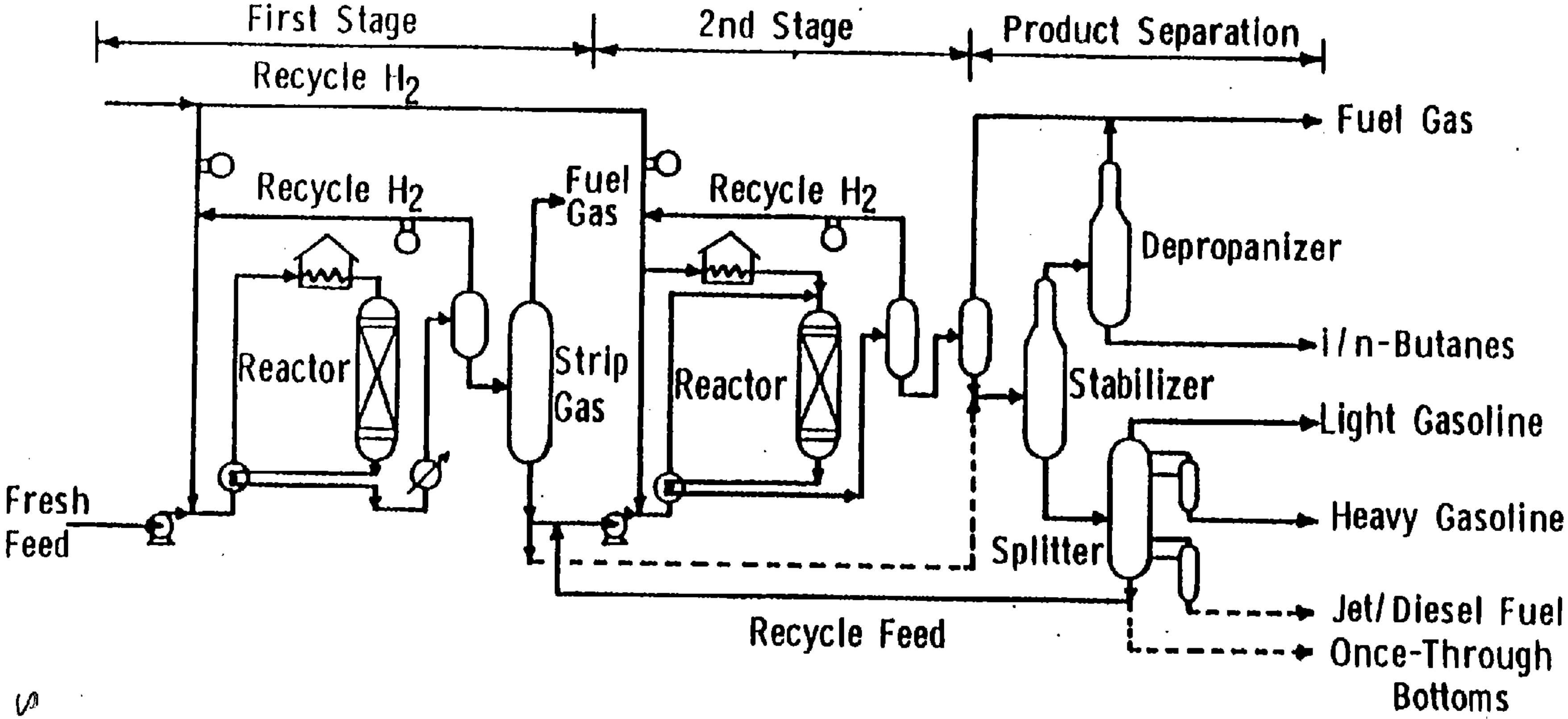
Mechanism: The first stage reactions are essentially those of hydrotreating; the second stage reactions combine cracking (C-C bond clearage) and simultaneous hydrogenation of the newly-formed products as well as coke precursors.

SPECIAL EFFECTS: The balance between the strength of the acid cracking sites and the metal hydrogenation sites is critical in determining product distribution.

ALTERNATIVES: A major alternative to hydrocracking is the hydrotreating-FCC combination.

SH6.122

ISOMAX HYDROCRACKING OF GAS OILS



SHB-123

PROCESS: PARAFFIN ALKYLATION

OBJECTIVE: Optimize refinery gasoline yield by recombining low molecular weight products of degradation via the buildup process of alkylation.

FEEDSTOCK: Isobutane is reacted with butene, propylene, or, less commonly, ethylene or pentene.

PRODUCT AND YIELD STRUCTURE: High octane, highly-branched paraffinic gasoline blending stocks are synthesized as shown: *iso*-$C_4H_{10} + C_4H_8 \longrightarrow C_8H_{18}$ (~96 R+O), and *iso*-$C_4H_{10} + C_3H_6 \longrightarrow C_7H_{16}$ (~93 R+O).

CATALYST: Concentrated liquid acids (88-95% H_2SO_4, 80-95% HF); $AlCl_3$ will catalyze ethylene alkylation.

PROCESS ENGINEERING:

Unit/Hardware: Dried olefin is mixed with isobutane and HF catalyst in liquid phase in reactor; the effluent is settled; HF is recycled to reactor; the settler overhead is fractionated, carrying isobutane and lighter overhead, with *n*-butane sidestream, and product alkylate as bottoms.

Operating Conditions:

	Temp., °F	Isobutane/ Olefin Ratio	Olefin Contact Time, min.	Acid in Emulsion, vol %
H_2SO_4	35-60	3-12	20-30	40-60
HF	60-125	3-12	8-20	25-80

Auxiliaries: A depropanizer is needed if propane content of feed is high; an HF stripper is required.

Mechanism: Buildup of C_7's and C_8's from C_3 and C_4 fragments operates by an acid-catalyzed chain reaction similar to certain types of polymerization; it is essentially the reverse of cracking.

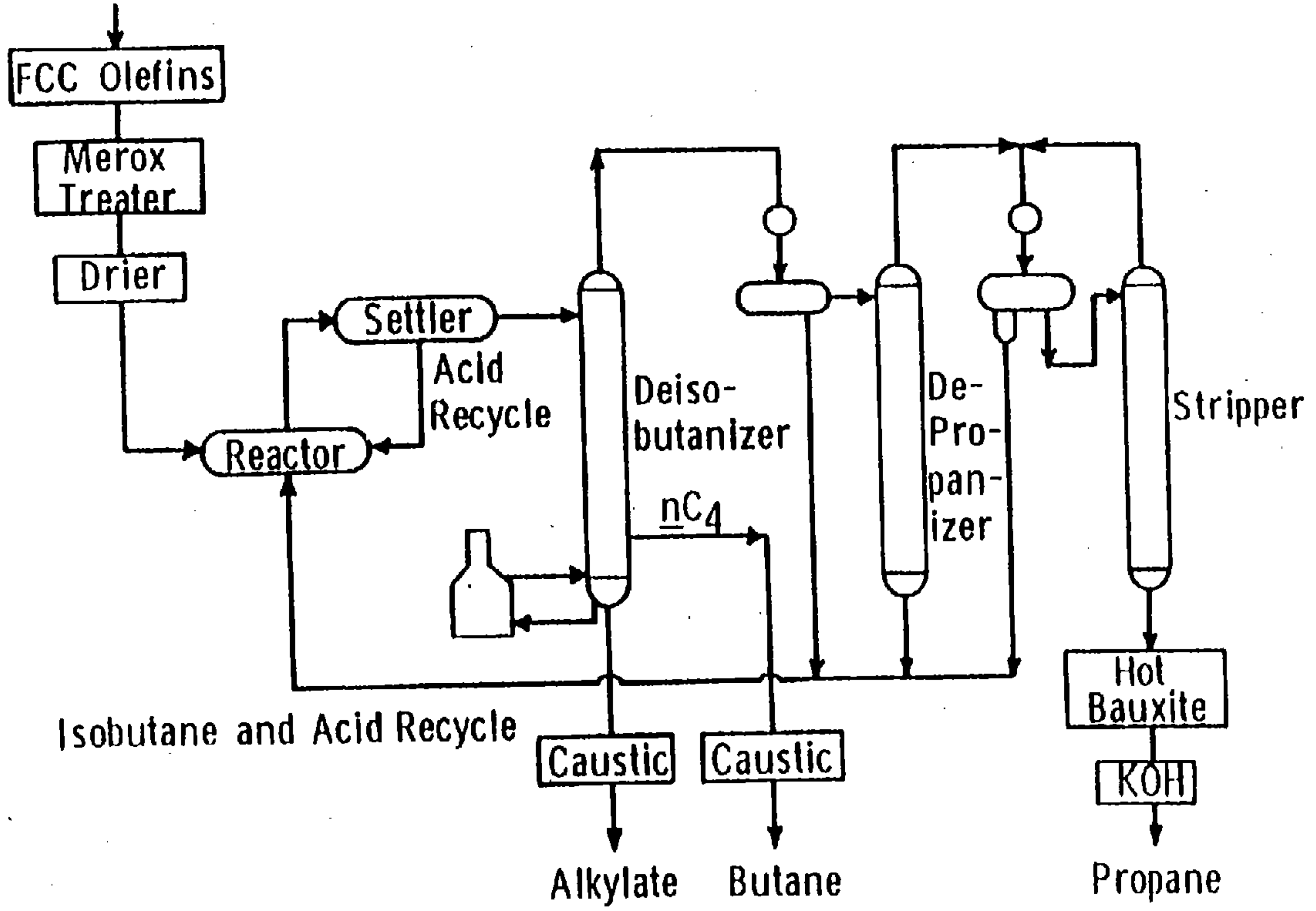
SOB-124

RESTRAINTS AND SPECIAL EFFECTS: Butadiene concentration must be kept low to avoid excess acid consumption.

ALTERNATIVES: Catalytic polymerization of propylene and butenes to liquids boiling in the gasoline range (supported phosphoric acid catalyst, 350-450°F, 500-1100 psig; novel catalytic propylene or butene dimerization processes could be attractive.

SHB-125

TYPICAL HF ALKYLATION UNIT



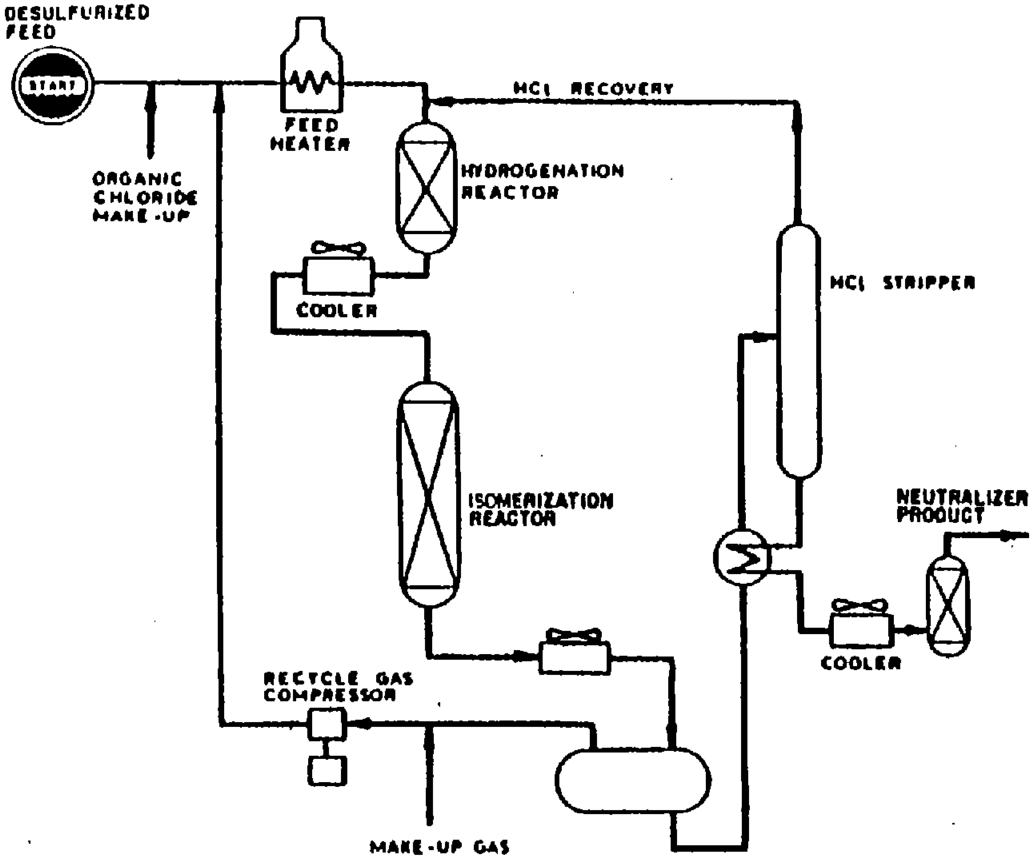
PROCESS:	PARAFFIN ISOMERIZATION
OBJECTIVE:	Rearrange the structure of naturally-occurring, low-octane light paraffins to more highly branched high octane gasoline blending stocks, without loss to gas or coke.
FEEDSTOCK:	Fractions rich in n-pentane, n-hexane, or mixtures of both; sometimes, n-butane.
PRODUCTS AND YIELD STRUCTURE:	Iso- or branched structures are formed from n- or straight-chain paraffins without change of carbon numbers, octane enhancement of ~10-12 R+O units from some C_5/C_6 streams; ~1% loss to gas.
CATALYST:	Modern paraffin isomerization catalysts are dual-functional, containing small amounts of noble metal; i.e., Pt supported on a high surface area, acidic Al_2O_3; acidity of Al_2O_3 is promoted by small amounts of $AlCl_3$ or organic chlorides; many variations are employed; catalyst is sensitive to water, sulfur, olefins and aromatics; catalyst life may be up to 3 years.
PROCESS ENGINEERING:	Unit/Hardware: Fixed bed, adiabatic, continuous-flow reactor, with cooler, high pressure separator, and recycle of H_2-gas; separator liquid passes through a stripper and HCl in overhead is recycled to reactor; feed is catalytically desulfurized, and passed through a "guard reactor", where benzene and olefins are hydrogenated. Operating Conditions: ~250-400°F range, 300-1000 psig H_2, H_2 consumption ~40-50 SCF/bbl; small amount of organic chloride (<100 ppm) is continuously injected to feedstock to make up for HCl losses; provisions for hydrocarbon recycle may be added. Auxiliaries: A feed dryer, source of H_2 gas and hydrodesulfurization facilities are usually required; a rerun column for removal of heavy ends may be needed. Mechanism: Acid function, assisted by the Pt, reshuffles the carbon skeleton of the C_5-C_6 paraffins; the Pt also hydrogenates coke precursors; chloride maintains acid strength.

SPECIAL EFFECTS AND RESTRAINTS: It is desirable to perform isomerization at as low a temperature as is feasible, since the thermodynamic equilibrium for the highest octane isomers is more favorable.

ALTERNATIVES: C_5/C_6 cuts can be blended directly to gasoline pool if desired; or they can be hydrocracked or selectoformed to LPG; or C_6's, with difficulty and high yield loss, can be reformed; much depends on refinery product slate and octane requirements.

SHB - 128

C_5/C_6 isomerization



SH3-129

SHB-130

PROCESS: DELAYED COKING

OBJECTIVE: In a fuels-oriented refinery, "squeeze out" the maximum amount of liquid fuels - gasoline and distillate - from the remaining "bottom of the barrel" of crude by thermal treatment; segregate and concentrate poisons and impurities deleterious to process operations in coke.

FEEDSTOCK: Vacuum residua, or almost any fraction rich in hydrogen-deficient asphaltenes, resins and aromatics; thus, chemicals or lube slops, shale oil, Athabasca bitumen, gilsonite, coal tar pitch, or even certain full-range crude oils can be used.

PRODUCTS AND YIELD STRUCTURE: As in any thermal cracking process, a broad spectrum of chemical classes of products in different boiling ranges is produced, the relative proportions of which are greatly influenced by the properties of the charge and unit operating conditions; typical yields from petroleum residue are: gas (~5-10%), gasoline (~10-20%), light fuel oil (15-20%), heavy fuel oil (30-45%) and coke (20-30%).

CATALYST: None

PROCESS ENGINEERING: Unit/Hardware: Fractionator (to distill off light material) and heater; 2 coke drums (furnaces), operating in alternating semi-continuous, 24 hr. coke-filling and coke-removal cycles (decoking is hydraulic via high pressure water).

Operating Conditions: ~900-950°F, ~1 atm. pressure, 15-20 min. coke-formation time, 0.1-0.5 recycle ratio for typical operations.

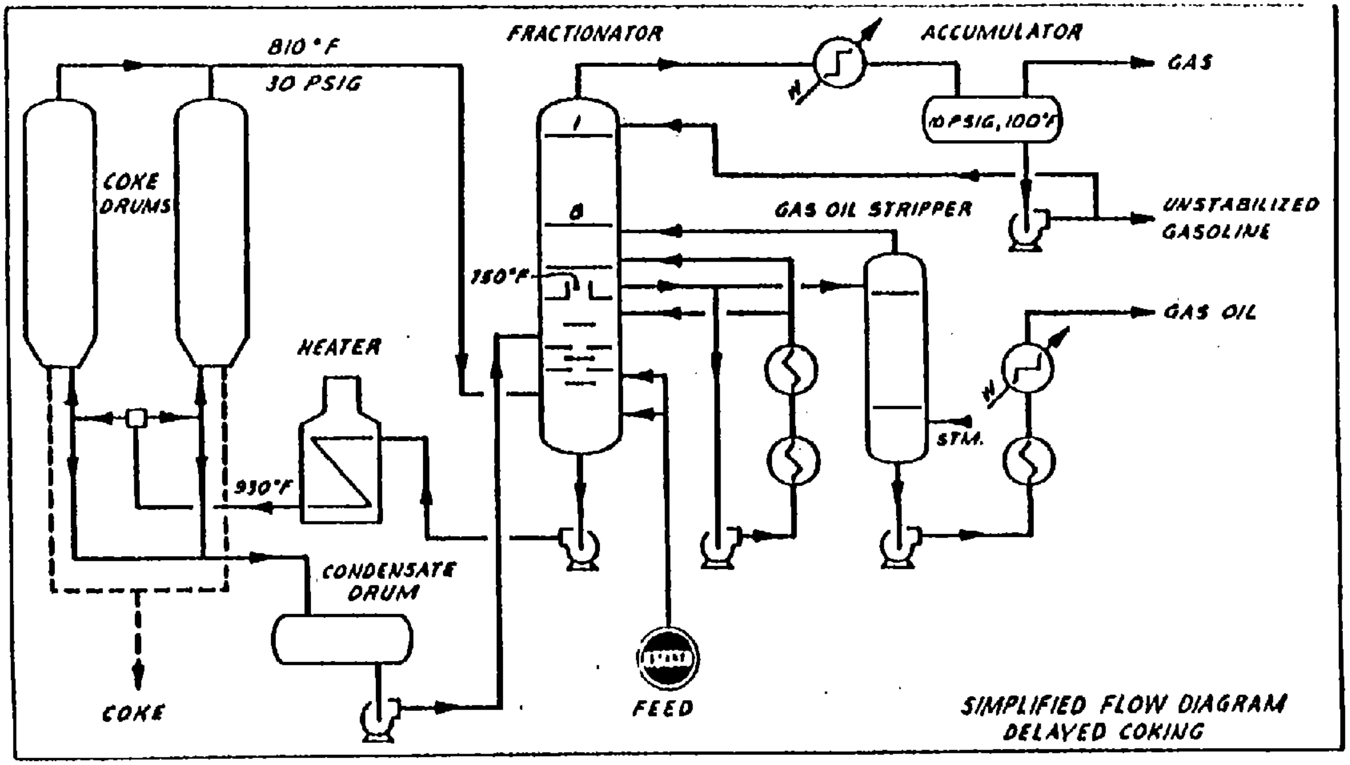
Auxiliaries: In addition to the main fractionator, gas plant facilities are required; due to the highly olefin content and general poor quality of coker products, further cleanup or upgrading is often required; i.e., pretreater/reforming for coker naphtha, CHD for fuel oil, etc.

Mechanism: Coking can be classified as a "destructive distillation", in which some heavy molecules are slowly cross-linked or polymerized to form coke, while at the same time, some fragments and chains are thermally cracked off to give a range of lighter products.

RESTRAINTS AND SPECIAL EFFECTS:	Pumpability problems may be encountered with very heavy stocks; coking heater must be carefully designed to prevent premature coking in the heater tubes.
ALTERNATIVES:	Fluid coking; or, instead of rejecting carbon via coking, heavy stocks can be hydrotreated (H_2 addition) to make up for the hydrogen-deficiency and then processed for liquid fuels.

SHB-131

COKING: SIMPLIFIED FLOW DIAGRAM



Sh3 132

PROCESS: SATURATED AND UNSATURATED GAS PLANTS

OBJECTIVE: Separate and clean up mixtures of light gases from collected diverse refinery sources for product use.

FEEDSTOCK: Saturated gas plant: H_2, C_1, C_2, C_3, i-C_4, n-C_4 - mainly light paraffins; these derive from crude unit off-gas, pretreater, CHD, natural gas plants;
Unsaturated gas plant: H_2, C1, C_2, C_2=, C_3, C_3=, i-C_4, n-C_4, C_4= -- both light paraffins and olefins (unsaturates); derive from FCC, TCC, coker, visbreaker, etc.; also contain non-hydrocarbon impurities and inerts: H_2S, CO_2, N_2, H_2O, NH_3, traces of volatile metals.

PRODUCT AND YIELD STRUCTURE: Straightforward separation process; splits vary with product slate and specifications, i.e., may include fuel gas, LPG (C_3 or C_3/C_3= or C_3/C_4), BB (C_4/C_4=, n-C_4, i-C_4), etc.

CATALYST: None

PROCESS ENGINEERING: Unit/Hardware: Gas plants are assemblies of light hydrocarbon fractionators; processing of saturated gas streams is usually segregated from that of unsaturated gas streams in the same refinery; depending on refinery product slate and economics, heavy products can be taken off first, or the reverse: light products can be taken off sequentially in order of boiling point; separations of closely boiling components, i.e., n-C_4/i-C_4, requires many plates and high reflux ratio and utility costs; sometimes deethanizer absorbers are used in unsaturated gas plants: feed to the deethanizer absorber consists of both FCC gas (compressed and fed to Absorber section) and unstabilized liquid gasoline (pumped to middle section of absorber); both the unstabilized gasoline and the heavy gasoline ("sponge") recirculated aid in soaking up and recovering valuable C_3's,; a reboiler-heated stripper comprises the bottom 1/3 of the column, where C_2- hydrocarbons that might contaminate gasoline are "boiled out".

SHB-133

SHB-134

Operating Conditions: These vary greatly with boiling range/vapor pressure of fraction: to separate high vapor pressure C_2- gas, a deethanizer requires ~430 psig pressure, severe overhead cooling and ~24 trays; a gasoline splitter, however, requires only 25 psig and 28 plates; separation of i-C_4 and n-C_4 in a deisobutanizer requires 110 psig, ~60 plates, and high (~7.5) reflux ratio.

Auxiliaries: Exact choice and sequence of towers, and physical location in refinery is a major variable.

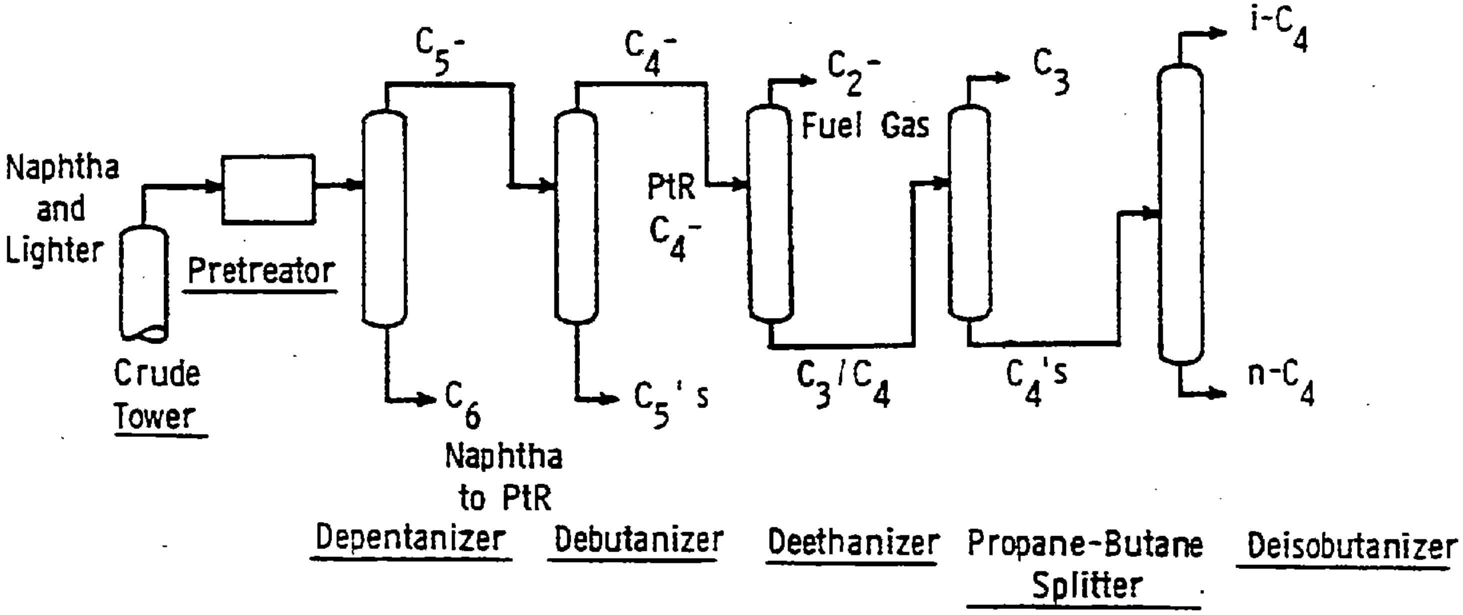
Mechanism; Separation efficiency depends on thermodynamically-defined vapor-liquid equilibria, and relative vapor pressures of components.

SPECIAL EFFECTS AND RESTRAINTS: In high-pressure deethanizers, low temperatures favor formation of troublesome gas hydrates; high pressures favor approach to critical pressures near bottom of tower, causing heat-absorption problems.

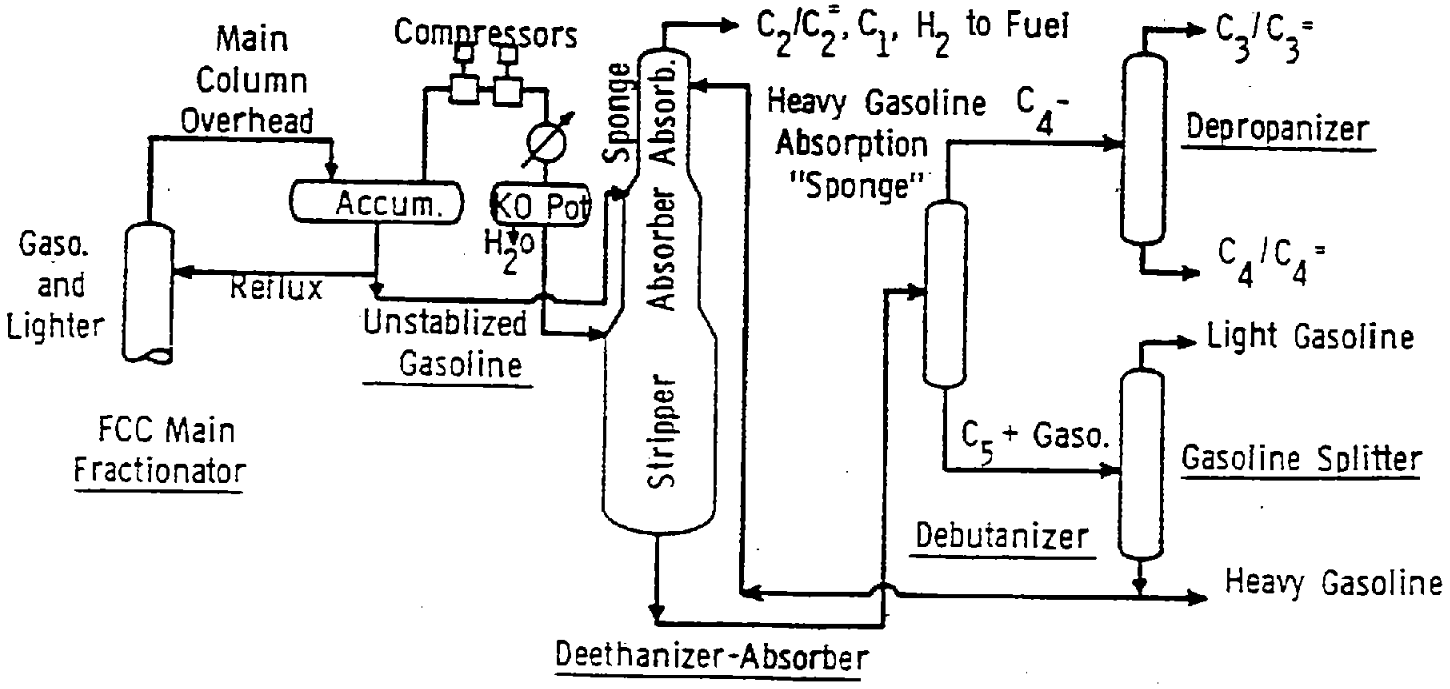
ALTERNATIVES: ——

EXAMPLES OF GAS PLANTS

A. Saturated Gas Plant for Handling Off-Gas From Crude Unit, Reformer, Etc.



B. Unsaturated Gas Plant (From Catalytic Cracker, Coker, Etc.)



SAB-136

SUMMARY OF PERIPHERAL PROCESSES IN LIGHT PRODUCTS REFINERY

AMINE TREATING:	Removal of H_2S from both liquid and gas streams via amine solutions; monoethanolamine (MEA) and diethanolamine (DEA) are used.
BENDER:	Process for sweetening distillates such as kerosine and jet fuel by converting mercaptans to disulfides in presence of fixed bed of catalyst (lead oxide and caustic).
CAUSTIC EXTRACTION:	Removal of H_2S, mercaptans, and related odoriferous compounds in gases, gasoline, and other liquid petroleum fractions by extraction with aqueous alkali (caustic, sodium or potassium cresylate, or Dualayer solutions).
CLAUS PROCESS:	Commercial process for recovery of sulfur from H_2S by vapor phase oxidation of H_2S with SO_2, i.e., $2H_2S + SO_2 \longrightarrow 3S + 2H_2O$, using bauxite or alumina catalyst.
DESALTING:	Removal of salts, solids and water from unrefined crude prior to distillation and downstream processing; water is added to heated crude, which is then emulsified to allow intimate contact of the 2 phases; the emulsion is broken by high-voltage electrostatic field, and the water phase containing extracted salts and other impurities is discarded.
DOCTOR PROCESS:	A sweetening process applied to virgin and cracked stocks ranging from naphtha to light distillates; mercaptans, etc., are oxidized to disulfides by treatment with sodium plumbite (Na_2PbO_2) in presence of sulfur.
FLEXICOKING:	Exxon's fluid coking process; equipment is similar to FCC, but operates with coarser, non-catalytic solids; small particles of petroleum coke, formed in the process itself, are superheated in the furnace section, and are circulated in a fluidized state between the major vessels and act as heat transfer medium.
ISOSIEVE:	A process for separation of high-purity n-paraffins in the C_5-C_{12} range from branched and cyclic hydrocarbons; a selective zeolite adsorbent is utilized.
MEROX:	Sweetening process for gasoline and lower boiling fractions by extraction of mercaptans, and for heavier stocks by conversion of mercaptans to disulfides; Merox solution contains istic and a cobalt phthalocyanine chelate-type catalyst.

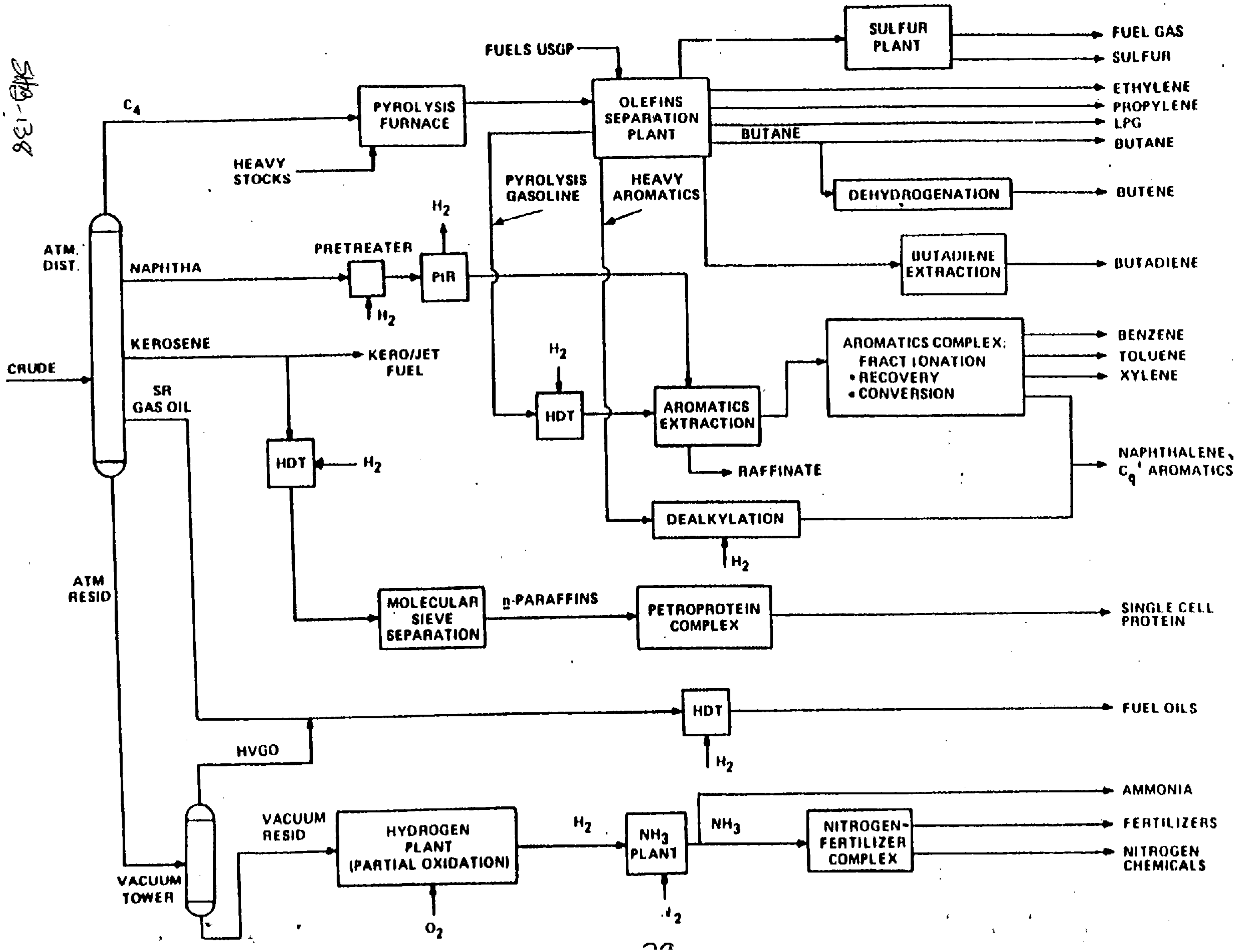
PART (2)
D.C.-174

MOLEX:	A method of separating normal paraffins as a class from isoparaffins and cyclic compounds in a single processing step; a molecular sieve adsorbent is employed; similar function to Isosieve.
OCTAFINING:	Xylene isomerization process (Engelhardt); catalyst is platinum supported on acidic alumina; requires H_2 pressure and operates at high temperature.
STRETFORD:	Sweetening of natural and industrial gases by complete removal of H_2S and partial removal of organic sulfur compounds; catalyst is mildly alkaline solution of oxidizing agents.
THERMAL CRACKING:	Cracking of hydrocarbons at high temperatures and pressure, and long contact times in the absence of a catalyst; large molecules fragment to smaller ones, but in an indiscriminate, non-selective way; gasolines so formed are of relatively poor quality, containing more gum-forming diolefins, having poor TEL - response and antiknock properties; a lot of gas and heavy tars are formed
UDEX:	Multistage, countercurrent extraction system for separation of high purity aromatics from mixtures with other classes of hydrocarbon, aromatics are extracted into a glycol solvent, and later separated by stripping; the non-aromatic fraction - raffinate - is available for further processing; commonly applied to reformates to obtain mixtures of aromatics for potential chemical application.
VISBREAKING:	Mild thermal treatment (850-950°F, 200-500 psig) of residua, waxy topped crudes, etc., to produce total product of improved viscosity, pour point, etc.

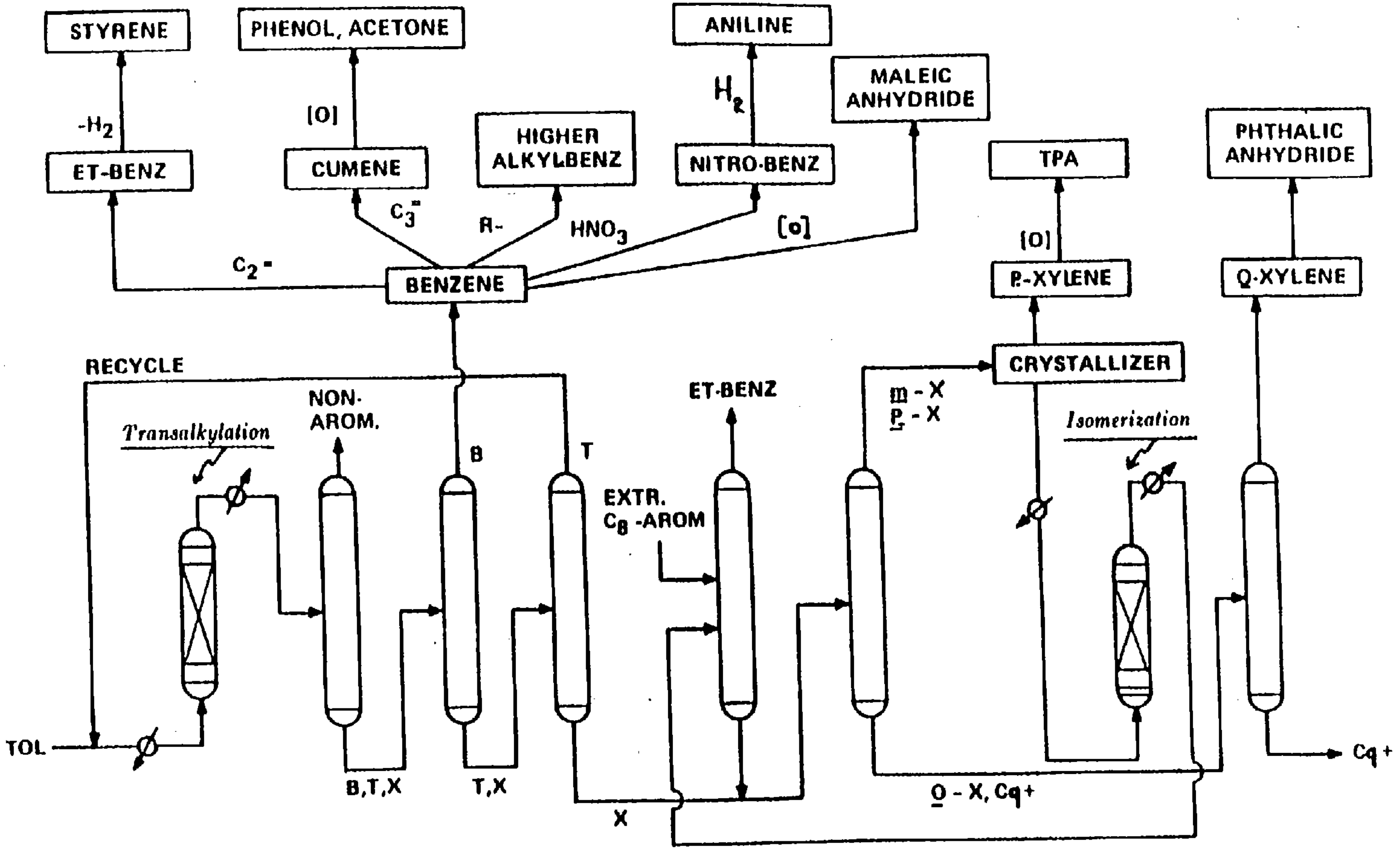
OLR-137

SHB-138

BROAD SPECTRUM CONCEPTUAL PETROCHEMICALS REFINERY



AROMATICS COMPLEX, OLEFINS, AND THE INTRODUCTION OF FUNCTIONALITY



SHB-139

SHB-140

SOME RELEVANT DEFINITIONS AND ABBREVIATIONS

"-Ate":	Suffix meaning "product of"; i.e., reformate is product of reforming; alkylate is product of alkylation, etc.
CHD:	Catalytic Hydrodesulfurization; a name for a hydrotreater.
CSO:	Clarified slurry oil; very aromatic heavy gas oil from fluid catalytic cracker; used as carbon black feed.
DEA-UNIT:	Amine-treating unit for H_2S removal containing diethanolamine.
DEBUTANIZER:	Light ends fractionator which is labeled by the key light hydrocarbon that goes overhead; thus butanes go overhead in a debutanizer; viz, depentanizer, dehexanizer, etc.
DECANT OIL:	CSO, clarified slurry oil.
DEHYDROCYCLIZATION:	An important catalytic reaction in reforming, where aromatic rings are formed from straight paraffin chains.
DEHYDROGENATION:	A key catalytic reaction in which the platinum catalyst strips hydrogen out of cycloparaffins (naphthenes) to form aromatic rings and gaseous H_2.
DISULFIDE:	Organic sulfur compound, R-S-S-R, formed by joining of 2 mercaptans (RSH) in the presence of oxidation catalyst, i.e., as in Bender, Doctor, Merox processes: $2\ RSH \xrightarrow[\text{catalyst}]{-2H} R\text{-}SS\text{-}R$.
DUALAYER:	Mercaptan extracting process: H_2S and cresols (phenolics) are removed by caustic prewash, with subsequent mercaptan extraction via concentrated potassium cresylate solution (cresylates are high-boiling mixtures of phenolics).
FCC:	Fluid catalytic cracking.

HCO:	Heavy cycle oil: essentially equivalent to heavy fuel oil produced during catalytic cracking; because it is a potential recycle stock, it is termed "cycle oil".
HDT:	Hydrotreater; includes pretreaters, CHD units, or any hydroprocessing or hydrogenative process configuration.
HFO:	Heavy fuel oil.
HOC:	Heavy oil cracking: direct fluid catalytic cracking of atmospheric resid (Kellog-Phillips process).
HOD:	Heavy oil desulfurization: hydroprocessing of heavy vacuum gas oil, with possible subsequent blending with vacuum tower bottoms to produce low sulfur fuel oil (operative in Japan).
HVGO:	Heavy vacuum gas oil: the overhead heavy gas oil from vacuum distillation; commonly used as FCC feed.
LCO:	Light cycle oil; light fuel oil produced by catalytic cracker (LFO).
LFO:	Light fuel oil, i.e., #2 or home heating oil.
LHSV:	Liquid hourly space velocity: the inverse of contact time; volumes of liquid passed over a given volume of catalyst per hour; high LHSV means efficient catalysis and high throughput; low LHSV means slower conversion rate, and, to meet throughput restraints, may require a bigger bed of catalyst (and larger reactor).
LPG:	Liquified petroleum gas: C_3, $C_3=$, C_4, $C_4=$ or mixtures of these (stored under moderate pressure to ensure liquidity; clean-burning fuel.
MERCAPTAN:	An organic sulfur compound, R-SH, where R- is a hydrocarbon chain (alkyl group), and -SH is a thiol group; because the thiolgroup is moderately acidic, water-extractable salts can be formed by treatment of mercaptans with strong bases such as caustic (NaOH).

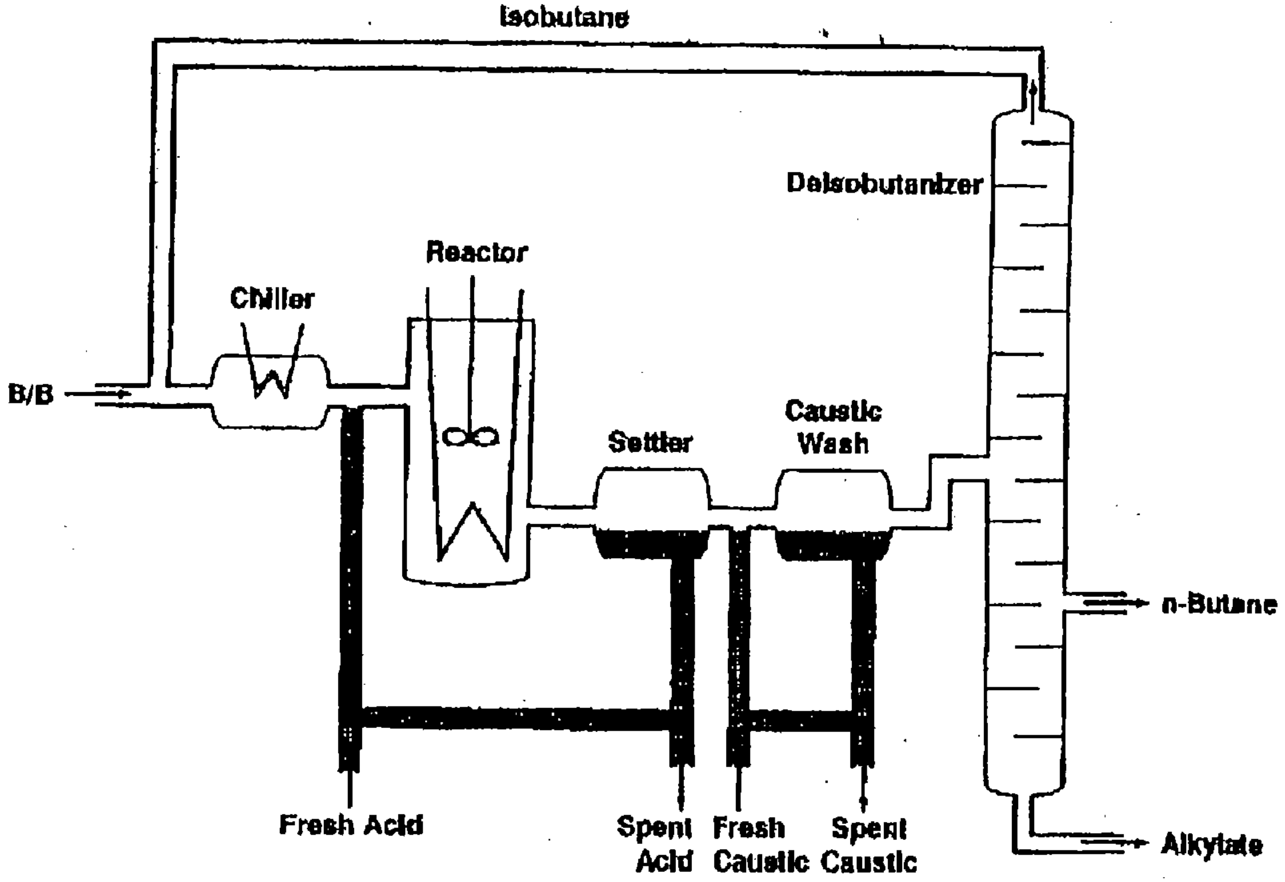
SHB-141

SHB-1A2

MIDDLE DISTILLATE:	A petroleum distillate fraction boiling between gasoline and heavy gas oil, i.e., between about 400 and 650°F; middle distillates generally include kerosene, jet fuel, light fuel oil, etc.
NAPHTHA:	A general term for a petroleum fraction in the gasoline boiling range; many feeds and products in a petroleum refinery are called "naphtha", including straight run naphtha (reformer feed), coker naphtha, cat cracked naphtha, hydrocracked naphtha, etc.
PSIG:	Pounds per square inch gauge: the units of pressure on the measuring gauge; absolute pressure (PSIA) = PSIG + 14.7).
PONA:	Abbreviation for the four major hydrocarbon classes encountered in petroleum fractions: paraffins, olefins, naphthenes, aromatics.
PtR:	Catalytic reformer; Pt refers to platinum in the catalyst.
R+O:	Relates to research octane number, plus zero cc of tetraethyllead (TEL).
RECYCLE:	That portion of a feed to a process that enters for another pass or series of passes through the reaction zone; recycle ratio is ratio of recycled feed to fresh feed.
RESIDENCE TIME:	The time period, usually in seconds or minutes, during which feedstock is in the reactor zone or contacting the catalyst in a conversion process; sometimes designated contact time.
SNG:	Substitute natural gas: fuel gas having essentially the combustion specification of natural gas (CH_4); synthesized by gasification of naphtha, resid, coal, etc.
STRAIGHT RUN:	This term is applied to petroleum stocks that have not been exposed to catalytic or thermal processing other than simple distillation on the atmospheric tower; thus, straight run naphtha is the feed to a reformer; SRGO, straight run gas oil, may be feed for a CHD unit.
STABILIZER:	Term for a fractionator, commonly a debutanizer, that removes C_4- from a stock such as reformate, thus effecting a vapor pressure stabilization.

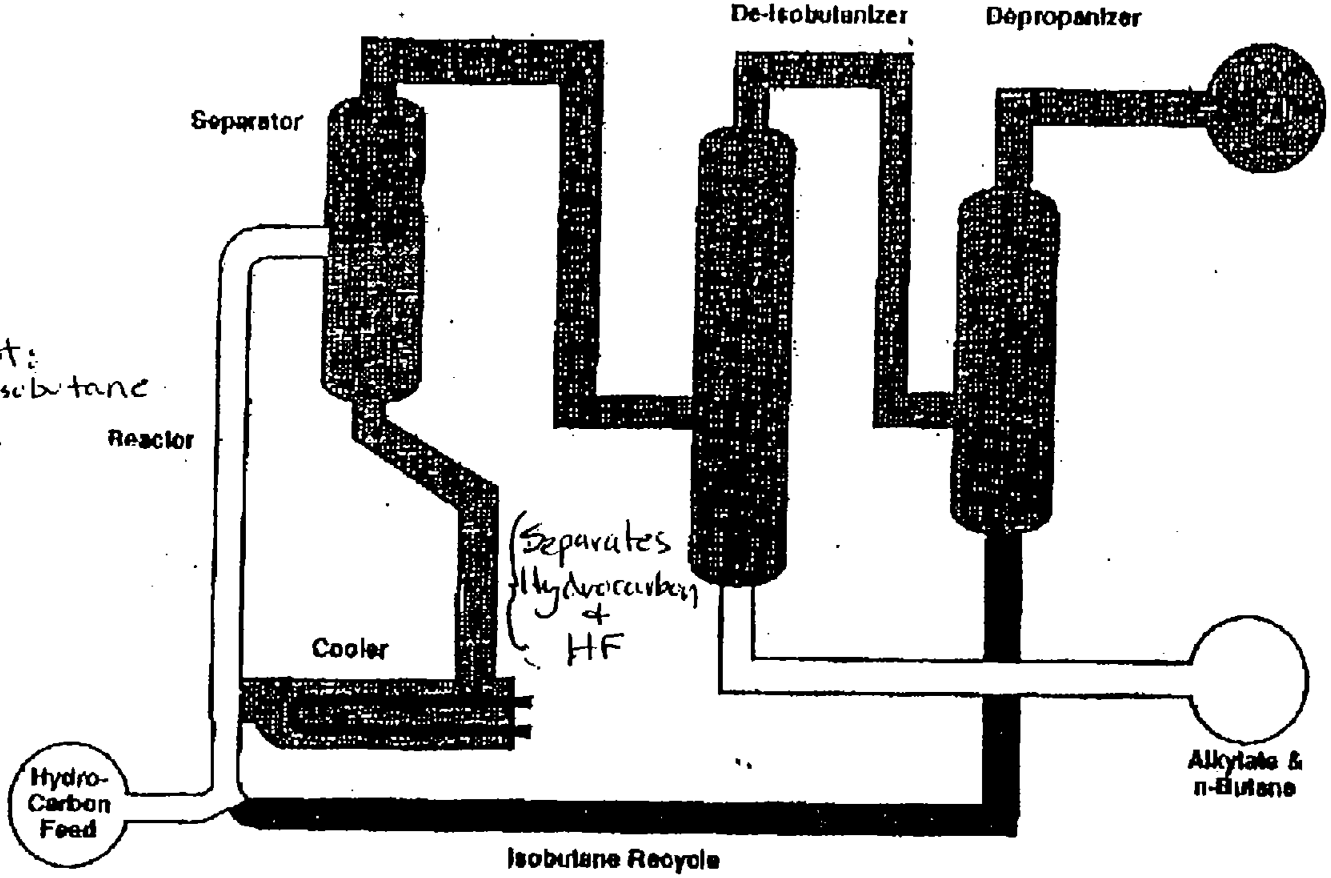
TCC:	Thermofor catalytic cracking: moving bed catalytic cracking employing bead catalyst.
TEL:	Tetraethyllead, octane appreciator.
TOPPED CRUDE:	Heavy fraction of a crude remaining after fractionating off (topping) the lighter fractions, i.e., naphtha, light gas oil; these are commonly 650°F+ stocks.
VGO:	Vacuum gas oil: overhead gas oil from vacuum distillation.

Sulfuric Acid Alkylation



HF Alkylation

Input:
Excess isobutane
+
HF



SHB-148

ALKYLATION UNIT OVERVIEW
(ALKY)

PROCESS	Conversion, Separation, and Purification
FEED/INPUT	PBB, isobutane, SB, and hydrofluoric (HF) acid as a catalyst
TEMP/PRESSURE	Ambient to 365°F / 150 to 350 psi.
PRODUCTS/OUTPUT	Propane, normal butane, and motor alkylate
MAJOR COMPONENTS	Reactors, settlers, acid regenerators, isostripper, depropanizer, HF stripper, alumina treaters, LPG treaters, relief gas scrubber, acid soluble oil (ASO) scrubber, acid evacuation system (AES), exchangers, and pumps
SAFETY HAZARDS	Volatile Lt. hydrocarbons, HF acid, sulfuric acid, caustic, polymers, steam, and rotating equipment
MSDS #'S	Feed streams: PBB - #361006, isobutane & SB - #361872, HF acid - #360560, sulfuric acid - #340919, butane - 362566, motor alkylate - #363077, ASO - #362517

ALKYLATION PROCESS OVERVIEW
(ALKY)

FUNCTION

The alkylation unit chemically combines low molecular weight olefins (C_3/C_4) with an isobutane (IC_4) in the presence of HF acid to produce gasoline components of high octane rating. A dry olefinic feed is mixed with excess isobutane and contacted with the liquid acid catalyst in a reactor vessel. The reactor effluent is separated into hydrocarbon and acid phases in a settler and the acid returned to the reactor. Traces of acid, organic sulfates and sulfonates are removed, from the product by distillation to provide a finished alkylate of the desired boiling range.

EXPOSURE POTENTIAL

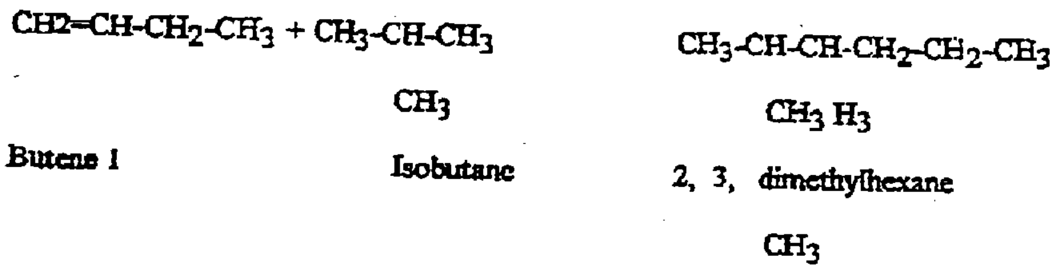
Alkylation is a continuous process and the streams are contained in piping and vessels. The potential for exposure is limited, but can occur during sampling, maintenance, or in the event if a leak, plant upset, or turnaround.

Skin, Eye: The Alkylation unit has the potential for skin contact with hydrofluoric acid, liquefied hydrocarbon gases, acid soluble oil, and caustic. Contact with hydrofluoric acid can cause severe skin and eye damage, and proper protective equipment, including gloves and eye protection, must be worn while in the unit for any reason. Due to the severely corrosive nature of this acid, extreme care should be taken during it's handling. Contact with liquefied hydrocarbon gases can cause cold burns of the skin and can damage the eyes. Wear protective equipment at all times while in the alky unit.

1.2 GENERAL DESCRIPTION

1.2.1 The Alkylation Process

Alkylation is the reaction in which an olefin is combined with a reactive paraffin to form a compound with an alky radical as follows:



$CH2{=}CH\text{-}CH_2\text{-}CH_3 + CH_3\text{-}CH\text{-}CH_3$

CH_3

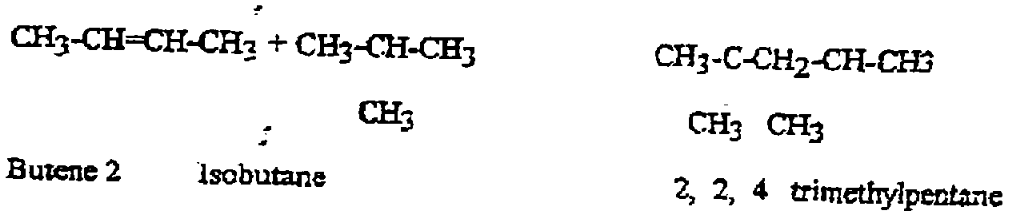
Butene 1 Isobutane

$CH_3\text{-}CH\text{-}CH\text{-}CH_2\text{-}CH_2\text{-}CH_3$

CH_3 H_3

2, 3, dimethylhexane

CH_3



$CH_3\text{-}CH{=}CH\text{-}CH_3 + CH_3\text{-}CH\text{-}CH_3$

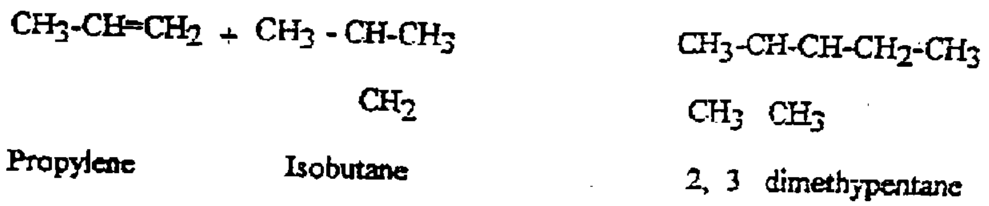
CH_3

Butene 2 Isobutane

$CH_3\text{-}C\text{-}CH_2\text{-}CH\text{-}CH_3$

CH_3 CH_3

2, 2, 4 trimethylpentane



$CH_3\text{-}CH{=}CH_2 + CH_3\text{-}CH\text{-}CH_3$

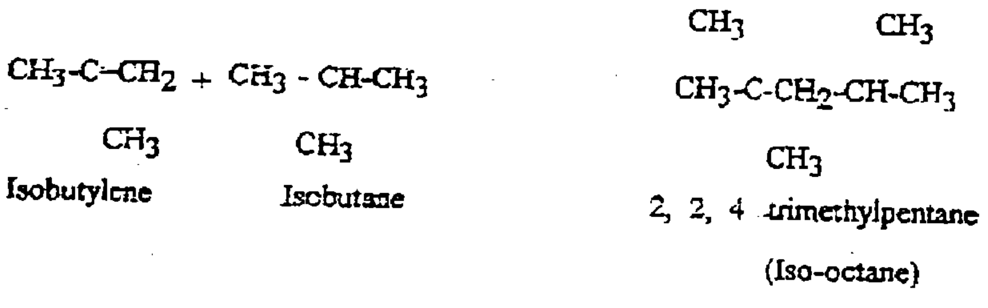
CH_2

Propylene Isobutane

$CH_3\text{-}CH\text{-}CH\text{-}CH_2\text{-}CH_3$

CH_3 CH_3

2, 3 dimethypentane



$CH_3\text{-}C{-}CH_2 + CH_3\text{-}CH\text{-}CH_3$

CH_3 CH_3

Isobutylene Isobutane

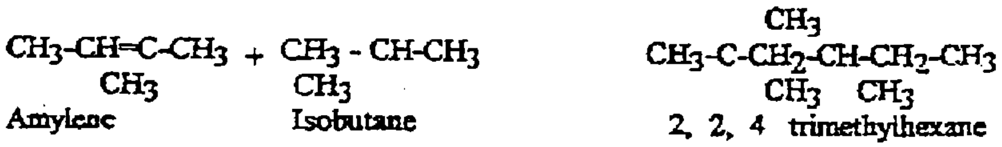
CH_3 CH_3

$CH_3\text{-}C\text{-}CH_2\text{-}CH\text{-}CH_3$

CH_3

2, 2, 4 trimethylpentane

(Iso-octane)



$$CH_3\text{-}CH{=}\underset{CH_3}{C}\text{-}CH_3 + CH_3\text{-}\underset{CH_3}{CH}\text{-}CH_3 \quad CH_3\text{-}\overset{CH_3}{\underset{CH_3}{C}}\text{-}CH_2\text{-}\underset{CH_3}{CH}\text{-}CH_2\text{-}CH_3$$

Amylene Isobutane 2, 2, 4 trimethylhexane

(i-Pentane)

Butene 2 isomerizes in the presence of HF acid to also form 2,2,4 trimethylpentane (iso-octane), but the primary product is 2,3,4 trimethylpentane.

Propylene forms primarily 2,3 dimethylpentane plus 2,4 dimethylpentane. A hydrogen transfer side reaction causes some propane to be formed from propylene and isobutylene from isobutane leading to formation of some 2,2,4 trimethylpentane.

Since the alkylation takes place in the presence of a strongly acidic catalyst such as HF acid, it is necessary to choose reaction conditions which favor alkylation rather than polymerization, since acidic catalyst will also promote polymerization of olefins. Low reactor temperatures, an excess of isobutane, and sufficient contact time with the catalyst are all required to maximize alkylate yield and quality and minimize polymer formation.

Olefin feed and make-up isobutane are introduced into the reactor together with a large excess of recycle isobutane. The reactor effluent is fractionated to separate the excess isobutane which is to be recycled to the reactor. The alkylate product is taken from the bottom of the isostripper, and to control alkylate vapor pressure on the bottoms out of the isostripper, excess normal butane is withdrawn as a sidecut. Normally the alkylate from the isostripper bottoms is sent to the Alkylate Stablizer for further fractionation to an even lower alkylate vapor pressure product. In some cases in may be necessary to send isostripper bottoms directly to storage as a finished product, but usually this is not the case. To avoid a buildup of propane in the recycle isobutane, a slip stream of recycle is charged to the depropanizer, the propane removed to the depropanizer's overhead stream, and the propane-free isobutane is returned to the recycle system in the depropanizer's bottoms stream. Propane produced in this fashion contains dissolved HF acid which is removed in an "HF Stripper" by taking advantage of the fact that HF acid generally leaves a fractionator with the overhead product. Both butane and propane are treated with Alumina and KOH to ensure neutrality.

Any water introduced into the unit will accumulate in the system HF acid as will the products of side reactions and reactions with sulfur and nitrogen compounds. A slip stream of system acid is withdrawn, purified by fractionation in the HF regenerator, and returned to the system. The impurities are removed from the bottom of the regenerator as acid soluble oil or polymers. The saturated butane from the Saturate Gas Plant is normally sent to the Deisobutanizer (DIB) to separate into a relatively pure iC_4 product for feed to the Alkylation unit and is lined up to the reactors. In the event that the DIB is shutdown for what ever reason, the saturated butane can be sent directly to alky unit's reactors.

1.2.2 Process Specifications

1 - Design Basis

This unit is designed to process 30,000 BPSD of unsaturated feed and a sufficient quantity of saturate feed to balance isobutane demand. Four basic product streams are to be produced:

a. LPG grade propane liquid

C_3 can have several uses for the refinery needs. It can be vaporized to fuel or sold as LPG. The hydrocracker and hydrotreater can also use propane in their vaporization operations.

b. Normal butane liquid containing not more than 1.0 mol percent isobutane and not more than 5.0 mol percent pentanes and heavier.

c. Seven pound RVP motor alkylate (with a road octane target of 92) is used for gasoline blending and is produced as isostripper bottoms.

d. Four to five pound RVP alkylate is to be used for blending of reformulated gasoline and is produced from the normal seven-pound RVP (isostripper bottoms) alkylate in the stabilizer.

VISBREAKING

PROCESS DESCRIPTION

When petroleum hydrocarbons are exposed to high temperatures and held at high temperatures, these oils tend to physically change into lighter oils having different properties from the original material.

This phenomenon, called visbreaking or thermal cracking, occurs without the use of a catalyst.

When the large molecules of hydrocarbon contained in the heavy oil break up into smaller molecules, they do so in a predictable pattern giving predictable yields of light gas, naphtha, distillate, and gas oil and the remaining material is called residuum or residual product.

Since paraffinic molecules break up easier than aromatic molecules, the heavy residuum does not crack as easily as the original material or, said another way, this material becomes more refractory. Similarly, the heavy gas oils produced become more refractory. Similarly the distillates produced, which may or may not be recycled, become more refractory.

When the lighter molecules are formed, their chemical makeup requires a higher percentage of hydrogen in the molecule. This is obtained at the expense of the heavy oil which becomes unsaturated (olefinic) in nature. Because of this hydrogen deficit, many of the lighter molecules are also olefinic.

The olefinic molecules exhibit unique properties when compared to virgin materials such as are obtained from the crude unit. Most pronounced are the qualities of instability and incompatibility. Olefins are unstable in the presence of air and tend to react to form gum and similar undesirable products. The visbreaker naphtha formed is treated and protected with inhibitors. The problem is less pronounced in residuum where color and gum need not be rigorously controlled. Incompatibility can occur when highly cracked materials are mixed with virgin materials where a change in apparent solvent ability causes deposits of heavy material to form in the oil. The chemistry of the proper mixtures should not concern the operator except to the extent that any change in basic blending schemes must be checked with supervision before use.

Both aromatic and olefinic molecules will be heavier in gravity than the paraffinic molecules of the same boiling range. This will become apparent when comparing virgin distillates

a thermal cracker.

When the large molecules are changed to lighter molecules by visbreaking, the amount of molecules changed varies with the temperature and with the time the oil is held at the temperature. The amount of molecules changed is called the conversion and the conversion is stated in weight percent. Changes in severity and conversion will be discussed in more detail later. In order to subject the heavy oil to these conditions, a heater is required. The temperature of the heater is controlled at the outlet. This temperature is called the transfer temperature. The transfer temperature is the critical temperature to establish the degree of cracking.

When subjecting the oil to visbreaking condition, the heat enters the oil through the heater tube walls. It has been found by experience that the amount of heat entering must be limited or immediate severe cracking will take place forming coke (carbon) on the inside of the heater tube. This limitation results in a limit on the conversion obtainable from once through (single pass) operation.

From the heater transfer, the oil flows to the flash fractionator flash zones. Products from the fractionator are a gas oil sidecut from the gas oil pan which is stripped of light ends in the stripper before being sent to a hydrocracking unit. Gas and naphtha are produced overhead and are condensed in the receiver from which the gas goes to the fuel gas system for recovery of this material and the naphtha goes to flash fractionator reflux with the net product going to a hydrocracking unit.

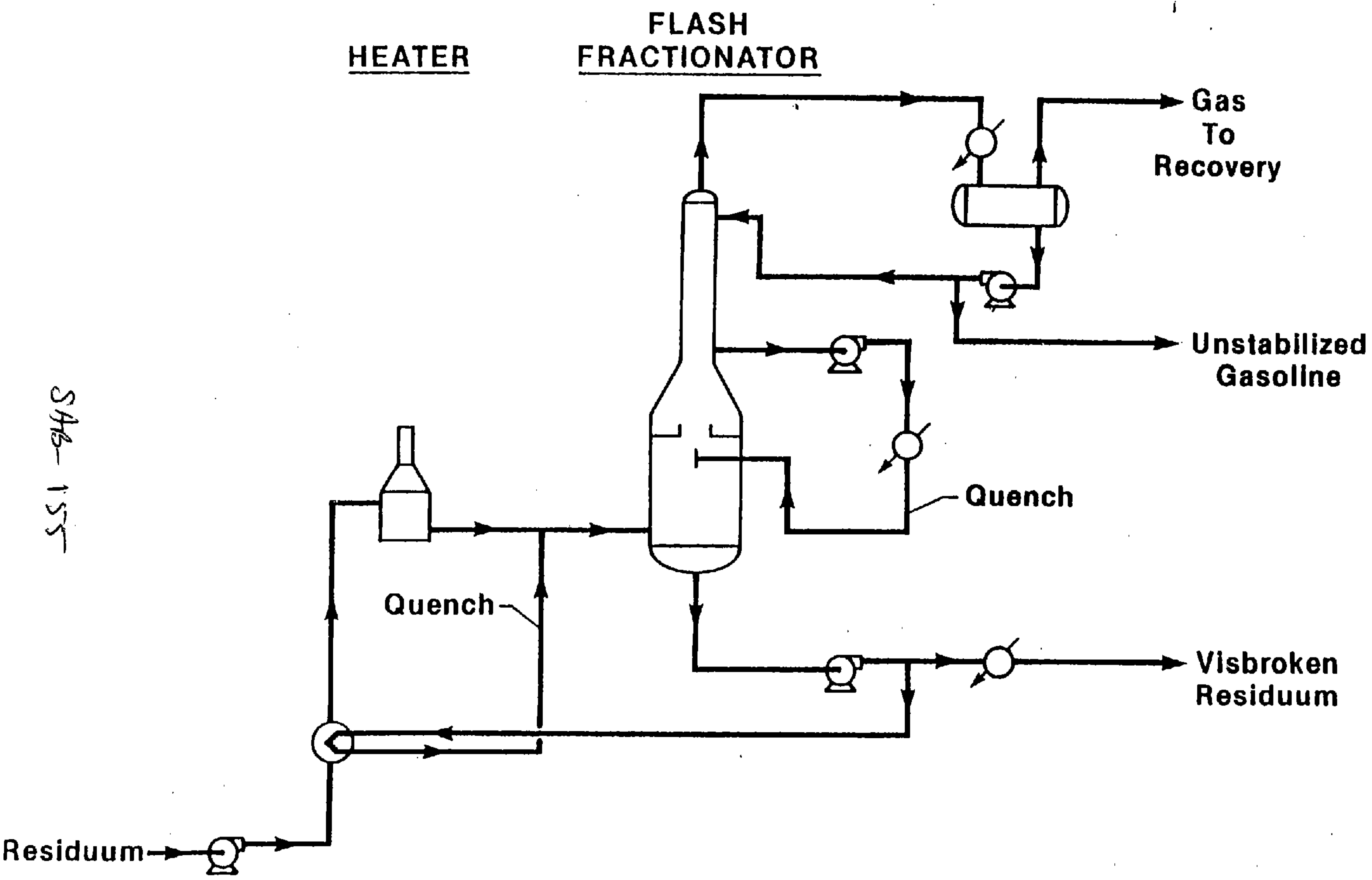
In many respects the fractionator will act quite similarly to a crude unit. It will differ in heat input as outlined above. It will also differ in the amount of gas make.

The flash tower bottoms is sent to the vacuum tower for further recovery of gas oils to be charged to a hydrocracking unit.

This unit will also differ in the degree to which coke will tend to form in all sections of the hot black oil circuit. To the end of controlling this effect, a quench stream is provided.

Further process description would be confusing at this point because of the interdependent nature of the unit. The startup procedure and the operating procedure discussion will make the nature of the process more apparent. If some point is not clear at first, set it aside for consideration later.

VISBREAKING PROCESS



SAB-155

DESCRIPTION OF THE FLEXICOKING PROCESS

A simplified flow diagram of the FLEXICOKING process is presented in Figure A-1. As shown on the figure, the process consists of a fluid bed reactor, a liquid product scrubber on top of the reactor, a heater vessel where circulating coke from the reactor is heated by gas and hot coke from the gasifier, a gasifier vessel, a heater overhead gas cooling system, and a fines removal system.

Residuum feed at 500 to 700°F is injected into the coker reactor where it is thermally cracked, typically at 950 to 1000°F, to a full range of vapor products and a coke product which is deposited on the fluidized coke particles. The sensible heat, heat of vaporization, and endothermic heat of cracking of the residuum is provided by a circulating stream of hot coke from the heater. Cracked vapor products are quenched in the scrubber vessel. The heavier fractions are condensed in the scrubber and, if desired, may be recycled back to the coking reactor. The lighter fractions proceed overhead from the scrubber into a conventional fractionator where they are split into the desired cut ranges for further downstream processing.

Reactor coke is circulated to the heater vessel where it is heated by coke and gas from the gasifier and partially devolatilized, yielding a small amount of light hydrocarbon gas and residual coke. A circulating coke stream is sent from the heater to the gasifier where it is reacted at an elevated temperature (1500-1800°F) with air and steam to form a mixture of H_2, CO, N_2, CO_2, H_2O, and H_2S, which also contains a small quantity of COS. The gasifier product gas, referred to as coke gas, plus entrained coke particles are returned to the heater and are cooled by cold coke from the reactor to provide a portion of the reactor heat requirement. A return stream of coke sent from the gasifier to the heater provides the remainder of the heat requirement.

The hot coke gas leaving the heater is used to generate high pressure steam before passing through the tertiary cyclones for removal of entrained coke particles. The remaining coke fines are removed in a venturi scrubber after an additional stage of cooling. The solids free coke gas is then sent to a gas cleanup unit for removal of the H_2S.

For comparison, a simplified flow diagram of a FLUID COKING unit is presented in Figure A-2.

Figure A-1

SIMPLIFIED FLEXICOKING FLOWPLAN

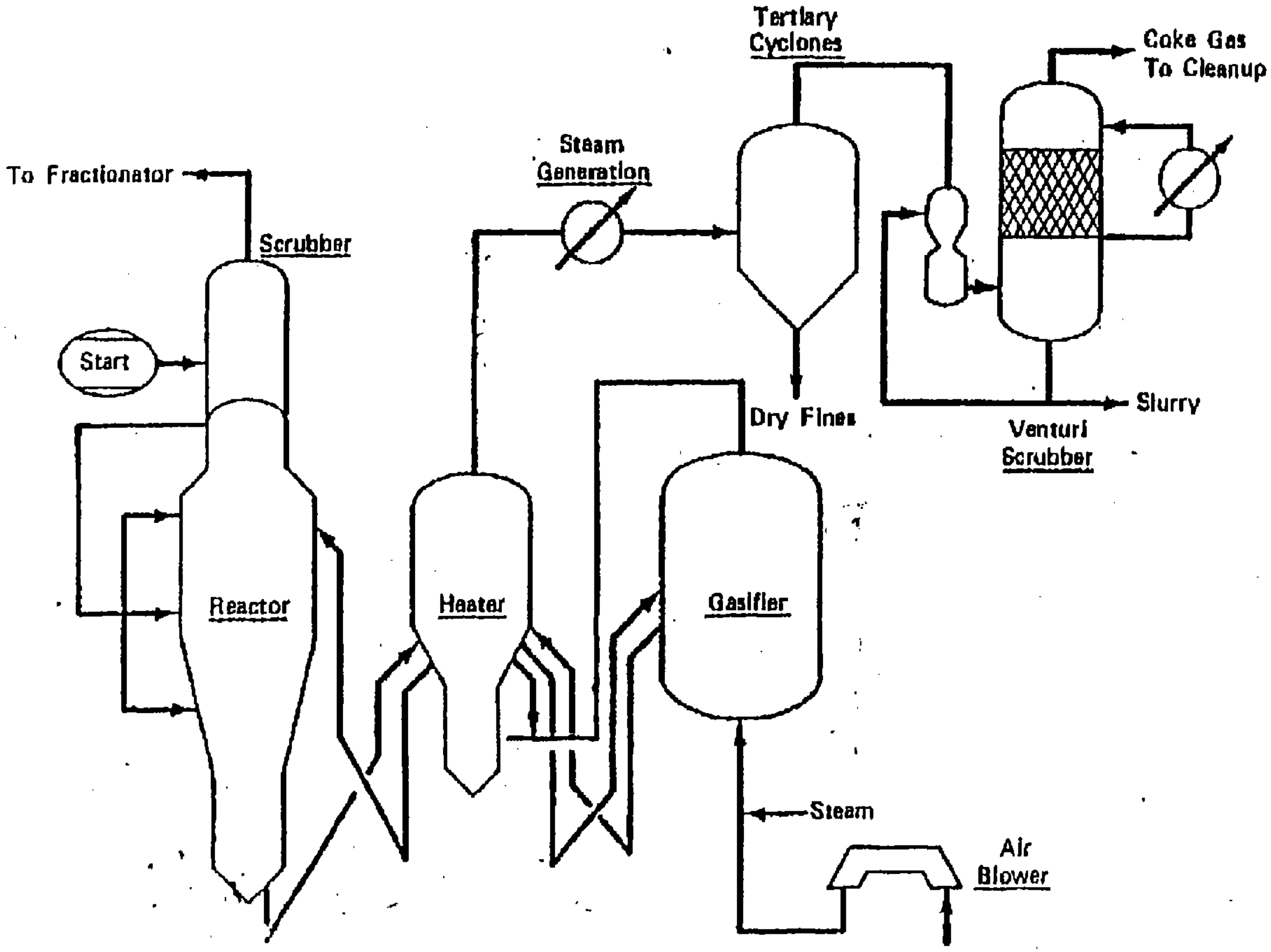
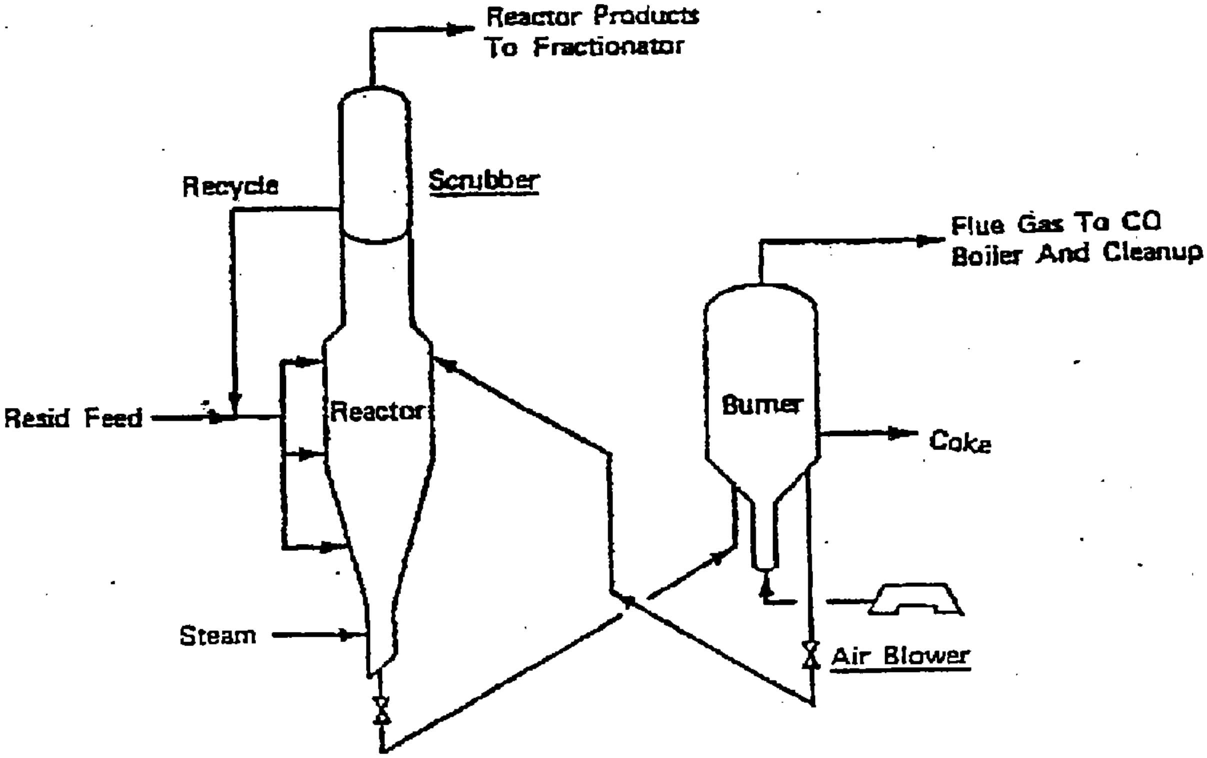


Figure A-2

SIMPLIFIED FLUID COKING FLOW PLAN



SHB-161

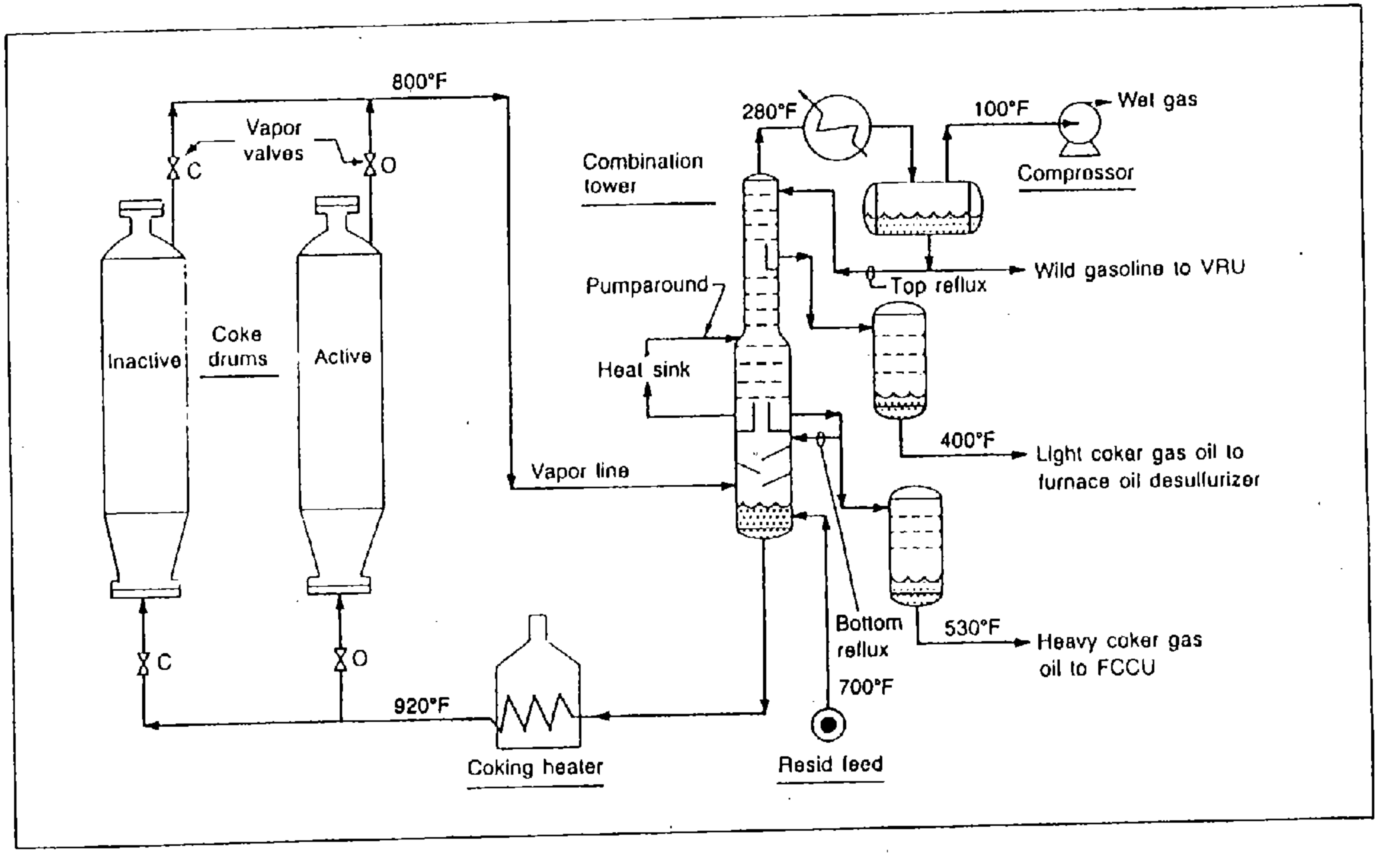
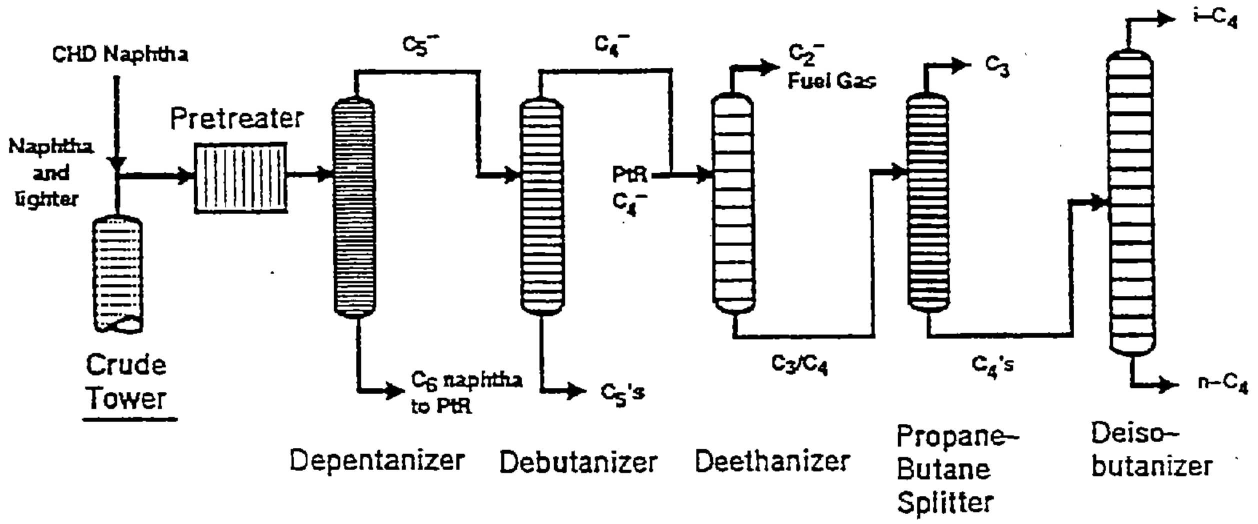


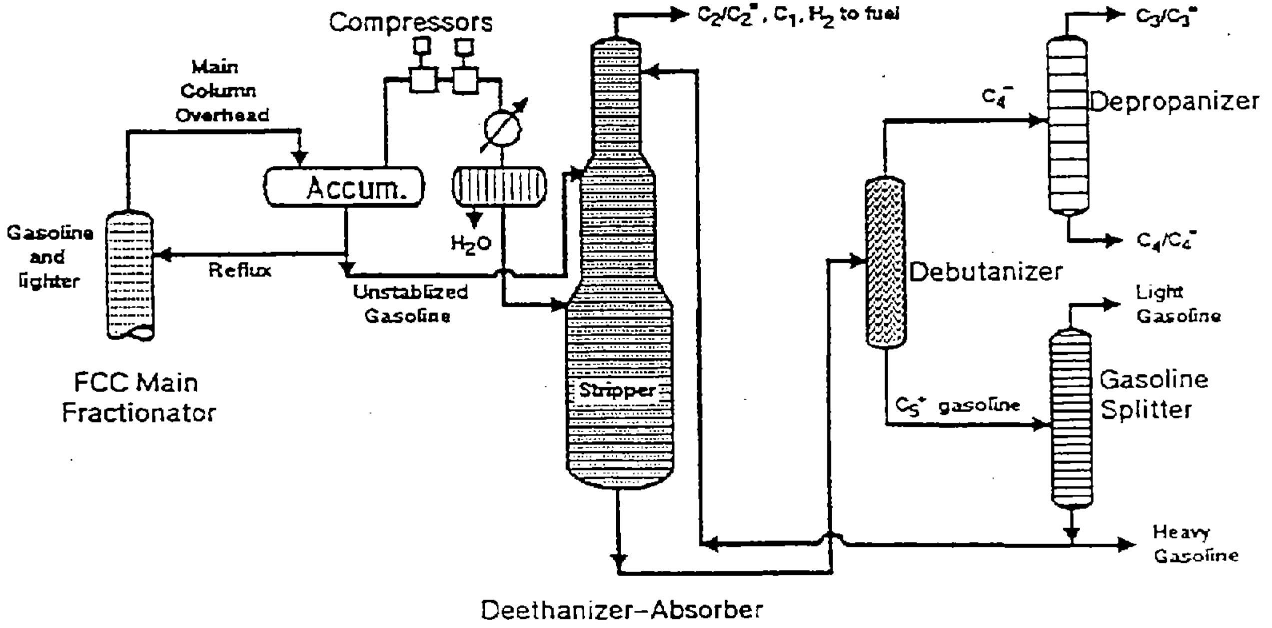
FIGURE 2-1 • A simplified process flow diagram of a delayed coker

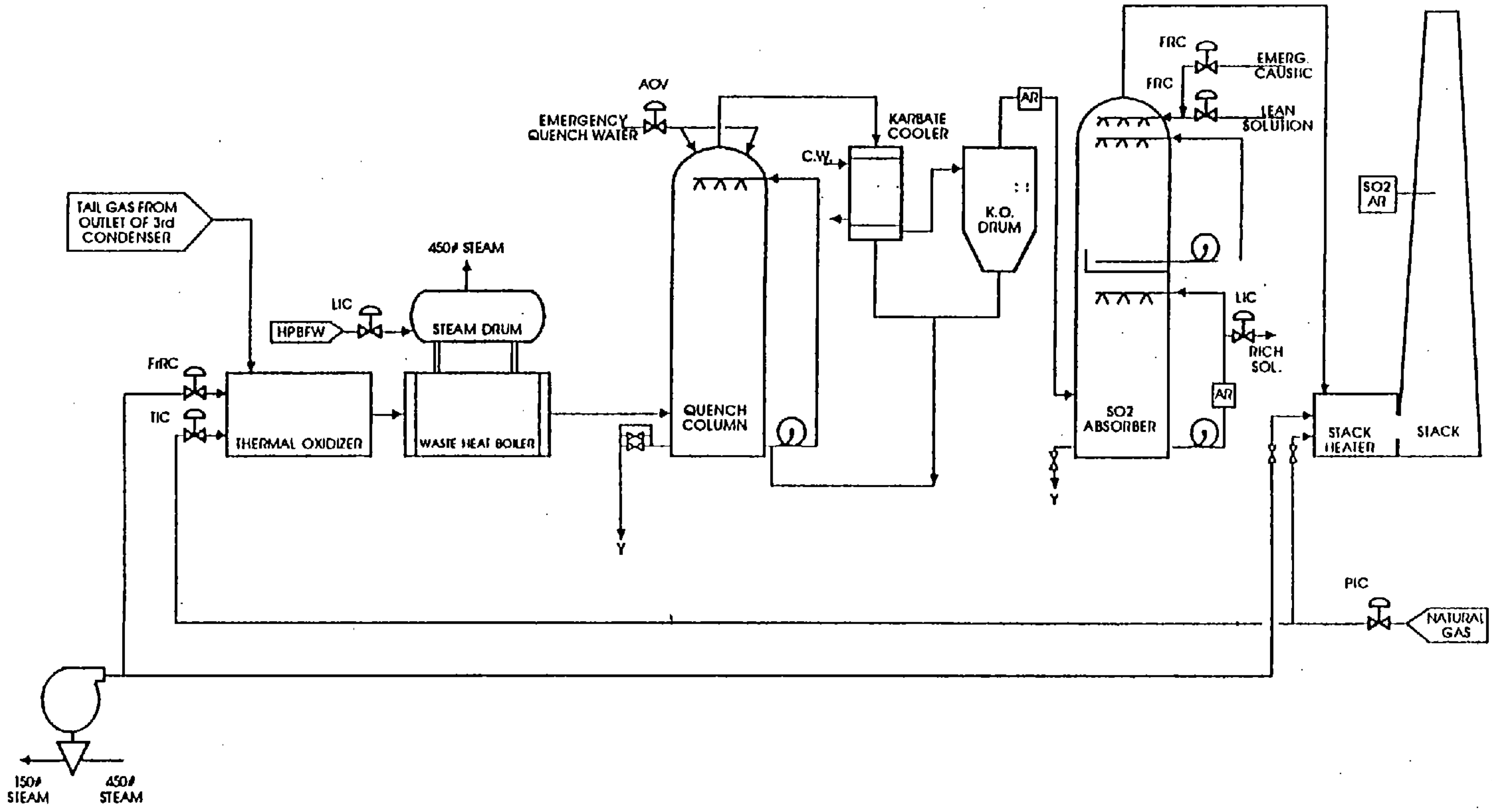
Comments: Exact choice and sequence of towers and physical location in refinery are major variables.

SATURATED GAS PLANT



UNSATURATED GAS PLANT



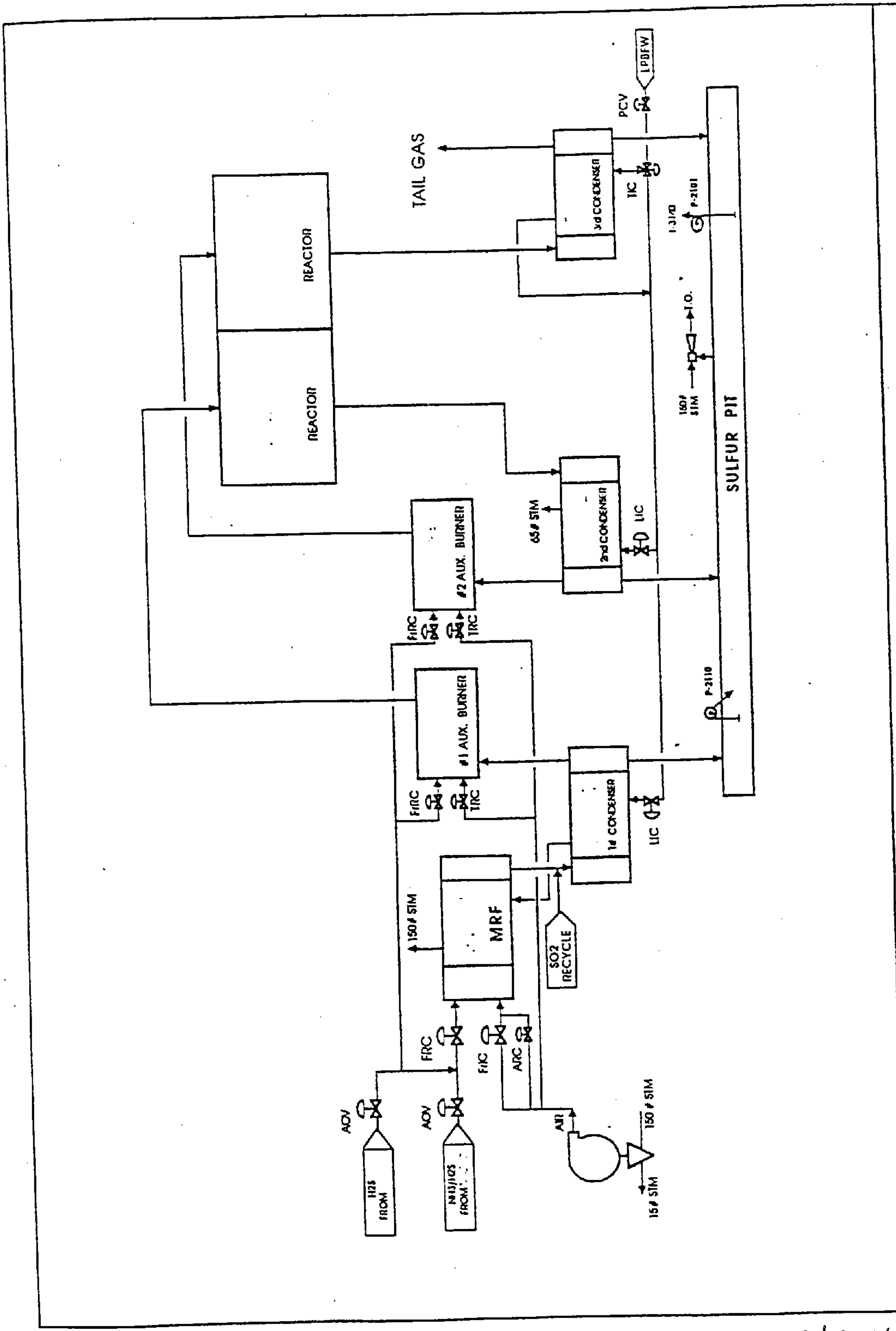


SRU TAIL GAS PROCESS FLOW

2/87lp

SHB-167

CHR-11.7



SRU TRAIN PROCESS FLOW

2/81/fp

SH3-169

Section II - C

GLOSSARY OF PETROLEUM REFINERY TERMINOLOGY

ABSORBER: Refinery apparatus in which gases or vapors are brought into intimate contact with a heavy absorbing fluid in which the vapors are to be retained. The absorbing fluid is sprayed from the top of the tower, so that its extended surface permits the gases or vapors to enter into the solution more quickly. The tower is usually packed or contains bell cap plates.

ABSORPTION: The disappearing of one substance into another substance in such a way that the absorbed or disappearing body loses its principal identifying characteristics, while the absorbing or receiving substance is but slightly modified in its physical aspects. The disappearance of the absorbed substance may be due to a simple mixing of its molecules with the molecules of the absorbing body, or to the dissociation of its molecules into ions, or to a partial or complete decomposition of its molecules.

ACID NUMBER: The number of milligrams of potassium hydroxide necessary to neutralize one gram of oil.

ACID TAR: The organic residue in acid sludge. Acid sludge is composed of acid and tar.

ACID TREATMENT: An oil-refining process in which unfinished petroleum products, such as gasoline, kerosene, diesel fuel, and lubricating stocks, are contacted with sulfuric acid to improve color, odor, and other properties.

ACCUMULATOR: A vessel for the temporary storage of a gas or liquid; usually used for collecting sufficient material for a continuous charge to some refining process.

ACCURACY: The difference between the "true" value and the ultimate average of a great number of test samples. See Precision.

ADDITIVE: A chemical which in small quantities is mixed with a petroleum product to improve the quality by conferring special properties upon it.

ADDRESS: In computer terminology, the address designates the location in computer storage at which a number or instruction may be found.

ADIABATIC: A process which takes place without loss or gain of heat from its surroundings.

ADSORPTION: Adhesion of extremely thin layers of gases or liquids to solids.

AERIAL CABLE: A multi-conductor or groups of single conductor cables supported in rings on a suspension messenger wire; also cable in conduit or channels mounted on pipe supports.

AFTERBURNING: The combustion of carbon monoxide and/or entrained coke particles in the dilute phase of the coker burner or cat regenerator.

AGGLOMERATION: The sticking together of two or more small particles of fluid coke to form one larger particle in the coker reactor.

AGITATOR: Tank with cone bottom used for mixing two liquids by blowing with air; also by a rotating paddle in a kettle.

AIR BLOWING: Forcing compressed air through a tank or line to mix, treat, or purge the contents.

AIR FIN COOLERS: A radiator like device to cool or condense hot fluids. The tubes containing the hot fluid have fins fastened to the outside surface over which air is blown by motor driven fans.

ALICYCLIC HYDROCARBONS: Hydrocarbons which contain a ring of carbon atoms but do not belong to the aromatic series.

ALIPHATIC HYDROCARBONS: Hydrocarbons of open-chain structure such as ethane, butane, octane, butene, acetylene.

ALKYLATE: A product obtained in the alkylation process.

ALKYLATION: Formation of complex saturated molecules by direct union of a saturated and an unsaturated molecule.

In the Petroleum Industry, the union of

olefines and paraffins; particularly the union of butylenes and isobutane using sulfuric acid or hydrogen fluoride as a catalyst to produce a material of high octane number known as alkylate.

ANHYDROUS: Free of water, especially water of crystallization.

ANILINE POINT: Aniline point is the minimum equilibrium solution temperature for equal volumes of aniline and sample. This test on petroleum products is to determine their aromatic content. The lower the aniline point runs the higher aromatic content or aromaticity of the product.

Mixed Aniline point is the minimum equilibrium solution temperature of a mixture of 2 volumes aniline, one volume of sample and one volume of n-heptane of specified purity.

ANTI-KNOCK VALUE: A term used descriptively as a synonym for octane number.

ANTI-LUMINOSITY PILOT: A flare pilot light enclosed in a tube to hide the pilot flame.

ANTIOXIDANT (INHIBITOR): Chemical used to prevent gum formation in gasoline during storage.

API GRAVITY: An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of "API" degrees. It may be calculated in terms of the following formula.

$$\text{deg. API} = \frac{141.5}{\text{sp. gr. } 60/60 \text{ F}} - 131.5$$

APPROPRIATION: Approved funds for installation of capital project.

APPROPRIATION PENDING: Accumulation of permissible charges against a capital project prior to an appropriate approval.

AROMATIC: Organic compounds which contain one or more benzene rings.

AROMATIC INDEX: A figure calculated from viscosity and gravity or other inspections on gas oils. It is indicative of the aromatic content and cracking value of the oil.

AROMATIC TAR: The bottoms product produced from thermal cracking a catalytic cracker fractionator bottoms.

ASH: The inorganic residue remaining after ignition of combustible substances, determined by definite prescribed methods.

ASPHALT: The black to dark-brown solid or semi-solid cementitious material which gradually liquefies when heated, in which the predominating constituents are bitumens, all of which occur in the solid or semi-solid form in nature or are obtained by refining petroleum, or which are combinations of the bitumens mentioned with one another or with petroleum or derivatives thereof.

ASPHALT BASE CRUDE: A crude whose residue in the still after fractional distillation is composed predominantly of substances generally occurring in natural asphalts, such as naphthalene and similar heavy hydrocarbons.

ASPHALTENES: The components of the bitumen in petroleums, petroleum products, asphalt cements, and solid native bitumens, which are soluble in carbon disulfide but insoluble in paraffin naphthas.

ASPIRATOR: An apparatus which serves to create a partial vacuum through pumping a jet of water, steam or some other fluid or gas, past an orifice opening out of the chamber in which the vacuum is to be produced.

ASSOCIATED FACILITIES: Used in budget work. The estimated value of facilities which are being used by a project, but for which investment is not required since they are already available.

ASTM DISTILLATION: A laboratory distillation procedure according to the method prescribed by the American Society for Testing Materials.

ASTM END POINT: The end point of a distillation as determined by a method prescribed by the American Society for Testing Materials. Actually, this is the maximum temperature shown on the thermometer at the end of the distillation.

ASTM OCTANE NUMBER: The octane number obtained on a specially designed ASTM engine. It correlates well with the performance of a fuel in an engine operating at high speeds.

ATMOSPHERIC TOWER OR STILL: A distillation unit run at atmospheric pressure.

ATOMIC ENERGY: Energy released in nuclear reactions. Of particular interest is the energy released when a neutron splits an atom's nucleus into smaller pieces (fission) or when two nuclei are joined together under millions of degrees of heat (fusion). "Atomic energy" is really a popular misnomer. It is more correctly called "nuclear energy".

ATTAPULGUS CLAY: A name given to the Fullers Earth produced by the Attapulgus Minerals and Chemical Corporation, Philadelphia, Pa. This is an impure form of aluminum silicate processed from a naturally occurring clay known as Attapulgite.

ATTRITION: The splitting of a large coke or catalyst particle into two or more smaller particles.

AUDIGAGE: A non-destructive test instrument used to determine metal pipe and vessel wall thicknesses. The instrument measures thickness from one side only by using ultrasonic resonance to determine the fundamental frequency of the material being measured.

AUTOCODER: A system of coding designed to make it easier to write programs for the IBM 705 Electronic Data Processing Machine.

AUTOMATIC LOGGER: A device which automatically records data in digital form from measuring instruments at preset intervals or upon demand.

AUTOMATION: The maximum economic mechanization of an operation including its planning, materials handling, process adjustments, and quality control -

A rather general term that people associate with instruments or machines that do a number of different jobs continually and in sequence at the command of a process, human, or computer -

The modern-day engineer's word for the state of being automatic. Once referred to machine tool applications, but has come to mean the act or method of making a manufacturing - or processing - system partially or fully automatic.

AUTO-REFRIGERATION: The cooling of a gas resulting from a reduction in its pressure.

AUXILIARY BURNER: A gas or oil burner used to start a process operation which is normally exothermic and self-sustaining.

AVIATION GASOLINE: A specially blended grade of gasoline suitable for use in aircraft engines. These fuels have high anti-knock ratings, high stability, a high overall volatility and low freezing points.

AXEOTROPE: A liquid mixture which shows a maximum or a minimum boiling point. It implies the ability of one liquid to be mixed with another or several liquids to form a mixture which boils at a constant temperature either higher or lower than that of the components.

BACK END VOLATILITY: Represents the high boiling portion of gasoline and affects normal running of an internal combustion engine.

BACKING UP RING: A backing in the form of a ring generally used in the welding of piping.

BACK PRESSURE: In an internal combustion engine, the exhaust pressure which acts adversely against the piston, causing power loss. It results from obstructions in the exhaust line or from insufficiently large piping for the exhaust gas.

BACK WELD: A weld deposited to seal a screwed connection.

BAFFLE: A partial restriction, generally a plate located to change the direction, guide the flow, or promote mixing within the equipment in which it is installed.

Anti-vortex baffle is used to stop the swirling of a liquid leaving a vessel thru a downflow nozzle to prevent sucking gas out of the vessel.

BAFFLE PLATE: A guide plate located in a tank or other vessel which changes the direction of flow of a stream of gas or fluid.

BALANCED DRAFT: Combination of induced and forced draft.

BAROMETRIC CONDENSER: A piece of equipment designed to use a cold medium, such as water, to condense hot vapors and in so doing produce a vacuum.

BARREL: The standard unit of liquid volume for oil in the Petroleum Industry, equal to 42 U.S. gallons or 34.97 Imp. gallons.

BASE STOCK: The primary petroleum fraction from which a specification product is blended.

BATCH PROCESS: Any process in which the charge is added intermittently in definite portions or batches; as opposed to continuous process.

BAUME GRAVITY: An arbitrary scale for measuring the density of liquids, the unit being called the "Baume degree". The scale bears an inverse ratio to the specific gravity scale as is indicated in the formula:

$$Be = \frac{140}{sp.\ gr.} - 130$$

which permits the translation of Baume gravity to specific gravity. When floated in pure water, the Baume hydrometer indicates 10°Be, while the specific gravity scale reads 1.000. The modulus 140 serves for liquids lighter than water, while a modulus of 145 is employed for liquids heavier than water. Formerly, the Baume scale was used extensively for the measurement of petroleum oils, but in 1922 it was supplanted by the API scale. The Baume scale is still employed by the Bureau of Standards, however, for the measurement of all liquids except oils.

BELLCAP: An inverted cup with slotted or notched sides, mounted on a tray which provides a means of counterflowing an upward moving vapor through the bellcap with a down flowing liquid moving across the tray.

BENZENE: A six carbon, unsaturated ring compound which is the basic compound of the aromatic series.

BLANK: Circular steel plate inserted between two flanges of a pipe, for isolating plant or equipment.

BLANK FLANGE: Circular steel plate for closing the open end of a flanged pipe.

BLEEDER VALVE: A small valve installed in conjunction with a block valve to determine if the block valve is holding tightly. Also used to release pressure on a closed liquid system.

BLEEDING: Process of drawing small amounts of liquid, particularly water, from a vessel, tank or line.

BLEND: Any mixture made up for special purpose, the products of a refinery are usually blended to suit market requirements.

BLENDING: The process of mixing two or more oils having different properties. Certain classes of lubricating oils are blended to viscosity, whereas naphthas may be blended to meet a distillation specification such as end point.

BLOCKED OPERATION: The use of a single process unit alternately in more than one operation.

BLOCK VALVE: Valve used for isolation of equipment.

BLOOM: The color of oil by reflected light when this differs from its color by transmitted light. Many petroleum oils which appear red or yellow by transmitted light exhibit a blue or green bloom.

BLOWBACK: A system in which a fluid or gas is continuously bled through an instrument meter's lead lines into the main line. This prevents the main line fluid from coming in contact with the meter body thus eliminating vaporization, corrosion or plugging.

BLOW-BY: Any leakage of gas past the piston of an engine is called blow-by.

BLOWCASE: A closed vessel with product inlet and discharge lines and an air connection. In the manually operated type, air is admitted through the hand regulation of the valve to force the liquid out through the discharge pipe. In the automatic type, the flow of air is controlled by a float valve inside the vessel.

BLOWDOWN: The process of removing hydrocarbon liquids or vapors from a process unit on an emergency or scheduled shutdown basis through special piping and drums provided for this purpose.

BLOWDOWN DRUM: (See Drums - Blowdown).

BLOWER: Equipment for moving large volumes of gases against low pressure heads.

BLOWING: Agitating a liquid by the introduction of compressed air near the bottom of the tank or container. In "blowing bright", the air assists in carrying off moisture, whereas in acid treating, the air is used only for agitation.

BOAT LINES: Large pipe lines used to load or unload tankers.

BOAT PROBE: A boat-shaped sample removed from a welded joint for examination of the welding.

BOB: A calibrated weight on the end of a measuring tape used for gauging tanks.

BOILING RANGE: The range of temperature, usually determined at atmospheric pressure in standard laboratory apparatus, over which the boiling or distillation of an oil commences, proceeds, and finishes.

BOOM: A log or other floating device to retard or catch oil floating on water.

BOOSTER COMPRESSOR: A compressor used in the high pressure hydrogenation of petroleum to raise the pressure of the gas which is being returned to the unit.

BOTTLENECK REMOVAL: An increase in capacity of a unit by replacement or changes to the limiting equipment.

BOTTOMS: Any residue remaining in a distillation unit after the highest boiling material to be distilled has been removed. The boiling range of the bottoms will depend on the feedstock to the still and the amount of material distilled off. (Tower bottoms).
Also liquid which collects in the bottom of tanks. (Tank bottoms).

BOTTOM SETTLING AND WATER (B.S. & W.): The sediment which accumulates when oil is stored, consisting of an oil-water emulsion with solid material. This is tested in the laboratory by use of a centrifuge.

BOTTOM STEAM: The steam admitted to the bottom of a still to prevent overheating and decomposition of the heavier components, or to increase the yield of light hydrocarbons.

BRASS: Alloy compound mainly of copper and zinc.

BREAKDOWN TIME: The time required for gasoline to begin absorbing oxygen in the bomb stability test for gasoline. This test is intended as an indication of gasoline stability in field storage.

BREATHING: The movement of gas (oil vapors or air) in and out of the vent lines of storage tanks due to alternate heating and cooling.

BRITTLE FRACTURE: Brittle fracture is an extremely rapid failure occurring without significant deformation. The failure is characterized by a brittle, crystalline appearance of the metal which might result from low temperature, carbon precipitation, improper stress relief, etc.

BROMINE NUMBER: The number of grams of bromine absorbed by 100 grams of oil indicates the "percentage of double bonds" in the material. The content of olefins can thus be calculated if their type and molecular weight are known.

BRONZE: Alloy composed mainly of copper and tin.

BUBBLE TOWER: A fractionating tower so constructed that the vapors rising pass up through layers of condensate on a series of plates. The vapor passes from one plate to the next above by bubbling under one or more caps and out through the liquid on the plate. The less volatile portions of vapor condense in bubbling through the liquid on the plate, and overflow to the next lower plate, and ultimately back into the reboiler. Fractionation is thereby effected.

BUDGET ADDITION: A funds request for a capital project in addition to those included in the approved yearly Plant & Equipment Budget.

BUDGET ITEM: A single proposal in a Plant & Equipment Budget for new equipment.

BULLNOSE: The rounded lower edge of a hanging furnace wall or baffle.

BUMPING: The knocking against the walls of a still which occurs during the violent boiling of a petroleum product containing water.

BUNKER FUEL: A fuel oil used on steamships.

BURNING LINE: System for collecting waste gas to be used for fuel.

BUS: A terminating bar, cable, or structural shaped electrical conductor from which smaller taps are taken for distribution. Usually of solid copper, flat shaped, 1/4" thick, mounted on porcelain insulators. Iron pipe size (IPS) copper tube is used on high voltages.

BUTTON UP: To do the final mechanical work necessary to make a piece of equipment ready for operation.

BUTT WELD: A weld in a joint between two members lying approximately in the same plane.

BUTYL RUBBER: Synthetic rubber made by low-temperature polymerization of isobutylenes containing a trace of isoprene. Butyl rubber has a very high resistance to air penetration.

BY-PASSED DEBUTANIZER BOTTOMS: The C_4 - 270°F fraction of thermal debutanizer bottoms which is not acid treated because it does not have a large adverse effect on the deposit-quality of gasoline. Debutanizer bottoms were once acid treated without splitting until it was shown to be economical to fractionate them into a 275°+ fraction and then to acid treat only the heavy fraction.

BY-PASS VALVE: A valve by which the flow of fluid or gas in a system may be directed past some part of the system through which it normally flows, e.g. an oil filter in a lubrication system.

CALENDAR DAY: A divisor regularly used to indicate equipment size or requirement volume. In an ordinary year there are 365 calendar days, and in a leap year there are 366 calendar days.

CAPACITY FACTOR (See also SERVICE FACTOR): A measure of the volume efficiency of an operation, generally expressed as the ratio of the actual calendar day throughput to the demonstrated stream day capacity of a unit.

CARBON BURNING RATE: The pounds per hour of carbon burned off of cracking-catalyst in the regenerator.

CARBONIZABLE SUBSTANCES: The chemically unsaturated components of paraffin and white oil.

CARBON RESIDUE (CONRADSON CARBON): The percentage by weight of coke formed by evaporating an oil to dryness under standard laboratory conditions; a measure of the coke-forming tendency of the oil.

CARBOXYLIC ACID: Organic acids containing the univalent radical COOH.

CARCINOGEN: A chemical compound or group of compounds which can cause cancer in human beings.

CARRY-OVER: Small amounts of heavier liquids in the top product from a separator or fractionating plate.

CAR SEALED VALVE: A car sealed valve is one which is tagged, normally with a railroad type car seal in the open or closed position for safety or operating reasons. The seal is only broken under controlled conditions or in emergencies.

CASCADE CONTROLS: A series arrangement of control instruments where the controlled output of one instrument (called the governing instrument) sets the set point of a second instrument known as the slave.

CATALYST: A substance which promotes chemical reaction between other substances without itself necessarily undergoing chemical change.

CATALYST ACTIVITY: In catalytic cracking, catalyst activity is expressed as the percent gasoline yield produced by contacting the catalyst with a standard gas oil under standard conditions.

In hydroforming, catalyst activity is determined by dividing feed rate required to give a given octane number when using the catalyst to be rated by the feed rate required to obtain the same octane with the standard catalyst.

CATALYST HOLD-UP: The amount of catalyst held in any vessel of a catalytic cracking unit.

CATALYST SELECTIVITY: In catalytic cracking, a measure of the tendency of the catalyst to produce gas and carbon.

In hydroforming, a term for the yield of C_5+ hydroformate reported as percent C_5+ at a given octane level.

CATALYTIC CARBON: In catalytic cracking, the carbon produced as a product of the cracking reaction. The amount varies with the severity of the cracking conditions.

CATALYTIC CRACKING: The refinery process whereby the breaking up of the molecules of heavier oil fractions into lighter fractions (esp. gasoline) is accomplished by use of heat and earth catalysts, which influence the rate and direction of the decomposition of the heavier fractions. At Bayway, the catalyst used is a finely divided (20-80 microns diameter) ore which flows like a liquid through the reaction and regeneration cycles.

CATHODIC PROTECTION: The use of an impressed direct current to prevent or reduce corrosion of a metal in an electrolyte.

CAUSTIC WASH: The process in which a petroleum distillate is treated with an aqueous solution of sodium hydroxide to remove acidic components usually those contributing to poor odor or poor stability.

"C" CLAMP: A device used to secure a tight flanged joint.

CENTIPOISE: A unit of absolute viscosity. It is one one-hundredth of the force which will move one sq. cm. of plane surface with a speed of one cm. per second relative to another parallel plane surface from which it is separated by a layer of liquid one cm. thick.

CENTISTOKE: A unit of kinematic viscosity. It is equal to centipoises divided by specific gravity.

CENTRALIZED CONTROL HOUSE: A building used to house instruments used to operate widely scattered equipment or to operate more than one process unit.

CENTRIFUGE: A whirling instrument for separating liquids of different specific gravity by use of centrifugal force.

CETANE NUMBER: A means of expressing the ignition quality of a diesel fuel. It is defined as and is numerically equal to the percentage by volume of cetane in a mixture of cetane and methyl naphthalene which has the same ignition quality when used in an engine as the fuel under test.

CFR COMMITTEE: An abbreviation for Co-operative Fuel Research Committee, sponsored by Society of Automotive Engineers, American Petroleum Institute, National Bureau of Standards and the Automotive Manufacturers' Association.

CFR OCTANE NUMBER: The octane number obtained on a special engine developed by the Co-operative Fuel Research to determine the knock tendency of gasolines. It correlates well with the performance of an engine operating at low speeds.

CHARACTERIZATION FACTOR: Variations in physical properties with change in character of the stock are quantitatively expressed by means of the UOP characterization factor, defined as the ratio of the cube root of the molal average boiling point, in degrees Rankine (deg R = deg F + 460), to the specific gravity as 60/60F;

i.e.: $K = \dfrac{(T_B)^{1/3}}{sp\ gr}$

This factor ranges from 12.5 for purely paraffinic stocks to 10.0 for the highly cracked aromatic stocks. Also called Watson factor.

CHECK VALVE: Device for permitting flow in one direction only in a pipe.

CHEMICAL CLEANING: The use of various solvents and chemicals (undiluted acids, etc.) to dissolve scale and other fouling deposits from the surfaces of refinery processing equipment.

CHIMNEY CAPS: Obround or rectangular risers and caps designed to operate the same as a bell cap.

CHROMATOGRAPHY: (See Gas Chromatography).

CHROME MOLY STEEL: Alloy steel used for cracking plant heater tubes containing 4 to 5% chromium and 1/2 % molybdenum.

CIRCULAR CHART: A recording instrument chart used to record variables. They are 8", 10" and 12" in diameter with a maximum usable time of 7 days.

CIRCULATING ACID: Sulfuric acid used as catalyst in Alkylation Process.

CLAD LINING: A homogeneously bonded or resistance welded metallic liner applied to a base metal such as carbon steel. Used in lines, vessels, and heat exchanger equipment to reduce corrosion and increase service life.

CLARIFIED OIL: The heavy oil which has been taken from the bottom of the fractionator in a catalytic cracking process, and which has had the residual catalyst removed in a mechanical thickener.

CLOUD POINT: The cloud point of a petroleum oil is the temperature at which paraffin wax or other solid substances begin to crystallize out or separate from solution when the oil is chilled under prescribed conditions.

CODIMER: The product formed by the union of two dissimilar olefin molecules. In the petroleum refinery, it is generally understood to mean the product of polymerization of isobutylene with one of the two normal butylenes. The product can be hydrogenated and thus converted into a blending agent (hydrocodimer).

COFFERDAM: A double bulkhead, particularly in tankers, between the tanks and sections of the vessel not serving as tankage space. Its purpose is to isolate the oil cargo from the engine and boiler space, or from the holds used for other cargo. It assures that there will be no leakage into the adjacent compartments.

COIL AND DRUM: A thermal cracking operation in which the cracking stock is preheated in a fired tube coil and is discharged into a drum of large volume where the major part of the cracking reaction takes place adiabatically.

COIL-ONLY: A thermal cracking operation in which the entire reaction is carried out in a fired tube.

COKE PETROLEUM: The residue obtained on the dry distillation or batch distillation of petroleum. Its composition is usually the following:

5% to 10% volatile and combustible matter.
0.3% ash;
90% to 95% fixed carbon;
0.5% to 1% of sulfur.

On account of its purity, this coke is much used in metallurgical processes and in making battery carbons and carbon pencils.

COKING: 1. The process of distilling a petroleum product to dryness. The petroleum contains complex hydrocarbons that break down in structure during distillation. With the production of lighter distillable hydrocarbons, an appreciable deposit of carbon or coke is formed and settles to the bottom of the still.
2. The undesirable building up of coke or carbon deposits on refinery equipment.

COLD WORK PERMIT: A permit issued by responsible Process representatives permitting mechanical work of a non-sparking nature in a given process area. The equipment used in the performance of the work should be normally of an explosion-proof or non-sparking nature.

COLOR: The color of an oil is expressed as a "number" which is determined by matching the light transmitted through a predetermined depth of oil with that same light transmitted through numbered and standardized glasses or disks.

COLORIMETER: An instrument for determining the color of petroleum oils as compared to a fixed standard.

COLOR STABILITY The resistance of oil to discoloration due to light, ageing etc.

COMBINATION FRACTIONATOR: A catalytic cracking unit fractionator designed to fractionate products from the cracking operation as well as reduced crude from the atmospheric pipe stills.

COMPOUNDED OIL: A petroleum oil to which has been added some animal or vegetable oil, or other chemical substance.

COMPRESSION PRESSURE: The pressure of the gases in the cylinder at the end of the compression stroke.

COMPRESSION RATIO: The ratio of the cylinder volume at the bottom of the stroke to the cylinder volume at the top of the stroke is called the compression ratio.

COMPRESSOR: A pump which draws in air or other gases, compresses it and discharges it at a higher pressure.

COMPUTERS: Computers are devices for calculation. There are two broad classifications: The Analog class in which problems are defined by setting up circuitry which closely represents the physical process and the Digital class in which information representing the process is submitted to the computer in digital form.

COMPUTER ROUTINE: An ordered series of coded instructions designed for use in an automatic computer for the purpose of solving a specific type of problem.

CONDENSATE: When vapor is liquefied by cooling, the resulting liquid is known as condensate.

CONDENSER: A piece of equipment designed to cool and condense a vapor, by means of removing heat from the vapor with a colder medium such as water.

CONDENSER, REFLUX: A condenser which constantly condenses the vapors and returns them to the original distilling flask or into the lower levels of a fractionating tower.

CONE ROOF: A fixed, cone-shaped tank roof with the high point in the center to shed rain water.

CONRADSON CARBON: A carbon residue test originated by Dr. Pontus H. Conradson. In the test, oil is burned in insufficient air. The residue formed is supposed to be an indication of the burning quality of the oil.

CONSOLE: A compact arrangement of miniature control instruments about a desk.

CONTACT COLUMN: A vertical tube or tower containing perforated plates, nozzles or packing materials, so that mixing or contacting may be obtained between substances passing through the column.

CONTINGENCY ITEM: An unforeseen capital item not covered by a Budget Project and costing no more than $25,000.

CONTINUOUS ANALYZER: A plant type analytical instrument which continuously monitors a refinery stream for specific qualities or components.

CONTINUOUS PROCESS: Any process in which the charge is added and the products are withdrawn continuously; as opposed to the batch process.

CONTROL CHART: A time series plot of data with upper and lower control limits within which operation is desired.

CONTROL MODES: Types of control responses obtainable in automatic controllers. Principal control modes are:

PROPORTIONAL:
Where the position of the final control element (usually a Control Valve) is proportional to the absolute value of the measured variable.

RESET:
Where the rate of travel of the final control element depends on the amount of deviation of

the controlled variable from the desired value.

RATE ACTION: Where the rate of travel of the final control element is proportional to the rate of change of the controlled variable.

CONTROL POINT: The stable or equilibrium value of a variable such as temperature or pressure which is being regulated by an automatic controller (as distinguished from the Set Point).

CONTROL VALVE: A variable opening valve used with a control instrument to maintain a predetermined flow rate, pressure, temperature or level. Valve can be electric, electrohydraulic, or air operated.

CONVECTION: The transfer of heat by the constant movement of a gas or liquid about the heat producing body or source of heat.

CONVECTION BANK (OR SECTION): That portion of a furnace in which the tubes receive heat from the hot flue gases primarily by convection.

CONVENTIONAL INSTRUMENT PANEL: A steel mounting board for the older type circular instruments which are mounted in rows.

CONVERSION: In general, the ratio of gasoline produced to the feed stock in a cracking process. The term has several specific definitions for specific circumstances.

COOLER: A heat exchanger in which hot gasoline or heavier stocks passes through pipes immersed in cool water in order to lower the temperature.

COPOLYMER: Mixed polymers or heteropolymers, products of polymerization of two or more substances at the same time to yield a product which is not a mixture of the separate polymers but a complex with properties different from each polymer alone.

COPPER NUMBER: The number of milligrams of mercaptan sulfur present in 100 milliliters of a light petroleum oil when determined by a standard laboratory procedure.

COPPER TREATING PROCESS: Sweetening process for distillate oils using copper chloride as catalyst for the oxidation of mercaptans by air.

CORRELATION ANALYSIS: A mathematical technique for developing a functional relationship between two or more variables - also termed regression analysis.

COSTS ACCOUNTING: Variable cost is one which changes directly with the level of production.

Semi-variable costs also vary with the production rate but not in direct proportion (include labor, supervision and other labor).

Fixed costs, as the name implies, have little relationship to the production rate (include depreciation, taxes and insurance costs).

COTTRELL PRECIPITATOR: A piece of equipment designed for the removal of dusts and mists from gases by the application of high voltage electric current.

COUNTER-CURRENT FLOW: The flow of two streams of material in opposite directions through a process or piece of equipment, for the transfer of material or heat.

CRACKED DISTILLATE: Petroleum distillate which has been "cracked" or broken up into lighter products.

CRACKED GASES: Gases resulting from the breaking down or cracking of petroleum oils.

CRACKED GASOLINE: Gasoline obtained by cracking heavier oils.

CRACKED NAPHTHA: A naphtha which has been produced in a cracking process.

CRACKING: The process of breaking up heavy petroleum products into lighter products such as gas and gasoline. This may be accomplished by the use of heat and pressure or catalysts.

CRACKING COILS: Refinery equipment employing heat and pressure for the cracking of petroleum oils. This consists essentially of coils running through a furnace, followed by fractionating equipment.

CRACKING, LIQUID PHASE: Decomposing petroleum oils in a liquid state.

CRACKING SEVERITY: The degree of change produced in a petroleum product when it is subjected to a cracking process. There are various specific definitions for cracking severity.

CRACKING STOCK: Petroleum distillates suitable for use in the cracking process.

CROWN SHEET: The apex or highest roof plates on a cone roof tank.

CRUDE ASSAY: True boiling point distillation and other quality information on a crude.

CRUDE PETROLEUM (CRUDE OIL): A naturally occurring mixture, consisting predominantly of hydrocarbons, and of sulfur, nitrogen and oxygen derivatives of hydrocarbons, which is removed from the earth in a liquid state.

CUBICLE: A metal enclosure housing electric circuit components which is completely wired as a unit.

CUMENE: Isopropyl benzene, $C_6H_5CH(CH_3)_2$.

CUT: A segregated part or fraction of the total overhead or sidestream in a distillation process.

CUT-BACK PRODUCTS: Petroleum or tar residuals which have been fluxed or diluted, each with its own or similar distillates.

CUT POINT: The boiling temperature division between cuts of a crude or base stock. Although actually signifying a temperature on the true boiling point curve, it is usually determined by averaging the ASTM distillation 95% temperature of the lower boiling cut and the 5% temperature of the higher boiling cut.

CYCLE GAS OIL: Cracked gas oil which is returned to a cracking unit.

CYCLE STOCK: Product taken from some later stage of a process and recharged to the process at some earlier stage.

CYCLE TIME: The time any one reactor remains in naphtha reforming service between regenerations.

CYCLIZATION: The formation of a closed ring from a straight chain compound.

CYCLONE SEPARATOR: A conical vessel provided with a tangential inlet for a gas stream containing powdered solids or liquid droplets and normally provided with a centrally located overhead gas-withdrawal line. Powdered solids or coagulated liquids are separated by centrifugal force and pass downwardly along the incline (conical) to a centrally located outlet. Usually a leg, known as a dip leg, is connected to the solids outlet and, in catalytic cracking, serves to convey the solids back to the dense-phase powdered catalyst.

DEACTIVATION: The reduction in catalyst activity by coating of catalyst particles by contaminants, or a change in the physical structure of the catalyst particles.

DEAD END SYSTEM: A dead end system is one which terminates at its destination. This is in contrast to a circulating loop type system.

DEADMAN: A large block of concrete or piling used to anchor guy wires for supporting derricks, stacks, etc.

DEAD ZONE: The largest change in a controlled variable which causes no response in the controller.

DEASPHALTING: A process for removing asphalt from reduced crude which utilizes the widely different solubilities of non-asphaltic compounds in liquid propane.

DEBUTANIZER: A fractionating unit which is designed to remove butane from a mixture of petroleum hydrocarbons.

DE-ETHANIZER: A fractionating column for the removal of ethane and fixed gases from a mixture of heavier hydrocarbons.

DE-FLOREZ HOLE: A 1/8" or 5/32" dia. hole drilled in piping which is in corrosive service and which operates at high temperatures or is inaccessible for normal inspection measurements. The hole is normally drilled to a depth of 1/32" less than the retiring wall thickness limit of the pipe or fitting. Leakage of product thru a de Florez hole indicates thinning of the pipe or fitting to a point below the retiring thickness, thus issuing a warning that renewals should be made. Safety (de Florez) drilling is sometimes referred to as "woodpecking".

DEFOAMER: A substance which is added to a liquid to prevent or retard the formation of foam.

DEGRADATION: The reduction in the quality of a product or process stock. Degradation may be due to heat, oxidation, bad blending, etc.

DEHYDROGENATION: A refining process which converts the lower hydrocarbons - ethane, propane and the butanes - into the corresponding olefines - ethylene, propylene and the butenes.

DEMAND METER: A demand meter is a device which integrates voltage and current of a circuit and indicates (or records) the wattage of the circuit. The demand feature is a hand which stays at the highest point on the scale since the last setting.

DEMULSIFY: To break down an emulsion.

DENSE PHASE BED: The normal bed of fluidized solids particles.

DEPENTANIZER: A fractionating column for the removal of pentanes and lighter fractions from a mixture of hydrocarbons.

DEPHLEGMATOR: An apparatus in which heavy liquid impurities are separated from an oil in the vapor state by condensation of the impurities. Specifically, the part of a distilling apparatus in which a partial separation of the vapors is effected by means of contact with cold, metallic diaphragms.

DEPROPANIZER: A fractionating tower which is designed to remove propane from a mixture of light petroleum hydrocarbons.

DERIVATIVE MODE: (See Control Mode - Rate Action).

DESALTING: Removal of calcium chloride $(CaCl_2)$, magnesium chloride $(MgCl_2)$, and sodium chloride $(NaCl)$ from crude oils, by chemical and/or electrical methods.

DESIGN BASIS MEMORANDUM: A written statement describing the basis for a design of the project under consideration.

DESULFURIZATION: A process which removes sulfur or sulfur compounds from petroleum products, usually by means of a chemical treatment.

DESUPERHEATER: A device to inject liquid into a superheated vapor to reduce the amount of superheat.

DETERGENT: A material which in water solution is surface active and can be used for cleansing.

DETONATION: In a gasoline engine, detonation is the "knock" which results because the anti-knock quality of the gasoline is insufficient to satisfy the combustion requirements of the engine.

DEW POINT: The temperature at which a vapor condenses.

DIAPHRAGM MOTOR OPERATOR: The actuator of a pneumatic control valve, where the valve stem position is determined by the pneumatic pressure applied to a diaphragm opposed by a spring.

DIATOMACEOUS EARTH: A mineral deposit of nearly pure amorphous silica which represents the inorganic residues from billions of aquatic single-celled algae or flowerless plants.

DIESEL INDEX: This is a figure calculated from the aniline point and specific gravity which is used as a rough indication of the ignition quality of a diesel fuel.

DIETHANOLAMINE (DEA): A liquid organic chemical having the formula $C_4H_{11}O_2N$, used to remove H_2S from a gas stream.

DIFFERENTIAL CONVERTER: A differential pressure transmitter of the force-balance (mercuryless) type.

DIFFERENTIAL PRESSURE FLOW METER: A meter which measures the pressure drop across an orifice restriction which in turn is calibrated into the rate of flow of a liquid or gas.

DIFFERENTIAL PRESSURE TRANSMITTER: A device which measures differential pressures up to about 400" H_2O and converts these signals to pneumatic analogs which can be transmitted to remote reading instruments. Used with orifice flow meters and level instruments.

DIFFERENTIAL PRESSURE INSTRUMENTS: Instruments used to measure the pressure drop across tower trays, filters, strainers, etc.

DILUTE PHASE: The dust cloud above a fluidized bed of solid particles.

DIMER: A polymer consisting of two molecules of hydrocarbons, usually referring to isobutylene.

DIP: A designation for para di-isobutyl phenol.

DIPLEG: The vertical pipe from the bottom of a cyclone separator which acts as a cyclone seal and transports catalyst from the cyclone. The dipleg is used to overcome the pressure drop across the cyclone and prevents bypassing.

DIP LEG SEAL: Dip leg seal refers to the method of sealing the outlet of a catalyst dip leg to prevent passage of vapors up the dip leg. It may consist of a seal pot, trickle valve, or splash plate immersed in the dense bed.

DIPS: A designation for di-isobutyl phenol sulfide.

DIP SEAL: A continuously flowing water seal in the base of a flare to seal the flare stack against flashbacks. Can also be accomplished with external seal drum.

DISENGAGING DRUM: (See Drum - Disengaging).

DISK AND DOUGHNUT: A type of fractionating tower construction consisting of alternating discs and doughnut-shaped plates which provides a separation of light and heavy materials. Disc and doughnut sections are used where fouling is a problem and precise fractionation can be sacrificed.

DISMANTLING REPORT: A report prepared by the field engineers to advise the Accounting Department that a piece of equipment has been removed from service and should be removed from the plant account records.

DISPLACEMENT METER: (See Positive Displacement Meter)

DISTILLATE: A product of distillation or the fluid condensed from the vapor driven off in the still. Gasoline, kerosene and light lubrication oils are examples of distillates.

DISTILLATION LOSS: In a standard laboratory distillation, the difference between the volume of liquid originally introduced into the distilling flask and the sum of the residue and the condensate recovered.

DOCTOR SOLUTION: A solution used to free gasoline, kerosene and other petroleum products from sulfur. It is usually an alkaline solution of sodium plumbite and free sulfur.

DOCTOR TEST: A test for the presence in light distillates of a particular type of sulfur compound known as mercaptans in which the sample is shaken with a solution of sodium plumbite. If perceptible quantities of mercaptans are present, the solution becomes brown and the sample is "sour".

DOCTOR TREATING PROCESS: A sweetening process for petroleum distillates employing plumbite solution and free sulfur whereby mercaptans are oxidized to disulfides.

DOG: A toggle. toggle is the preferred term.

DOLOMITE: A double salt of calcium carbonate and magnesium carbonate containing 40 to 50% of magnesium carbonate.

DOSIMETER: An instrument used to determine the radiation dose a person has received.

DOWNCOMER: A means of conveying liquid from one tray to the next below in a bubble-tray column.

DOWNFLOW: A term applied to process equipment in which the stream of gas or liquid flows from the top to the bottom. An example is the soaking drum used in connection with some cracking processes in which hot stock enters at the top and leaves from the bottom.

d/P CELL: (See Differential Converter)

DRAWOFF PAN (OR TRAY): A collecting tray or pan in a fractionating tower to permit withdrawing a fluid during the fractionation process.

DRUM: A cylindrical metal container used for the shipment or storage of petroleum products under pressure.

BLOWDOWN:
A vessel used to confine discharges of liquid and vapor material from attendant process equipment. The discharges usually occur during the time when the normal process system is in some way interrupted such as during emergencies.

CONDENSABLE BLOWDOWN:
A condensable blowdown drum is one equipped with direct water cooling to condense the high boiling portion of safety valve discharges such as those on furnace outlet safety valves.

DISENGAGING:
A vessel used for rapid separation of gas from liquid or liquid from liquid. Distinguished from "settler" by low residence time required for separation. Sometimes referred to as a knockout drum.

FLASH:
A primary separator which permits the oil stream to vaporize or "flash". The operating pressure of the drum is below that of the incoming oil, thus allowing the lighter fractions of the oil to vaporize and separate from the heavy constituents.

PUMP OUT:
A drum used to collect liquids pumped from an operating unit as an emergency or normal operating procedure.

WATER DISENGAGING:
A water disengaging drum is used to permit separation of light hydrocarbons (resulting from exchanger leakage, control valve failure, direct contact, etc.) from cooling water. The drum may be vented to the atmosphere or the flare and the water passes to the sewer.

DRY GAS: Very low boiling, petroleum hydrocarbon gas which has been passed through the gas absorption equipment. The molecules will contain one to three carbon atoms. It is distinguished from "wet" gas which contains light naphtha.

DUPLEX PUMP: Reciprocating pump having two working cylinders side by side.

ECONOMIZER: Equipment for utilizing the waste heat of flue gases for preheating boiler feed water.

EFFLUENT: The outgoing product in a refinery process.

EJECTOR (JET PUMP): Device utilizing the flow of a gas or vapour to create a suction or vacuum.

ELCOMETER: An instrument used to measure the thickness of paint and other protective coatings.

ELECTRIC PRECIPITATOR: A device utilizing high voltage direct current which energizes a network of wires or plate which attract solid particles thereby removing them from a stream of gas.

ELUTRIATION: To purify by washing or purging with a suitable medium. In petroleum refining, the removal of finer catalyst particles by a stream of gas under controlled conditions.

EMULSIFY: To make a stable dispersion of any liquid in another liquid or gas in liquid in which it is not soluble - specifically, here, of oil in water or of water in oil. This may be done by mechanical agitation with the addition of an emulsifying agent to stabilize the emulsion.

ENDOTHERMIC: Relating to or designating a reaction which occurs with the consumption of heat so that heat must be supplied from an external source if it is to continue.

END POINT: In the ASTM distillation of petroleum products, the end point is the maximum temperature observed on the distillation thermometer and is usually reached after the bottom of the flask has become dry.

ENGINEERING FLOW PLAN: A line drawing showing process piping and mechanical information which are used as a basis for preparation of detailed piping and equipment drawings.

ENGLER DISTILLATION: A standard test for determining the volatility characteristics of a gasoline by measuring the per cent distilled at various specified temperatures.

ENNISCOPE: A dielectric constant meter adapted for use as an automatic water drawoff for tanks.

ENTRAINMENT: 1. Relatively non-volatile contaminating material which is carried overy by the "overhead" effluent from a fractionating column, absorber, or a reaction vessel. This may be as liquid droplets or finely divided solids suspended in a gas, a vapor, or in a discrete liquid.
2. That portion of a finely divided catalyst which escapes the cyclones of a reactor or regenerator of cracking units. See Carry-over.

ENTRAINMENT SEPARATOR: A layer of metal mesh installed in the vapor space of towers and drums to separate entrained liquid from the vapor.

ESTIMATE:

BUDGET:
A cost estimate of usually ± 10% accuracy for use in preparation of the yearly Plant and Equipment Budget.

STUDY:
A quick order of magnitude cost estimate for use

in the very early stages of Budget preparation.

DEFINITIVE: A cost estimate of + 10% accuracy for use in preparation of our appropriation request.

EXCHANGER: A piece of equipment designed to transfer heat between two flowing mediums of different temperatures.

EXOTHERMIC: Relating to or designating a reaction which occurs with the evolution of heat, so that the temperature of the reacting bodies is raised.

EXPANDED METAL: A perforated and deformed steel sheet used to support insulation material applied in plastic form. It is used as a wire lath and as such has openings of a diamond shape with the lower edges of the diamond formed such that they would support plastic material which finally hardens. The material being supported or reinforced can also be a refractory. This is used especially in lines and vessels subjected to erosion by fluid catalyst.

EXPANSION JOINT: A joint employed in the connection of long lines of pipe, which contains a bellows or telescope-like section to absorb the thrust or stress caused by linear expansion or contraction of the line due to changes of temperature or to accidental forces.

EXPLOSION SEAM: A tank roof seam purposely made weaker than other roof seams to control direction of throw and minimize damage to a tank in the event of an explosion.

EXPLOSIVE LIMITS: The limits of percentage composition of mixtures of gases and air within which an explosion takes place when the mixture is ignited. The lower limit of flammability corresponds to the minimum amount of combustible gas and the upper limit to the maximum amount of combustible gas capable of conferring flammability on the mixture.

EXPLOSIVITY STRIPPER: An explosivity stripper is a stripping vessel normally employing steam used to decrease the explosivity of fuel oil components.

EXTRACTION: The process of separating a material by means of a solvent into a fraction soluble in the solvent (extract) and an insoluble residue.

EXTREME-PRESSURE LUBRICANTS: A term applied to lubricating oils or greases which contain a substance or substances specifically introduced to prevent metal-to-metal contact in the operation of highly loaded gears. In some cases this is accomplished by the substances reacting with the metal to form a protective film.

FATIGUE: Denotes the tendency for a metal to break under conditions of repeated cyclic stressing below the ultimate tensile strength.

SHB 182

FAT OIL: The extract drawn from the absorber. Cf. lean oil.

FEED BACK: The portion of a closed loop control system that brings back information about the condition under control for comparison to the target value. The function of an automatic controller of being able to detect a change in a controlled variable which it (the controller) has caused.

FEED STOCK: Crude oil or a fraction thereof to be charged to any process equipment.

FEEDER CABLE: An electric cable carrying the total load from the generating source to a distribution center.

FILLET WELD: A weld of approximately triangular cross-section joining two surfaces at right angles to each other in a lap joint, tee joint or corner joint.

FILM BADGE: A piece of masked photographic film worn like a badge by nuclear workers. It is darkened by nuclear radiation, and radiation exposure can be checked by inspecting the film.

FILM STRENGTH: The ability of a lubricant to maintain a film to separate bearing surfaces without breaking down and allowing metal-to-metal contact. The higher the film strength, the greater load the lubricant can support.

FILTER AIDS: Porous, absorbent materials, such as fuller's earth, used to speed up filtration by preventing the filter from clogging.

FINES: The smaller particles in a body of crushed solids. In catalytic cracking, the particle size of the fines may be from 0 to 20 microns.

FIRE BANK: A continuous wall of earth around a petroleum tank to prevent spreading of oil in case of leakage or fire.

FIRE POINT: The temperature at which an oil takes fire and burns continuously when a small flame is held near to the surface.

FIRE WALL: A continuous wall of concrete, brick, or steel to contain a fire. Also, a wall installed to protect operators when using safety devices.

FISSION: The splitting of an atomic nucleus into two parts accompanied by the release of a large amount of radioactivity and heat. Fission reactions occur only with heavy elements such as uranium and plutonium.

FIXED BED: A type of cracking operation in which the catalyst remains stationary. It is normally regenerated periodically.

FLAME ARRESTOR: Device in gas lines or tank vents to prevent the passage of a flame without obstructing the flow of gas; usually consists of a metallic grid or gauze.

FLARES: A device for disposing of gases by burning.

GROUND FLARE:
A ground flare is a device for burning excess refinery gases especially during periods of emergency in a ground level combustion zone. The top of the stack on a typical installation would be about 35 feet above grade.

ELEVATED FLARE:
A relatively tall flare for burning excess refinery gases with heights in the range of 100-300 feet.

MULTI-JET FLARE:
A specially designed ground flare having an appreciably larger combustion zone and multiplicity of jets for injection of the gas which results in essentially complete combustion of the gas with very little smoke or luminosity.

FLASH, CLEVELAND: An open cup tester for determining the flash point of petroleum distillates.

FLASH DRUM: (See Drum - Flash)

FLASHING: An operation in which a heated body of oil under pressure is suddenly vaporized in a tower by reducing pressure.

FLASH POINT: The lowest temperature at which under specified conditions, a petroleum product vaporizes rapidly enough to form above its surface an air and vapor mixture which gives a flash or slight explosion when ignited by a small flame.

FLOATING HEAD: That end of the tube bundle in a heat exchanger or condenser which is not attached to the outer shell but is free to move with the thermal expansion of the bundle.

FLOATING ROOF: An oil storage tank roof which floats on the surface of the oil, thereby eliminating breathing and evaporation losses.

FLOODING: In a fractionating column, filling up with liquid.

FLUE GAS COOLER: A device used to lower the temperature of hot exit gases from a gas turbine or process by generating steam or heating another fluid or gas stream.

FLUID: A substance which flows under the slightest pressure, term includes gases and liquids.

FLUID CATALYTIC CRACKING: A cracking process making use of finely powdered catalyst which when mixed with a moving stream of oil vapor, assumes many of the properties of a liquid.

FLUID COKING: A fluid solids process for thermal cracking of residual oils to remove carbon as coke and yield a liquid product boiling lower than the feed. The solids are coke particles.

FLUX: A petroleum stock which is used to fluidize a heavier residual stock so that the heavier stock can be pumped and utilized.

FOAMITE: Mixture of aluminium sulphate, sodium carbonate and liquorice, which forms a stable foam with water, used for blanketing oil fires.

FOOT VALVE: Check valve at the inlet end of the suction pipe at a pump, which enables the pump to remain full of liquid when not in operation.

FOREBAY: The intake structure on the suction side of the water-front salt water pumps which is equipped with travelling screens to keep debris out of the salt water system.

FORCED DRAFT: System of forcing air into a furnace or heater by a fan, as contrasted with induced draft.

FOULING: Accumulation of deposits in condensers, heat-exchangers, etc.

FRACTION: A product of a fractional distillation having a restricted boiling range.

FRACTIONATING COLUMN: An apparatus arranged to separate various fractions of petroleum by single distillation, the condenser of "column" being tapped off at different points along its length to separate various fractions in the order of their condensing temperatures (boiling points).

FRESH FEED: Crude petroleum or petroleum distillate which is being fed to a particular process unit for the first time.

FRONT END VOLATILITY: Represents the low boiling portion of gasoline and effects the starting-up and warming-up of an internal combustion engine.

FUEL GAS: Any gas used for heating.

FUEL OIL EQUIVALENT: Used in indicating the Bunker "C" equivalent of the fuels on a heating value basis.

FURNACE:

BOX:
Box-shaped fired heater consisting of one or two radiant sections and a convection section in the same horizontal plane. Tubes and burners are horizontal and furnace is at ground elevation.

CABIN:
Cabin-shaped fired heater in which the convection section is located directly above the radiant section. Tubes are horizontal and the furnace is fired either horizontally or vertically.

PETROCHEM:
A cylindrical fired heater usually consisting of a radiant and convection section in a vertical plane. Tubes and burners are vertical and furnace is elevated above ground.

SELAS:
A cabin type furnace with a large number of small horizontal gas fired burners to give

accurate temperature gradient control.

FUSION: The combination of atomic nuclei to form a heavier nucleus. It is accompanied by the release of a great deal of heat energy.

GAGING: The act of measuring the height of liquid in a tank for the purpose of calculating the volume of liquid in the tank.

GAUGE PRESSURE: Pressure measured above atmospheric pressure.

GAS CHROMATOGRAPHY: A technique of hydrocarbon analysis involving separation of the vapor hydrocarbon mixture into its individual components by means of liquid absorption or solid adsorption and desorption.

GASKET: Thin sheet of material used for making pressure tight joints between surfaces.

GAS OIL: Petroleum distillate with viscosity intermediate between kerosene and lubricating oil, boils within the range 400°F to 800°F.

GASOLINE: A refined petroleum naphtha which by its composition suitable for use as a fuel in internal combustion engines.

GASOLINE POOL: A planning concept which considers gasolines of various qualities as one group for purposes of blending to meet final product specifications.

GAS TEST: An analysis of air to detect unsafe concentrations of toxic or explosive vapors.

GAS TURBINE: A driver in which the gases of combustion drive a turbine which turns the drive shaft.

GATE VALVE: A valve with a sliding blank which opens to the complete cross section of the line. Used for complete opening or complete shutoff of the flow of material in pipes; it is not designed for throttling or control purposes.

GAUGING HATCH: A hinged manhead on the roof of a tank which can be opened to use a tape to measure the depth of liquid or take a sample of the material in the tank.

GEIGER COUNTER: An electrical device for detecting radioactivity by counting ions formed by the passage of radioactive particles.

"G-FIN": The trade name for a Griscolm-Russell pipe in pipe exchanger with excellent heat transfer characteristics in small areas due to the installation of fins on the inside pipe.

GIRBOTOL: A process for removing hydrogen sulphide, carbon dioxide, and/or other gases from petroleum gases and liquids.

GLAND: Device on a rotating or reciprocating shaft to prevent leakage of gas or liquid.

GLOBE VALVE: Valve in which flow is controlled by a movable plate (disc) set parallel to the flow. Is used for throttling operations.

GO-DEVIL: A cleaning device inserted in a pipe or tube and forced thru by air pressure or the movement of the material in the pipe.

GOOSENECK: A reverse bend in piping to provide a trap effect.

GRAL SWITCH: An oil-immersed electric disconnect switch. This switch must not be used for interrupting load. It is used in lieu of a "T" type splice, and facilitates testing.

GRAPHIC PANEL: A steel mounting board for instruments which presents a simplified flow diagram of the process. The instrument components are located in this diagram at the same relative positions as are their points of application in the actual process.

GRAPHITE: A crystalline form of carbon either natural or synthetic in origin. It is used for acid proof construction as pipe liners or brickwork.

GRASS ROOTS: Normally referred to with respect to new equipment. Indicates cost of equipment when starting with no existing investment.

GREASE: A semi-solid lubricant consisting essentially of a stabilized mixture of mineral oil and soap. The properties of the material depend on the type of soap employed and the viscosity and other properties of the constituent mineral oil.

GRID: A perforated plate designed to mix catalyst with air or vapors and which supports the catalyst dense bed.

GROUNDING: Connecting electrical apparatus to fixtures attached or inserted into the earth. Grounding is divided into System Grounding where the circuit itself is grounded and Equipment Grounding where the accidental connection of live currents to the housings, etc., are carried to earth reducing the hazard to humans.

GROUT: A concrete mixture made with fine aggregate to fill in under machinery after alignment to provide secure and level base.

GUM: A rubber-like, sticky deposit, black or dark brown in color, which results from the oxidation of lubricating oils in service and from unstable constituents in gasoline which deposit during storage or use.

GUNITE: A trade name for a process which sprays concrete on a steel mesh support to line tanks and drums or to fireproof structures.

GUSSET: A steel plate used as a brace, most often for small pipe connections to larger pipe or vessels when the connection is subject to vibration or mechanical loads. Also a bolting or riveting plate used to connect structural steel members to each other.

HAMMER LINE BLIND: A spectacle-type blanking device which operates similarly to a valve and eliminates the need for removing pipe flange bolts to remove or install a line blank.

HAMMER TEST: Method of locating weakened sections of steel equipment by striking with a standard hammer.

HAMMER TESTING: Used by Equipment Inspector to ascertain the presence of thin sections of piping, heads and shells of pressure vessels, tanks, etc. It is normally a supplementary method of testing.

HASTINGS FLOW METER: A thermal conductivity type of gas flow meter where the cooling of a heated filament in the flowing gas stream is correlated with gas velocity

HEADER: A common manifold into which a number of pipe lines are connected.

HEADER BOX: Header box refers to an entire furnace tube end assembly. Header boxes are of two types, square type, which are equipped with flat or deflector plugs, and sectional type, which are equipped with return bends.

HEAT BALANCE: Calculation in which the total of the various quantities of heat entering a system are compared with the total of the various quantities of heat leaving the system.

HEAVY ENDS: The higher boiling fraction of a product, especially of gasoline. The term is general, used differently by different people. Heavy ends are frequently of poorer quality than the product. The true boiling range of heavy ends is higher than the ASTM end point of the product.

HEEL: The oil remaining in a tank after normal emptying.

HELIARC WELDING: An inert-gas metal arc welding process using a non-consumable electrode for heat. The arc is shielded by an inert gas such as helium or argon and the filler metal is fed by hand.

n-HEPTANE: The straight chain, seven-carbon paraffin with an octane rating of 0 used as a reference fuel ingredient in making motor-fuel octane-number tests.

HEXSTEEL: Grating or mesh, fabricated of strip steel forming a hexagonal pattern. Used to support castables in erosion resistant liners. May be stainless or carbon steel and is available in 3/4", 1" and 1-1/4" thicknesses.

HIGH LEVEL ALARM: An instrument device which will actuate an audible horn and signal light when a liquid level has risen above a safe point in a vessel.

HIGH LINE OR HIGH-PRESSURE GAS: Those gases coming off the distillate drums from cracking operations at about 100 lb. which join the low line gas after compression as feed stock to the gas absorption plant.

HIGH VISCOSITY FUEL: Residual fuel - usually tar - which has not been fluxed. It is used in the refinery wherever possible since it has the the same (actually slightly higher) BTU value as Bunker "C" fuel and does not include any components saleable as distillates.

HISTOGRAM: A frequency distribution presented in bar graph form.

HOLDDOWN BAR: A bar used in bubble cap design to hold down a group of caps on a tray.

HOT SPOT: An area of a vessel or line wall appreciably above normal metal operating temperature. Usually due to deterioration of a an internal insulating liner which exposes the line or vessel shell to the temperature of its contents.

HOT TAP: Welding a short piece of pipe to a tank, drum or another pipe line while the equipment is in service. A specially designed machine cuts a hole of the required size.

HOT WORK PERMIT: Permit issued by an operator or foreman to allow performance of work involving heat or sparks such as welding, burning, grinding, and hot riveting.

HYDROCODIMER: A high octane blending agent resulting from the hydrogenation of codimer.

HYDRODESULPHURIZATION: The removal of sulphur from a material by the addition of hydrogen at the proper conditions to form hydrogen sulphide.

HYDROFINING: A catalytic treating process carried out in the presence of hydrogen but at lower pressure and temperature levels than hydroforming. This process is a net consumer of hydrogen, and is used for naphthas, heating oils and kerosenes in place of acid treating.

HYDROFORMING: The catalytic reforming of naphtha at elevated pressures and temperatures in the presence of hydrogen. This process is a net producer of hydrogen and is used in place of thermal reforming. Can be carried out with fluid or fixed bed catalyst system.

HYDROGENATION: The chemical addition of hydrogen, using in the presence of a catalyst.

HYDROGEN SULPHIDE (H_2S): A poisonous gas produced especially in refining sour crude.

HYDROSTATIC HEAD: Pressure at the base of a stationary column of liquid due to the weight of the liquid.

HYPOID LUBRICANTS: Types of extreme-pressure lubricants used for the lubrication of hypoid gears.

IMPINGEMENT AREA: The area where moving catalyst particles strike the metallic surfaces in a catalytic cracking unit.

INCREMENTAL COST: The estimated cost of running additional barrels through a unit which is operating below its capacity.

INDUCED DRAFT: System of creating a pressure lower than atmospheric in a furnace or heater by means of a fan, so drawing in air, as contrasted with forced draft.

INDUSTRY STANDARD: A term used to describe the degree to which marginal equipment is included in the design and construction of a unit. Some chemical and petroleum refining industries build plants that are not as conservatively designed from safety, pollution and reliability standpoints as are our units.

INERT BALLS: An inert material in the shape of spheres placed above and below the catalyst bed in each reactor to prevent movement of the bed.

INERT GAS: A non-combustible gas. Also called inert.

INFRA-RED ANALYZER: A plant or laboratory type of composition analyzer which identified compounds through their characteristic absorption of infra-red radiation.

INHIBITOR: An additive which will prevent or retard undesirable changes taking place in the quality of the product, or in the condition of the equipment in which the product is used. Inhibitors frequently act as anti-oxidants and corrosion preventives.

INHIBITORS: Substances, the presence of which in small amounts in a petroleum product prevents or retards undesirable chemical changes taking place in the product, or in the condition of the equipment in which the product is used.

INITIAL BOILING POINT: The temperature a which the first drop of distillate leaves the condenser during a standard ASTM laboratory distillation.

INNAGE: The height of a liquid in a tank, usually measured in inches with a measuring tape and bob.

INSTRUMENT FLOW PLAN: A line drawing which shows all of the required instrumentation process data for the design and procurement of instruments and controls.

INTEGRATOR: A device which continuously totalizes a measured variable such as a flow.

INTER CONDENSER: A condenser installed between two process stages.

INTERCOOLER: A cooling unit placed between two stages of a gas compressor.

INTERLOCK SYSTEM: A safety system whereby valve opening and closing sequence is assumed by physical or electrical means such as:- a hydrocarbon block valve which cannot be opened before an oxygen gas valve is closed.

INTERNAL COMBUSTION ENGINE: An engine in which the heated gases for doing work are developed within the engine as compared, for example, to a steam engine where the heated vapors are developed by an outside source.

INTERRUPTING CAPACITY: The physical design of electrical equipment which indicates the level of short circuit current that can be interrupted without freezing or welding of disconnecting contacts.

INTERSTAGE: The process equipment between different pressure stages of a compressor circuit.

INVESTMENT CREDIT: Used in Budget economics. Reduction in planned investment which will occur because other equipment is built.

INVESTMENTS - TYPES:

Gross (or Original Investment): The Gross Investment is the original cost of constructing the facilities in question. Budget projects are presented and analyzed on this basis.

Net Investment (Net Book Value): Gross Investment less depreciation reserves equals net investment.

Depreciated, Escalated Investment: This investment is obtained by adjusting Net Book Value to take into account changes in construction costs or the value of the dollar since the plant was built.

Original Investment Adjusted to Current Costs: This investment is self-explanatory and is a rough measure of the cost of replacing the plant in question. In fact, the investment is sometimes referred to as replacement investment.

Replacement Investment: The cost of replacing the facilities required to do a given job is known as replacement investment. It is usually lower than original investment adjusted to current costs because of Technological advances.

INVITATION TO BID: A compilation of process and mechanical data for the design and construction of facilities which is forwarded to contractors for bidding.

ISOMERIZATION: The chemical conversion of one hydrocarbon into another hydrocarbon of exactly the same molecular weight and with the same hydrogen-carbon ratio.

ISO-OCTANE: The popular name for 2, 2, 4 tri-methyl pentane. This hydrocarbon has excellent anti-knock characteristics and the octane number assigned to gasolines is based upon a value of 100 for iso-octane. At the time the octane scale was set up, iso-octane had the best anti-knock characteristics of any known hydrocarbon.

ISOTOPES: Elements which occupy the same place in the periodic system, have the same nuclear charge, but have a different atomic weight. They contain the same number of protons but a different number of neutrons. Uranium-238 contains 92 protons and 146 neutrons while the isotope Uranium-235 has 92 protons and 143 neutrons.

JACK SCREW: A device for locking return bends or plugs in position in a furnace header box.

JET CLEANING: A chemical cleaning technique using a very high pressure jet of water, detergent or hydrocarbon to remove deposits in exchanger tubes.

JET MOLE: A pipe line cleaning technique using a very high pressure jet attached to a hose which pulls itself like a mole thru the pipe and washes deposits out behind it.

JET TRAY: A new fractionating tray developed by Esso Engineering consisting entirely of punched tabs.

JUMPOVER: A piping connection between two or more lines or between two sections of a furnace.

KARBATE: A carbon and resin material used for lining piping and vessels in acid service.

KAURI-BUTANOL VALUE: A laboratory test for determining the dissolving power of a solvent, based on natural kauri gum as a standard. It is especially used for lacquer solvents.

KERYL: A term applied to chlorinated kerosene having an average of 12 carbon atoms. It is used to alkylate benzene which is sulphonated to produce a detergent.

KING POST: The center column in a tank which is used to support the roof.

KNOCKER: A knocker is an air-operated cutter mounted on a universal joint. It is used in cleaning the inside of severely coked furnace tubes before turbining is attempted.

KNOCKOUT DRUM: A vessel in which suspended liquid is separated from gas or vapour.

KNOCK RATING: A colloquial synonym for octane number. See octane number.

LAG: Preferred engineering term for delay in response. (See also Process Lag and Transmission Lag).

LAGGING: Any material which can be used to reduce heat losses.

LATERAL: A branch connection from a utility main to a process consumer.

LATIN SQUARE: An arrangement for conducting an experimental program to obtain the most information from the optimum number of experiments.

LEADED FUEL: Gasoline containing tetra ethyl lead (TEL).

LEAD SUSCEPTIBILITY: The increase in octane number of a gasoline or other hydrocarbon obtained by the addition of a standard amount of tetraethyl lead.

LEAN OIL: The stripped solvent in the operation of an absorption tower. The solvent is fed to the tower in which the gas is to be stripped. It is then lean oil. It absorbs the heavy ends from the gas. It is then fat oil. The fat oil is stripped of these heavy ends and is again lean oil.

LIGHT ENDS: The low boiling fraction of gasoline, generally pentane and lighter.

LIGHT NAPHTHA: One of the lower boiling gasoline components; those with 95% off at or below 320°F.

LIGHTNING PROTECTION: An arrestor designed to bleed off to ground any pre-determined maximum level of voltage which would injure insulation or otherwise damage equipment and minimize lightning strikes.

LIGHT THERMAL BY-PASS NAPHTHA: A term applied to naphtha which has been produced on a thermal cracking coil unit but which has not been acid treated. Usually, this naphtha is the overhead from a splitter tower; the bottoms would be acid treated.

LINEAR PROGRAMMING: A mathematical method for finding the optimum value of a linear expression which is subject to linear constraints. This is referred to as programming because the solution methods require a series of trials, or programs for solution to a linear expression.

LINE BLENDING: The mixing of two or more components to some predetermined ratio in a pipe line.

LIQUEFIED PETROLEUM GAS (LPG): Light hydrocarbon material, gaseous at atmospheric temperature and pressure, held in the liquid state by pressure to facilitate storage, transport and handling. Commercial liquefied gas consists essentially of either propane or butane.

LIQUID LEVEL INSTRUMENT: An instrument which indicates the liquid level in a vessel.

LIQUID PUMPOUT: Those lines and equipment whose sole purpose is to empty the tower or drums of oil and slop during shutdowns or emergencies. The act of withdrawing the liquid from the equipment by means of pumps.

LIVE STEAM: Steam direct from a boiler, as against exhaust steam which is steam that has been used.

LOAD CENTER: A strategically located electrical distribution center from which 440 or 2300 volt power is distributed.

LOADING JACK: A flexible piping arrangement with swivel joints for loading tank wagons or cars.

LOADING RACK: A structure to provide access to the top of tank wagons and cars for loading purposes.

LOGGER: A device which automatically records data in digital form from measuring instruments at preset intervals or upon demand.

LOOK BOX: A box with glass windows installed in a pipe line to permit visual inspection of the flowing material.

LOOP DISTRIBUTION SYSTEM: A system of electrical distribution feeders arranged in a ring where every tap has a source of power from either direction.

LOOP SYSTEM: A loop system is a distribution system for such utilities as electricity, steam and fire lines, which is designed to permit supply from two directions.

LOW LEVEL ALARM: An instrument device which actuates an audible horn and signal light when a liquid level has fallen below a safe point.

LOW LINE OR LOW PRESSURE GASES: Those gases from atmospheric distillation and vacuum recovery systems (usually at about 5 lbs. pressure) which are collected in the gas plant for compression to higher pressures. Low line gases are distinguished from high line gases - those which have already been compressed or which result from high pressure operations.

MAGNAFLUX: A tool used for inspection of magnetic materials. A magnetic field is set up in a part to be inspected, interruptions to the magnetic field such as cracks are indicated by crowding or collecting of the flux at the flaw.

MAHOGANY ACIDS: The oil-soluble petroleum sulphonic acids remaining dissolved in the oil, when, in the manufacture of white oils with fuming acid, the acid sludge has been settled and drawn off. These acids are converted to sodium soaps (mahogany soap) by neutralization with caustic and removed from the oil by extraction with alcohol. After further purification they are extensively used in the refinery in the manufacture of soluble oils, rust preventives, and special greases. The sodium-mahogany soaps are converted to calcium soap for motor-oil detergent additive. Surplus amounts are sold for various uses.

MAHOGANY SOAP: See mahogany acids.

MANHEAD: An access opening into a tower or drum to allow entry of personnel during shutdowns for inspection or repair. May be round or oval.

MANIFOLD (HEADER): Pipe system having a number of branches connected together.

MANOMETER: A measuring device for determining pressures of gases and vapors.

MASS SPECTROMETER: An analytical instrument which selects charged masses in a vacuum with magnetic and electrostatic fields. This renders a spectrum which can be interpreted in terms of the type and quantity of the molecules present in the original sample. Samples must be vaporizable.

MASTER PLAN: A long range program for refinery betterment, usually applied to some specific phase such as tankage allocation or refinery layout.

MATERIAL BALANCE: Calculation in which the total of the various quantities of material entering a system are compared with the total of the various quantities of material leaving the system.

MATERIAL LIST: A list of stock items prepared by the Engineering Department for the use of the Storehouse, Purchasing Department and Mechanical Trades to determine the type and quantity of material required to construct a given project.

MAXIMUM ALLOWABLE WORKING PRESSURE: The maximum working pressure of a vessel rated in accordance with the API code under new and cold conditions.

MECHANICAL ORDER: A request submitted by the Process Department for mechanical repair work.

MECHANICAL SEAL: A mechanical device to seal the flow of liquid along a centrifugal pump shaft by using a fixed and rotating element of two different materials.

MELTING POINT: The temperature at which a given solid begins to liquefy; there are special test methods for wax, asphalt, grease, etc.

MENSTRUUM: The solvent used in an absorption process - specifically, at this refinery, in gas absorption. See Lean Oil.

MERCAPTANS: Organic compounds having the general formula R-SH, meaning that the thiol group -SH, is attached to a radical such as CH_3 or C_2H_5, etc. The simpler mercaptans have strong, repulsive garlic-like odors which become less pronounced with increasing molecular weight and higher boiling points. Reduce lead susceptibility of gasoline and promote gum formation in the presence of sulphur.

MERCURY NUMBER: The number of milligrams of corrosive sulphur present in 100 milliliters of petroleum oil, such as naphtha, when determined by a standard laboratory procedure.

METHOD OF STEEPEST ASCENTS: A method of experimental design which attempts to provide a sequential approach to the optimum response of the process being studied. In certain experimental areas the use of this method minimises the number of experiments to be performed.

MICROCRYSTALLINE WAX: Wax extracted from certain petroleum residues and having a finer and less apparent crystalline structure than paraffin wax.

MID-BOILING POINT: A term approximately equal to the point at which 50% of a material has distilled. There are, however, several specific definitions of the mid-boiling point and the term should be used only with a clear understanding of its meaning in the context.

MIDDLE DISTILLATES: Distillates obtained between kerosene and lubricating oil fractions in the refining processes. These include light fuel oils and diesel fuel.

MINERAL OIL: Any oil derived from a mineral source. Such oils include liquid products obtained from petroleum, shale, and coal.

MISTING: The entrainment of lean oil from the top of an absorber.

MOLECULAR SIEVE: A chemical, having a zeolite crystalline structure, capable of separating molecules based on their size and/or structure by adsorption and/or sieving.

MONEL METAL: Alloy of nickel with about 30% copper, having high corrosion resistance and strength equal to mild steel; used in condenser tubes etc.

MONOLITHIC LINING: An insulating liner with an erosion resistant surface, installed without joints inside lines or vessels. Consists of 3" of insulation underneath a 3/4" thick Hexsteel reinforced erosion resistant castable. The Hexsteel is supported on 3" high Nelson studs spot welded on approximately 10" centers to the line or vessel wall.

MONTE CARLO METHOD: A procedure, usually numerical, for securing pseudo experience on a physical process known to follow certain laws and certain distributions by randomly sampling from these distributions.

MOTOR STARTER An electrical device for starting motors with either magnetic or thermal overload protection. May be electrically operated for remote control or manual. Motors up to 7-1/2 HP are usually manually controlled. Must be used in conjunction with a circuit breaker or fused switch for short circuit protection. Undervoltage protection is standard where motor drops off line when voltage goes below 85%.

MULTICLONE: A device for separating catalyst from gas, which consists of a series of cyclone separators combined into one unit.

MUSHROOM VENT: An open vent with a weather shield in the shape of a mushroom which is used on atmospheric storage vessels to permit the vessel to breathe due to changes in temperature or pumping in or out.

NAPHTHA: A general term for light petroleum distillates, covers unfinished gasoline fractions as well as finished solvents.

NAPHTHA SLUDGE: An acid sludge resulting from the treatment of naphtha distillates. Cf. sludge.

NAPHTHENATES: The alkali and metal salts of naphthenic acids. They are used as paint driers and as preservatives for wood and textiles.

NAPHTHENE INDEX: The weight per cent of total carbon atoms actually in Naphthene ring structures in a petroleum oil.

NAPHTHENIC ACIDS: Carboxylic acids containing naphthenic radicals. They have a characteristic unpleasant odor and are used mainly for the preparation of naphthenates.

NAPHTHENIC HYDROCARBONS: Hydrocarbons in which the carbon-hydrogen groupings are arranged in the form of two closed rings and have an empirical formula of C_nH_{2n}.

NATURAL DRAFT: System in which air for combustion is drawn into a furnace by the hot flue gases rising up the stack.

NATURAL GAS: Hydrocarbon gas of variable composition occurring in nature either alone or in association with petroleum.

NEEDLE VALVE: A valve with a cone seat and needle point plug to control small and accurate flow of a liquid or gas.

NET RETURN: Monetary per cent return on investment after allowances have been made for depreciation and income taxes.

NET WORTH: An index frequently used to measure the overall money making ability of an organization is "return on net worth". It is, in effect, profit after taxes divided by shareholders' money tied up in the venture.

NEUTRALIZATION NUMBER: The weight in milligrams of the amounts of potassium hydroxide (KOH) required to neutralize the acid constituent in one gram of oil. The neutralization number of an oil is normally a measure of its organic acidity.

NON-SPARKING TOOLS: Tools for use in hazardous areas, made of bronze or an alloy of copper with about two percent beryllium.

CTANE: Any of the fifteen isomers of C_8H_{18}. The word octane is sometimes used to refer specifically to 2,2,4 trimethylpentane. See iso-octane.

CTANE NUMBER: A term numerically indicating the relative anti-knock value of a gasoline. It is based upon a comparison with the reference fuels iso-octane (100 octane number) and normal heptane (0 octane number). The octane number of an unknown fuel is the per cent volume of iso-octane with normal heptane which matches the unknown fuel in knocking tendencies under a specified set of conditions.

FFSET: A sustained deviation between the set point and the control point of a proportional controller.

FFSTREAM: The status of a unit which is shut down or operating without performing its process function. Examples of the latter would be the operation of a batch reactor during a regeneration cycle or a fluid catalytic cracking unit during startup.

FFSITE: An adjective designating the facilities that are geographically outside the regular operating unit boundaries.

OHMART CELL: An industrial radiation detector. It is commonly used in conjunction with a radioactive source such as Cobalt 60 or Cesium 137 for the measurement of fluid density or level.

OILINESS: Under certain conditions of lubrication, one lubricant may reduce the friction in a bearing more than a similar oil of the same viscosity and applied in the same way. The oil that reduces friction the most is "oilier" and is said to have a higher degree of "oiliness".

OKADEE VALVE: A quick opening valve used in liquefied gas service consisting of a handle-operated sliding disc that is held closed against a seat by the liquid pressure.

OLEFINIC HYDROCARBONS: These are straight chain hydrocarbons having the general formula C_nH_{2n} and containing a double bond or unsaturated linkage in the chain. They are appreciably more reactive than the paraffins or naphthenes and combine readily with elements such as hydrogen, chlorine and bromine.

OLEUM: Also known as fuming sulphuric acid. Has sufficient SO_3 dissolved to make it the equivalent of 104 1/2 percent H_2SO_4. It is sometimes referred to as 20 percent oleum, since 20 percent excess SO_3 over 100 percent acid requirements is present.

ONCE THROUGH: An adjective describing a continuous process in which no portion of the product is recycled.

ONSITE: An adjective designating the facilities located within a geographical boundary that usually constitutes an operating unit.

ONSTREAM: The status of a unit performing its process function.

ON-STREAM INSPECTION: The use of non-destructive testing techniques such as X-ray, Penetron and Audigage to determine the condition of refinery equipment while process units are operating.

OPERATING PLAN: The estimated operating plan. The pertinent information with respect to the operation of the refinery in any given period. For example, crude rate, product production, operating conditions, and product quality.

OPTIMUM REFLUX RATIO: The ratio between "total reflux" and "minimum reflux" that gives the most economical design for process equipment columns and auxiliaries.

ORIFICE MIXER: A pipe containing orifice plates, which are transverse sections having one or more holes in them. When two or more liquids are pumped through this device at the same time, intimate mixing is obtained.

ORIFICE PLATE: A steel plate with a sharp-edged circular restriction which is placed in a pipe to measure flow by the differential pressure created across the restriction. Also a steel plate with several openings used to increase contact between two immiscible liquids. For this purpose, several orifice plates are placed in series.

ORIFICE RUN: The minimum required length of pipe upstream and downstream of an orifice plate to assure smooth flow and accurate flow measurements.

OUTAGE: The distance from the surface of the liquid in a tank to the standard gauging point at the top of the tank.

OXIDATION: Chemical reaction in which oxygen combines with another substance (asphalt oxidation, gum formation, rusting).

PACKING: Material used to make pump or other glands pressure tight. Also the specially-fabricated filling in packed fractionating columns and absorbers.

PAN ROOF: A pie-pan type floating roof without pontoons which depends on the depth of the lip for its buoyancy.

PANTOGRAPH MACHINE: A machine that permits automatic flame cutting of pipe or sheet steel.

PANTOGRAPH SEAL: A device for sealing the void between the roof and shell of a floating roof tank.

PARAFFINIC HYDROCARBONS: The whole series of saturated aliphatic hydrocarbons having the general formula C_NH_{2N+2}.

PARAFFIN WAX: (As a Finished Product) Wax of very low oil content, highly refined, white, with some degree of translucency, almost tasteless and odorless. Setting points range from about 90°F. to 160°F.

PARTIAL CONDENSER: An exchanger, located in or near the top of a tower, which condenses a part of the overhead vapors so that they drop into the tower as reflux.

PENETRATION (of Bituminous material): The consistency of bituminous material expressed as the distance that a standard needle penetrates vertically into a sample of the material under known conditions of loading, time and temperature.

PENETRON: A non-destructive test instrument used to determine pipe and vessel wall thicknesses, liquid densities, liquid levels in vessels, and the interface of two immiscible liquids. The instrument is a calibrated Geiger-Mueller Counter which measures the amount of gamma ray absorption of the material being measured.

PENNSYLVANIA-GRADE CRUDE: Petroleum produced in Pennsylvania,New York, West Virginia and Eastern Ohio. Crude from this region generally contains a high percentage of excellent paraffin lubricating stock.

PETROLATUM: A soft, salve-like material obtained from petroleum oils, and consisting essentially of micro-crystalline waxes in association with substantial quantities of oil. It may vary in color from white to dark brown.

PETROLEUM: A liquid material occurring naturally in the earth, and consisting essentially of hydrocarbons, solid, liquid, and gaseous.

PETROLEUM COKE: Solid matter formed as a by-product of the thermal decomposition of petroleum. It consists mainly of carbon and has an ash content very much smaller than that of coal cokes.

PHYSICAL PROCESS: Any process not involving chemical reactions, e.g. distillation compression, solvent extractions, etc.

PIG: A jointed metal device forced through pipe lines by hydraulic pressure to scrap off rust and scale or to mark an interface between two different products. Also, a container, usually lead, to ship and store radioactive materials.

PIPE STILL: A primary distillation unit for use on petroleum oils to separate the various components having different boiling points. It consists essentially of a furnace containing banks of tubes and a fractionating tower with accessory equipment.

PITCH: The residuum from the distillation of crude petroleum. It is distinguished from tar which is the residuum from cracking operations.

PLANIMETER: A measuring device for determining the quantity flow recorded on a chart either mechanically or electrically by averaging the area inside of the flow curve.

PLANT AND EQUIPMENT BUDGET: A summary in book form of the Planned Capital Projects for the coming year. The Proposed Budget is prepared during the first half of the year. After reviews with our Management and the Parent Companies, the budget is adopted in December preceeding the Budget Year.

PLANT AND MATERIAL TRANSFER ADVICE (PMTA): A material requisition (issue slip) to withdraw material from the storehouse for construction or maintenance purposes.

PLATE EFFICIENCY: The extent to which the compositions of the liquid and vapor leaving a bubble-cap plate of a fractionating column or absorber approach equilibrium. This is usually expressed as a percentage, taking perfect

PLATFORMING: The oldest and most widely used fixed-bed reforming process employing a platinum catalyst.

PLENUM CHAMBER: A collecting chamber, used in catalytic cracking units to collect the gas and catalyst. Used in conjunction with cyclones for separating gas and catalyst.

PLOT PLAN: A scale geographical layout of operating equipment, piping, etc.

PLUG VALVE: A valve used mostly in gas service consisting of a rotating cylindrical plug in a cylindrical body with an opening running thru the plug.

PLUG WELD: A circular weld made by either arc or gas welding, through one member of a lap or tee joint joining that member to the other.

PODBIELNIAK: A low temperature fractional distillation apparatus for making quantitative determinations of the composition of mixtures of low boiling hydrocarbons.

POISONS: Any compound which causes a catalyst to loose activity. Such as:- arsenic, sulphur, oxygen and nitrogen compounds.

POLYFORMING PROCESS: A means for producing high quality motor gasoline by the thermal conversion of naphtha or gas oils at high temperatures and high pressures in the presence of recirculated hydrocarbon gases.

POLYMER: A compound formed by the joining together of two or more organic molecules in the process of polymerization.

POLYMERIZATION: The act of combining two or more unsaturated organic molecules to form products having same elements in same proportions but of higher molecular weight. Frequently used in petroleum refining to combine propylene and/or butylene molecules to form high quality gasoline components.

POSITIONER: (See Valve Positioner).

POSITIVE DISPLACEMENT METER: A flow metering device which measures the total volume of liquid passing through it on a volume displacement basis.

POT HEAD: A sealing device for terminating electrical cables, either single conductor or multi conductor.

POUR POINT: The lowest temperature at which oil will pour or flow when it is chilled without disturbance under prescribed conditions.

POUR POINT DEPRESSANT: An additive used in a lubricating oil to lower the pour point.

POWERFORMER: A fixed bed catalytic naphtha reformer to upgrade components by improving their octane rating.

REGENERATIVE TYPE: A unit in which the catalyst in one reactor can be regenerated while the rest of the unit is on stream.

SEMI-REGENERATIVE TYPE: A unit in which the catalyst is regenerated in place after several months operation while the unit is offstream.

NON-REGENERATIVE TYPE: A unit in which the catalyst is removed and returned to the manufacturer for reworking.

PRECISION: The spread of test results, or the difference between two or more determinations regardless of proximity to true value.

PRECOAT: Also called filter aid, is any material applied in a thin layer to the surface of a filter to improve its filtering efficiency. Diatomaceous earth is most often used.

PREFACTIONATOR: A flash vaporization tower with several fractionating trays in which gas, light naphtha, and water are removed from partially heated crude before it enters the pipe still furnace.

PREHEAT: To heat immediately before some treatment or use, as an oil which is to be subsequently distilled, or as a body of gas or oil that is about to be used as fuel.

PREHEATER: An exchanger used to heat a gas or liquid before putting it into an operating unit.

PREIGNITION: The premature ignition of a charge in a cylinder of an internal-combustion engine while the inlet valve is open or before compression is completed. This may be caused by red-hot carbon deposits, badly cooled spots in the cylinder head, or hot spark plugs.

PRESSURE DISTILLATE: The light, gasoline-bearing distillate product from the pressure stills which has been produced by cracking, as contrasted with virgin or straight-run stock.

PRESSURE REDUCING VALVE: A valve used to maintain a constant set pressure either upstream or downstream.

PRESSURE-VACUUM VENT: Venting device used on storage tanks to prevent the build-up of internal pressures or vacuum on the shell of the vessel.

PRIME CUT NAPHTHA: A synonym for virgin naphtha. Naphtha which has been produced in primary distillation and which has not been subjected to other refining processes - esp. cracking.

PRIME FUEL PRODUCTS: Refers to Petroleum Products as against Chemical Products.

PRIMING: Of boilers, the carryover of water with the steam.
Of pumps, the displacement of gas with liquid to obtain suction.
Of fractionating columns, the flooding of the trays or packing with liquid.

PROCESS FLOW PLAN: A simplified diagrammatic presentation of an operation showing the names of the products involved, the names of the equipment used, and the routing of the products through the equipment.

PROCESS LAG: Retardation or delay in response of a controlled variable at its point of measurement to a change in value of the manipulated variable.

PROCESS SPECIFICATION: (See Specification - Process).

PROCESS STOCK: Any petroleum fraction which is to be subjected to further manufacturing operations. The term is not applied to petroleum fractions which need only to be blended to become finished products.

PRODUCT GIVEAWAY: The difference between the minimum specification and the actual quality as shipped on any specification on any product.

PROGRAMMING: The designing of a series of coded instructions for the purpose of solving problems on a computer (See Computer Routine).

PROJECT BASIS MEMO: A memorandum which sets forth the basic design and economic information on a potential project. It will include reasons for the project, incentives, desired size, feed quality, project quality, location of the plant and possible alternates.

PROPANE: A saturated three carbon hydrocarbon gas, useful for heating and metal cutting and flame welding purposes. It can be stored under pressure as a liquid at atmospheric temperatures.

PUMP AROUND: A system on a distillation tower for withdrawing liquid from a plate, cooling it and returning it to another plate for the purpose of inducing the condensation of vapors.

PUMP OUT: (n.) Those lines and equipment whose sole purpose is to empty the tower or drums of oil and slop during shutdowns or emergencies. (v.) The act of withdrawing the liquid from the equipment by means of pumps.

PUMP OUT DRUM: (See Drum - Pumpout).

PURCHASE REQUISITION: A request for the purchasing department to procure material described therein.

PURGING: The displacement of one material with another in process equipment, frequently displacement of hydrocarbon vapors with inert gas.

PURLIN: The lateral supports in a roof structure that fasten to the rafters and support the roofing material.

PUSH BUTTON STARTER: Magnetically operated motor starter for remote control of motors contrasted with manual starters which are at the motor.

PYROLYSIS: The decomposition of a substance by means of heat.

QUALITY CONTROL PROGRAM: A program for assuring quality workmanship by verifying the satisfactory performance of the worker, on a statistically calculated basis, instead of checking the work itself. This type of program has been successfully applied to welding and painting work.

QUENCH OIL: Oil injected into the product leaving a cracking or reforming heater to lower the temperature and arrest the cracking reaction.

RADIAL DISTRIBUTION SYSTEM: An electrical system where each feeder radiates from a common center, with no external ties. This system is simple where overload and short circuit protection is elementary.

RADIANT BANK (OR SECTION): The tubes in a pipe-still or boilers which receive heat primarily by radiation from flames and hot brickwork; see also Convection Bank.

RADIOGRAPHIC TESTING: A non-destructive test method used to examine the interior of opaque material. Radiography makes use of gamma or X-ray penetrating radiation and radiation detectors such as X-ray film, fluorescent screens or geiger counters.

RADIOISOTOPES: An unstable isotope characterized by the emission of energy and/or mass from its nucleus.

RAFFINATE: In petroleum technology, a material which has been refined as compared with an extract, which is material removed by a refining agent.

RASCHIG RINGS: Tower packing consisting of small hollow cylinders with length equal to their diameter; may be made of metal, stoneware, carbon or other material.

RATE ACTION: (See Control Modes).

RATOSLEEVE: A high capacity variable area flow meter especially suited for dirty service.

REACTOR (ELECTRICAL): A coil of wire inserted in an alternating current circuit which limits the flow of current. It usually has no core and can be purchased for either indoor or outdoor installations. It passes the normal current but restricts the passage of high currents during short circuit conditions.

REACTOR (PROCESSING): The vessel in which all, or at least the major part, of a reaction or conversion takes place. In catalytic cracking, it is the enlarged space in which hot oil is contacted and cracked with the catalyst; in isomerization, it is the vessel containing catalyst in which the hydrocarbon is isomerized; in alkylation plants, it is the vessel containing emulsified acid in which most of the alkylation occurs, etc.

REBOILER: An auxiliary of a fractionating tower designed to supply additional heat to the lower portion. Liquid is usually withdrawn (or pumped) from the side or bottom of the tower; is reheated by means of heat exchange; and the vapors and residual liquid, separately or together, are re-introduced to the tower.

RECIPROCATING PUMP: A positive displacement type pump employing either pistons or plungers in the liquid cylinder end; they may be simplex (1 cylinder), duplex, or, in some cases, multiples. Simplex and duplex units are usually either steam or motor driven.

RECTIFYING SECTION: The part of a continuous fractionating column above the feed inlet.

RECYCLE GAS: A term applied to a hydrocarbon gas which is being returned to a unit for further processing.

RECYCLE RATIO: Ratio of the amount of product reprocessed to the amount of fresh charge in a recycle operation.

RECYCLING: The procedure of recirculating those portions of a feed stock which have passed unchanged through a refining process. The term is also used to describe the continuous returning of unwanted by-products to the process.

RED CONCRETE ENVELOPE: A red concrete envelope encasing electrical cable, conduit and duct banks for identification as a safety precaution. Green concrete is used for telephone cables.

REDUCED CRUDE: The designation given to the bottoms or residual liquid from the atmospheric pipe stills.

REFERENCE FUEL: Specifically blended fuels with definite octane or cetane numbers which are used in determining the octane or cetane numbers of a test sample of gasoline or diesel fuel.

REFINERY GAS: Any form or mixture of gas

[redacted]

gathered in a refinery from the various units.

REFLUX: In fractional distillation that part of the distillate which is returned to the fractionating column to assist in making a more complete separation into the desired fractions. The material returned is the reflux, the process is refluxing.

REFLUX RATIO: A term commonly applied in two different ways in connection with rectification problems, as follows: 1. In plant usage, when referring to the operation of equipment, the term most frequently denotes the quantity of reflux per unit quantity of distillate removed from the process as a product. Values may range from 1 to infinity. 2. For design purpose, the term is more logically taken as the ratio of liquid reflux to vapor at any given point in a rectifying column. Values may range from zero to unity.

REFORMING: Cracking of naphthas to obtain more volatile products of higher octane number. May be thermal or catalytic. Differs from other cracking only in using more volatile charge stock.

REFORMING YIELD: A measure of the gasoline yield as a percent of fresh feed on reforming. The percent yield and the quality of the gasoline are functions of the severity or intensity of the reforming.See yield.

REFRACTORINESS: The resistance to change which is shown by a petroleum fraction when it is subjected to a cracking process.

REGENERATION: Removal from the catalyst of coating contaminants, such as coke, by burning.

REGRESSION ANALYSIS: (See Correlation Analysis).

REID VAPOR PRESSURE: One of the important specifications for gasolines. It is a measure of the vapor pressure of a sample at 100°F. The test is commonly made in a bomb and the results are reported in pounds per square inch.

REINFORCING PAD: A plate placed around nozzle and manway openings to strengthen the shell of a drum, tower or tank.

REJUVENATION: The restoration of catalyst activity following regeneration by changing the catalyst back to its original form and chemical composition.

RELIEF VALVE: Safety device for automatic release of gas or liquid at a predetermined pressure.

REPEATABILITY: A measure of deviation of test results from their mean value, all determinations being carried out by one operator and without change of apparatus.

REPRODUCIBILITY: A measure of deviation of test results from their mean value, the determinations being carried out by different operators using apparatus generally understood to be located in different laboratories.

RERUNNING: Fractional distillation of an oil which has already been distilled - usually implies taking a large proportion of the charge overhead.

RESET: (See Control Mode).

RESIDENCE TIME: The period of time during which a petroleum fraction or catalyst remains in any specific piece of equipment.

RESIDUAL FUEL OIL: As used here, a petroleum product intended for combustion in large industrial installations composed principally of pitch and tar with enough lighter oil added to give an oil of satisfactory viscosity. In this refinery fuel oil never means heating oil, although in the trade at large it frequently does.

RESIDUAL STOCKS: Bottoms products from distillation, either primary distillation or distillation after cracking.

RESIDUE (RESIDUUM): The material remaining as unevaporated liquid or solid from processes involving distillation or cracking.

RESPONSE SURFACE: An equation for a response (dollars, yield, etc.) in terms of independent variables.

RETURN ON INVESTMENT: The yearly profit from a refining unit divided by the total investment; may be expressed as the return either before or after income taxes are deducted from the profit.

RICH OIL: Absorption oil containing dissolved fractions.

RING JOINT: A type of piping and valve joint for high pressure and temperature service consisting of matching concentric rings machined into the face of a flange into which a metallic ring is installed before bolting together to effect the seal.

RIPPLE TRAY: A trade name for a pierced corrugated fractionating tray.

RISER: A transfer line in a fluid solids system.

ROLL: The internal expanded section of a tube end which seals the tube to the tube sheet.

ROSS CARRIER: A four-wheeled vehicle with the body high in the air so designed to straddle a load on a pallet, lift it, and transport it as required.

ROTAMETER: A variable area flow meter.

RUN DOWN LINES: A pipeline connected to a petroleum processing unit which carries a product away from the unit to a tank.

RUN DOWN TANK: Tankage into which a unit stream is run.

RUNNING: Term used in the Petroleum Industry for the distilling of crude oil.

RUPTURE DISC: A rupture disc is a device calculated to fail at a specific pressure. It is used in lieu of a safety valve in installations where corrosion of the valves would be a serious problem and reseating is not essential.

SADDLES (WELDING): A type of fitting used to reinforce a pipe joint where a branch is welded directly into a main or header.

SADDLES (SUPPORT SADDLES FOR DRUMS): A concrete, brick, or metal drum-support formed to fit the curvature of the vessel. When the drum temperature is below 150°F a corrosion plate is installed between the drum shell and the concrete support.

SAFETY FUEL: A motor fuel with a flash point of 100°F or higher.

SAFETY VALVE: See relief valve.

SAPONIFICATION NUMBER: The number of milligrams of potassium hydroxide required to neutralize the free acids and saponify the esters in one gram of oil.

SAYBOLT CHROMOMETER: An instrument used to determine the color of refined petroleum oils, such as gasoline, kerosene and white oil.

SAYBOLT FUROL VISCOSITY: A viscosity test similar in nature to the Saybolt Universal Viscosity Test, but one more appropriate for testing high viscosity oils. Certain transmission and gear oils, and heavy fuel oils are rated by this method.

SAYBOLT, GEORGE M.: The inventor of the Saybolt Viscosimeter and the Saybolt Chromometer; an employee of the Standard Oil Company of New Jersey, now deceased.

SAYBOLT UNIVERSAL VISCOSITY: The time in seconds for 60 cubic centimeters of oil to flow through standard capillary tube in a Saybolt Viscosimeter.

SCAVENGING AGENT: A compound used to aid in the removal of lead compounds from the combustion chamber of an engine. Ethylene dibromide (scavenging agent) reacts with tetraethyl-lead during combustion to form lead bromide which is volatile and passes out the exhaust as a gas.

SCREW PUMP: A screw pump is a rotary positive displacement type pump usually applied when handling viscous liquids at high pressures, above the range of the ordinary gear pump. As the name implies, the pumping rotors are meshing screws running close clearance which progress from suction to discharge with trapped liquid to effect positive displacement.

SCRUBBING: The process of removing an impurity from a petroleum product. For example, the removal of hydrogen sulphide from a hydrocarbon gas.

SEAL FLUID: Generally a 50% solution of glycerine in water. Used to seal the lead lines of instruments against the fluid being measured.

SEAL POT: A pressure tight container interposed between a process line and a measuring instrument used as a reservoir for seal fluid.

SEAL WELD: Any weld used primarily to obtain tightness.

SECONDARY SELECTIVE: An electrical system where two sources of primary (high voltage) power feed two transformers and through secondary (low voltage) breakers feed two busses with a tie breaker. The station is operated with the tie breaker open. If one transformer fails the tie closes and the faulty secondary breaker opens thereby feeding both busses from the remaining operable transformer.

SEED COKE: Fine particles made in a fluid coking unit to replace the large particles withdrawn as product coke.

SELECTIVE POLYMERIZATION: The polymerization of a single type of molecule.

SEPARATOR: A large flat tank, generally set in the ground, through which refinery sewer water is poured to recover oil.

SERVICE FACTOR: A measure of the continuity of an operation generally expressed as the ratio of actual running time to calendar days.

SET POINT: The set or desired value of the controlled variable on a control instrument.

SETTLING PAN: A low tank of relatively large diameter used in the chemical treating of petroleum products for gravity separation into liquid layers.

SHED SECTION: The lower section of a fractionating tower consisting of shed baffles. Used normally in dirty or coking service, where the fluids may contain solids such as coke, catalyst or dirt, to desuperheat vapors and scrub out solids.

SHELL AND TUBE UNIT: A type of exchanger consisting of a cylindrical shell for one medium with a bundle of tubes inserted inside for the other medium.

SHINGLE LINING: A lining similar in construction to that of the overlapping wood shingles on a house. It affords protection to the material being lined in that it deflects the liquid away from the base material. This type lining is used within towers and drums.

SHORT RESIDUA: Low gravity bottoms or pitch from vacuum pipe stills.

SHUT DOWN: The procedure used to discontinue operations on a process unit on a regular or emergency basis.

SIDESTREAM: A liquid fraction drawn from an

[redacted]

intermediate bubble-tray in a fractionating column.

SINGLE FLASH: An adjective used to characterize fractionating towers which do not have reboilers. The feed stock is heated and released into the tower. The tower bottoms are not reheated and reflashed into the tower.

SKIMMER: A device for recovering the floating oil layer from a body of water.

SKIRT SHEET: A cylindrical steel support for vertical vessels.

SLAGGING: The formation of a coating on the outside of furnace tubes due to impurities in the fuel that is burned.

SLEEPER: A pipe line support, usually consisting of a concrete block on the ground with a steel member cast in the top to provide a small area of contact with the pipe, thereby minimizing rusting.

SLIDE VALVE: A type of valve consisting of a body with a large sliding disc usually in the horizontal plane which is actuated by a compressed air or hydraulic cylinder.

SLIGH OXIDATION TEST: A test for determining the oxidation resistance of oils.

SLIP-ON FLANGE: A type of pipe flange which is slipped over the pipe and then back-welded to the pipe.

SLOP OIL: Contaminated oil which has been recovered from a separator or other contaminated source. This oil must be redistilled before use in finished products.

SLUDGE: Sludge is used commonly in three separate senses - acid sludge, engine sludge, and tank sludge.

ACID SLUDGE:
A heavy, black, viscous, material of high specific gravity formed during the chemical refining treatment of oils by sulphuric acid, and usually separable by settling or centrifuging.

ENGINE SLUDGE:
The insoluble degradation product of lubricating oils and motor fuels, formed during their use in internal combustion engines and deposited from the oil on to engine parts outside the combustion space.

TANK SLUDGE:
Material which collects at the bottom of storage tanks. Such sludge usually contains a considerable amount of water.

SLURRY: A free-flowing mixture of solid and liquid; specifically, a suspension of cracking catalyst in cycle oil.

SMOKE POINT: A measure of kerosene burning cleanliness. It is expressed in terms of flame height in millimeters obtainable in a standard laboratory lamp before smoking is obtained.

SOAKER: In the thermal cracking process, a vertical cylindrical drum about four or five feet in diameter and forty feet high, designed for high pressure. This drum allows the hot oil to soak and react at a high temperature after leaving the coil. Most of the cracking occurs in this drum when it is used. In reference to thermal cracking the expression "coil only" means that no soaker is used. Coil-only cracking is common.

SODAFINING: The process of promptly soda-washing petroleum fractions, followed by inhibitor injection and air sweetening - esp. from catalytic cracking - before any exposure to air. Aromatic mercaptans can be removed by sodafining. If not promptly removed, aromatic mercaptans are oxidized to disulfides which are refractory to soda washing, and which are important contributors to poor stability.

SODAWASH: The process in which a petroleum distillate is treated with an aqueous solution of sodium hydroxide to remove acidic components usually those contributing to poor odor or poor stability.

"SOLUBLE" CUTTING OIL: A mineral oil containing an emulsifier which makes it capable of mixing easily with water to form a metal-cutting coolant.

SOLVENCY: The power of a substance to dissolve another substance.

SOLVENT NAPHTHA: Refined naphtha of high flash-point and restricted boiling range; used for dry-cleaning.

SOUR: Denoting a petroleum oil which contains odoriferous sulphur compounds, such as mercaptans.

SOUR GAS: Hydrocarbon gas containing undesirable sulphur compounds such as hydrogen sulphide and methyl mercaptan.

SPACE VELOCITY: A measure of the amount of oil which is contacted by a pound of catalyst or coke particles in one hour. To obtain the W/Hr/W, divide the pounds of oil charged per hour by the pounds of reactor holdup.

SPALLING: To crumble as occurs with the concrete lining in vessels.

SPARGER: A device to provide an even distribution of a gas or liquid over the cross-section of a tower usually in the form of a perforated or slotted pipe or disc.

SPARK ADVANCE: In a spark-ignited engine, a change in the timing so that sparking occurs earlier in the compression cycle.

SPECIFICATION:

DUTY:
A short statement which presents the basis for engineering, usually to an outside contractor. It will include feed and product qualities, heat and material balances and design information that might be unique.

JOB:
The combined process and mechanical specs which are used as the basis for contractors' bids.

MECHANICAL:
The detailed mechanical instructions that include materials of construction, specifications on painting, insulating, etc.

PROCESS:
A definitive design of the process equipment required for a project.

SPECIFIC CARBON BURNING RATE: The pounds per hour of carbon burned per pound of catalyst above the grid in the regenerator. This term is used in catalytic cracking.

SPECIFIC DISPERSION: A laboratory procedure for determining the separation, by the tested oil, of light into its colors. The test is used to characterize cracking feed stock.

SPECIFIC GRAVITY: The ratio of the weight of a given volume of substance to the weight of an equal volume of water for liquids and air for gases at the same specified temperature.

SPECTACLE BLANK: Sometimes called a "Figure 8 Blank". Made from steel plate in a figure 8 shape with one of the circles solid and the other circle open. When the line is in use the open end is placed between the flanges and when the line is to be blanked off the "Spectacle Blank" is reversed and the solid end inserted between the flanges.

SPHERICONE: A tank made in the shape of a teardrop and used as a settling tank in the boiler feed water treating process.

SPLASH PLATE: A plate placed in the path of a fluid stream and used to effect good stream dispersion and/or as a liner.

SPLITTER: A fractionating tower with an overhead stream and a bottoms stream only, no sidestreams. There are many such operations and this is a general term.

SPLITTER BOTTOMS: The bottoms stream from a splitter tower.

SPREAD: Normally refers to the difference in value of crude and the average value of all products obtained therefrom.

STABILIZATION: The removal from light naphtha of the more volatile components (H_2S is frequently an important, undesirable component) in order to hold the vapor pressure to a specified maximum.

STABILIZER: A unit of fractional distillation equipment for removing light hydrocarbons from an oil to reduce vapor pressure.

STANDARD DEVIATION: A standardized measure of the spread or dispersion of a set of numbers.

STANDPIPE: A vertical line or pipe used to transport catalyst down from a vessel and to provide a static head to the catalyst.

STARTING INRUSH CURRENT: The current needed to start a motor, usually 8 to 10 times normal running current, which may last from 6 to 18 seconds.

START-UP: The procedure used to start operations on a process unit.

STEAM CRACKING: High temperature cracking of hydrocarbons in the presence of steam.

STEAM DISTILLATION: Distillation in a current of steam of a liquid at a temperature below its normal boiling point.

STEAM EMULSION NUMBER: The number of seconds required for an oil to separate when emulsified and separated under definitely prescribed conditions.

STEAM TRACING: The application of small diameter steam filled tubing or pipe around the outside of other pipe, vessels, pumps, etc., which keeps the material therein warm.

STEAM TRAP: Device for automatically removing condensate water from a pipe or vessel under pressure, while preventing escape of steam.

STEARYL ALCOHOL: A saturated aliphatic alcohol having 18 carbon atoms.

STILL: Vessel in which liquids are vaporized.

STILLING WELL: A pipe installed vertically in a tank for gauging to eliminate the splashing and wave action effect on the gauge when pumping into the tank.

STIRRED REACTOR: Alkylation unit reaction vessel agitated by mechanical mixers.

STOCK: In general, any oil which is to receive further treatment before going into finished products. Used also, in a more restricted sense, to mean any oil which is finished as far as refining operations are concerned, but which must still be mixed, blended, or compounded with some other oil or rebranded before becoming a finished product; more properly spoken of in this sense as "finished stocks".

STORED PROGRAM: A feature which makes modern computers so powerful is the "stored program". The series of coded instructions of a computer routine are stored on a magnetic drum or core rather than on cards. Quick and random access can be had to stored instructions whereas in card programming the order of instructions is limited and the mechanical device for feeding the cards is slow.

STRAIGHT RUN: Synonym for virgin; an

adjective applied to a petroleum distillate which has been fractionated from petroleum but changed in no other way.

STREAM DAY: An operating day on a refinery unit, as distinguished from a calendar day. The term stream day is only used by manufacturers. Supply statements are always on a calendar day basis. If the word "day" is used with no suffix, calendar day is understood.

STRESS RELIEVING: A means of removing the stresses imposed in vessels or piping from welding by heating to a predetermined temperature followed by slow cooling.

STRESS RUPTURE: Is the tendency of a metal undergoing creep, usually at elevated temperatures to deform and ultimately fail under constant load.

STRIP CHART: An instrument roll chart to record variables. They are 3" - 4" and 12" wide with a maximum usable time of 40 days.

STRIP LINING: Liners in pressure vessel usually field installed in strip shape (rectangles 6" x 36") and lap welded in shingle fashion to the shell.

STRIPPER: Equipment in which the lightest fractions are removed from a mixture. In a natural-gasoline plant, gasoline fractions are stripped from rich gas. In the distillation of crude petroleum, light fractions are stripped from the various products.

STRIPPING: Substantially complete removal of the more volatile components from a mixture. Normally used in petroleum refining in order to raise the flash point of kerosine, gas oil, or lubricating oil, or to remove heavy "slop cut" from asphalt to improve its stain test. It is usually accomplished by passing the hot bottom or side cut from a flash drum or tower through a stripping vessel (or section) through which open steam or inert gas is passed, to sweep out the volatile components.

STRONG BACK: An improved mechanical aid used mostly by boilermakers to bend, straighten or align two plates for the purpose of welding.

STUB BUS: One of a group of electrical distribution busses tied together through tie breakers and reactors to a main synchronizing bus. Arrangement allows lower interrupting capacity equipment to be used on each stub than would be required if all equipment were tied to one large bus.

STUD BOLT: A continuously threaded bolt usually made of alloy steel and heat treated to meet ASTM specifications. They are threaded their entire length for maximum elasticity and strength which prevents failure at high temperatures.

STUFFING BOX: A stationary enclosure through which a rotating shaft passes designed to prevent fluid from leaking through. Stuffing boxes are used on pumps, agitators, etc., and contain either rings of packing fitted directly around the shaft or mechanical seals to prevent fluid leakage.

SUBMARINE CABLE: A copper cable with lead sheath and wire armor over all, designed for use under water, or direct earth burial.

SUB-ROUTINE: A computer routine which itself is a part of a larger computer program and which is referred to quite often in the solution of a problem. As an example, the development of the square root of a number is a small program inserted as a subroutine in a larger program used for calculating flows through orifices.

SUB-STATION: A convenient center for distributing secondary voltage power, usually in combination with a transformer in same building or site.

SULPHURIC ACID TREATING: An oil refining process in which unfinished petroleum products, such as gasoline, kerosine, diesel fuel, and lubricating stocks, are contacted with sulphuric acid to improve color, odor, and other properties.

SULPHURIZATION: The process of combining sulphur or sulphur compounds with petroleum oils, usually lube oil stocks. The resulting lubricant is chemically stable and has far greater film strength and load carrying ability than ordinary mineral oil.

SUMP: Pit or tank at a low level into which liquids can drain.

SUPERCHARGED ENGINE: One in which air supplied for combustion is boosted in pressure before intake to the cylinder.

SUPERFICIAL GAS VELOCITY: This is the rate at which gas would pass through a vessel in the absence of fluidized solids.

SUPERFICIAL VAPOR VELOCITY: The apparent velocity of vapor in a line or vessel neglecting the effect, for example, of catalyst carried along with the vapor.

SUPER HEATER: 1. An apparatus which imparts heat to a material above that required for vaporization. 2. An apparatus used for adding heat to steam above the saturation temperature.

SUPERVISORY CONTROL: Electrical equipment which permits the control of motors, motor operated valves, etc., from a remote location by means of coded pulses over telephone wires or by microwave radio relay facilities.

SURGE DRUM: A vessel used to provide reserve capacity in a continuous process.

SWAGE: Colloquialism used to indicate a change in piping size in the form of a reducer. This reducer is made from pipe which is deformed through heating and hammering (swaging or forging) to create a smaller size on one end of the pipe. On piping sketches swages are indicated as 4" x 2" Swage, 4" being the original size and 2" being the reduced size.

SW[illegible]: A [illegible]criptive term given to a petroleum fraction which is relatively free from odoriferous sulphur compounds such as mercaptans.

SWEET CRUDE: Crude petroleum oil containing so little sulphur as to render unnecessary any chemical treatment for the removal of sulphur or sulphur compounds.

SWEETEN: To improve the odor of a petroleum stream by removing the odoriferous sulphur compounds or by converting them to other non-offensive compounds, usually by oxidation. The method of sweetening most widely used is the Doctor Sweetening Process.

SWEETENING: In the chemical treatment of petroleum oils, the conversion of mercaptans to disulphides by some type of oxidation. The method of sweetening most widely used is the Doctor Sweetening Process.

SWING REACTOR: A reactor vessel which is provided with sufficient valving and piping so that it can take the place of any one of the normal reactors.

SWITCH CRIB: An enclosure (fenced) wherein circuit breakers and motor starters are mounted on a common rack. Equipment is energized from a bus which is fed from an incoming feeder from a switch house or sub station.

SWITCH GEAR: A group of related electrical equipment components in a housing. May be oil immersed or air break type. The equipment is designed to control the making and breaking of electrical connections and to provide for overload or short circuit conditions. Must be sized for voltage, current carrying capacity, short circuit interrupting capacity and for operation under different atmospheric conditions.

SWITCH HOUSE: A building which houses the equipment used to switch loads between primary electrical power transmission cables.

SYNCHRONIZING BUS: An electrical transmission bus common to several generators which keeps all generators feeding a system in synchronism. A generator must be synchronized before connection to a system. This bus permits feeders to be energized while one generator is disconnected.

SYNTHETIC CRUDE: The total, liquid multicomponent mixture resulting from a process involving molecular rearrangement of charge stock. Commonly applied to such products from cracking, reforming, vis-breaking, etc.

TAG-ROBINSON COLORIMETER: An instrument used to determine the color of petroleum oils. It has its own scale of color values.

TAIL: A term used in the petroleum industry [illegible] relatively high boiling material in a distill- [illegible] restricted boiling range, usually caused by poor fractionation.

TAIL GAS: The lightest hydrocarbon gas released from a refining process.

TANK BOTTOMS: The oil in a tank below the level of the suction line, which cannot be removed by normal pumping operations.

TANK FARM: Site upon which oil storage tanks have been erected.

TAR: The bottoms product from any cracking operation. It is usually 12 API gravity or less. Cf pitch.

TELEBRINELLER HARDNESS TESTER: A portable instrument which measures hardness in terms of the Brinell hardness system.

TELEMETERING: Transmission of a measurement over long distances, usually by electrical means.

TELL-TALE: A device used to indicate the amount of oil in a tank. Consists of a float which controls the movement of an indicator on a graduated scale on the outside of the tank.

TEMPERATURE CONSOLE: An arrangement of temperature indicating instruments normally in the form of a desk for operators scanning of unit temperatures.

TEMPERATURE INDICATOR: Used to indicate unit temperatures by means of a thermocouple at the source and an electrical receiving instrument

TERMINALLING: Storing in or sending products to a Marketing Department storage tank for future shipments to consumers.

TETRAETHYL LEAD (TEL): A chemical compound which increases the octane number and improves the anti-knock quality when added in small quantities to a fuel for spark-ignition engines.

THERMAL AFTERCRACKING: Thermal cracking of a hydroformed product due to soaking of re. the product at high temperature.

THERMAL CRACKING: The refinery process by which the breaking up of the molecules of heavier oil fractions into lighter fractions (esp. gasoline) is accomplished by application of high temperatures and pressures. Cf catalytic cracking.

THERMAL DEGRADATION: The reduced quality of a petroleum fraction resulting from overexposure to heat.

THERMAL ELECTRIC SYSTEM: A system for applying low voltage electrical energy heating to a pipeline for the purpose of keeping the oil in the pipe at a constant temperature.

THERMO COMPRESSOR: A piece of equipment which is designed to use the thermal properties of steam at two different pressures to economically provide steam at an intermediate pressure.

THERMOCOUPLE: An electrical temperature-measuring device consisting of two wires of different metals with the ends joined; when this junction is heated, an electromotive force is produced which is proportionate to the temperature. The temperature can be measured as a function of this electromotive force.

THERMOWELL: A tube, having one end closed, inserted into a vessel, pipe, or furnace as protection for a thermocouple or thermometer bulb.

THIEVING: The determination of the height of water at the bottom of a tank by the use of a water indicating paste film on the measuring tape. When the bob on the end of the measuring tape is dropped to the bottom of the tank, the indicating paste turns purple in the water, and the water height is observed on the tape. Taking sample from vessel with thieving device on end of gaging tape.

THIXOTROPY: Property of certain jelly-like substances to behave as liquids when agitated or stirred.

THROUGHPUT: The volume of feed stock charged to process equipment. Frequently, but not necessarily, per unit of time.

TOGGLE: The welding member which positions the return bend of a sectional type header box. In a square type header box, it is the member which holds either the deflector plug or the flat plug.

TOLERANCE: An allowable variation from a specified limit.

TOPPED CRUDE: Crude petroleum oil from which some of the lighter constituents have been removed by distillation.

TOPPING: A rough fractionation of crude petroleum to separate it into naphtha, heating oil, gas oil and bottoms.

TORPEDO: A flanged tapered tube, in the lower of the two tube sheets of catalyst separation multiclone assembly, which aids in the centrifugal separation of catalyst and transports the catalyst down from the multiclone assembly.

TOTAL ALKYLATE: Term for crude alkylate which is rerun to produce aviation alkylate and alkylate bottoms.

TOTAL CONNECTED LOAD: The combined power requirement of all the electrical equipment attached - whether or not it is in operation - to some power source. "Connected load" is distinguished from "operating load" which is kthe power requirement of the electrical equipment actually working and drawing current from the power source at any one time.

TOTAL FEED: The sum of the volumes of oil pumped into a processing unit from various sources. It includes recycled products as well as fresh feed. See fresh feed.

TRACER: A radioisotope which is mixed with a stable material. The radioisotope enables scientists to trace the material as it undergoes chemical and physical changes.

TRANSFER LINE: In a fluid solids system any line through which solids are being moved by gas.

TRANSMISSION LAG: Retardation or delay caused in transmitting a measurement of a variable from the primary measuring element to the controller.

TREPAN: A cylindrical core removed from a welded joint for examination of the welding.

TRIBUTARY AREA: That geographical area which should be supplied from a given distribution point when considering only transportation costs.

TRIM CONDENSER: A salt water exchanger placed in series with an air-fin cooler to further reduce and control the effluent temperature.

TRIMER: A polymer consisting of three molecules of any hydrocarbon that polymerizes, generally isobutylene.

TRUE BOILING POINT DISTILLATION: Method of determining the boiling range of petroleum oils by distillation under standard conditions; involves a higher degree of fractionation than the ASTM distillation. Often used for analysis of crude oil.

TUBE: A drawn metallic pipe of small diameter usually seamless, used in exchanger construction to provide a path for one of the mediums involved.

TUBE BUNDLE: A group of fixed parallel tubes, such as is used in a heat exchanger; the tube bundle includes the tube header with the tubes, the baffles and the spacer rods.

TUBE CLEANER: A device usually electric or air driven, which cleans the inside of furnace tubes by means of rotating cutters.

TUBE METAL TEMPERATURE: The metal temperature of a tube or pipe in a furnace usually determined by a thermocouple welded to the tube or pipe.

TUBE SHEET: A heavy metallic plate used in exchangers and boilers, into which the ends of tubes are rolled to provide support for the tubes and to provide a seal between the space outside of the tubes and the inside of the tubes. Also, in furnaces, the structural members which support the tubes.

TURBINING: Turbining is the cleaning of the inside of a furnace tube with an air-operated cutter.

TURN AROUND: Period in which an entire process unit is overhauled, inspected and repaired. Intervals vary with the types of processing equipment involved.

TURNKEY CONSTRUCTION: A plant that is engineered and constructed by a contractor without help from the customer. The customer is handed a key to the completed plant which will turn on the process.

UBBELOHDE VISCOSIMETER: A suspended level apparatus for accurately determining the kinematic viscosity in centistokes of a petroleum oil. The kinematic viscosity is converted to Saybolt Universal Viscosity by means of a table.

ULLAGE: The distance from the surface of the liquid in a tank to the standard gauging point at the top of the tank. Ullage is the same as outage.

ULTRA-VISCOSON: A plant type continuous viscosimeter of the vibrating reed type.

UNDERCUT: Refers to taking a lower final boiling point on a stock than is normal.

UNDERCUTTING: The fractionation of a virgin or cracked naphtha such that the 325-375°F or 400-430°F fractions are diverted from gasoline to heating oil in order to improve the volatility and octane number of the remaining gasoline fraction.

UNDERGROUND CABLE: Lead or neoprene jacketed electric cable installed in conduit or armored cable for direct earth burial, which is protected by a red concrete slab.

UNFIRED PRESSURE VESSEL CODE: ASME - Section VIII - Rules governing minimum requirements for design, fabrication and inspection during construction of unfired pressure vessels. Appendix X of this code provides a guide for inspection of vessels after they are in service.

UNIFLUX TRAY: A unique fractionating device that combines functional as well as mechanical features. The tray consists of individual "S" members interlocked to perform as a single unit.

UNILARM: A device with signal lights and audible alarm which indicates normal and abnormal conditions in flow, level, pressure, and temperature. It may also shut down equipment in an emergency.

VACUUM DISTILLATION: Distillation under reduced pressure. The boiling temperature is thereby reduced sufficiently to prevent decomposition or cracking of the material being distilled.

VACUUM LINE: A pipe line system for gathering hydrocarbon gases released from processes at low pressure and delivering them to compressors.

VALVE POSITIONER: An auxiliary servo device which enables precision positioning of a control valve stem. It is used in conjunction with a standard valve operator (such as a Diaphragm Motor). Its purpose is to overcome stuffing box friction and stem thrust caused by fluid pressure.

VANE: A device used to direct the flow of liquid or gases in ducts, cyclones, etc.

VAN STONE FLANGE: A type of pipe flange which is slipped over a light weight pipe, and held in position by flaring the pipe end. The flange bears against the flared portion of the pipe.

VAPOR: Strictly, any gas above its critical temperature. Generally used to designate a gaseous substance which can be at least partly condensed by moderate cooling or compression.

VAPOR DOME: An inflatable membrane used to reduce vapor losses from cone roof tanks.

VAPOR FRACTOMETER: A Gas Chromatograph.

VAPOR LOCK: A condition in the fuel system where excessive fuel vaporization interferes with the function of one or more of the components, usually either the fuel pump or the carburetor. Unseasonably high ambient temperatures, unusually volatile fuels, and poor design of the fuel system are among the more important factors contributing to vapor lock.

VAPOR PHASE CRACKING: A cracking process in which the conditions of temperature and pressure are so chosen that the oil remains in the vapor state during the cracking reaction.

VAPOR PRESSURE: The pressure exerted by the vapors released from any material at a given temperature, when enclosed in a vapor-tight container.

VARIANCE: The square of the standard deviation.

VARIANCE ANALYSIS: The technique for dividing an overall variance into components belonging to specific causes.

VENT: Pipe or opening to permit the escape of gas.

VIRGIN: Any oil which has not been subjected to cracking.

VIRGIN GAS OIL: The gas oil cut from the primary distillation, which has received no further treatment.

VIRGIN NAPHTHA: Naphtha which has been produced in primary distillation and which has not been subjected to other refining processes - esp. cracking.

VARNISH: Engine deposits derived primarily from contact between fuel combustion products and the lubricant. It is organic in nature, contains appreciable quantities of oxygen (up to 20%), and is readily soluble in organic solvents.

VISCORATOR: A plant type viscosimeter of the variable area meter type.

VISCOSITY: The measure of the internal friction or the resistivity to flow of a liquid. In measuring viscosities of petroleum products, the values of the viscosity are usually expressed as the number of seconds in time required for a certain volume of the oil to pass through a standard orifice under specified experimental conditions.

VISCOSITY BREAKING: A cracking process usually conducted at low cracking temperature (830°-870°F) to reduce the viscosity or pour point of a heavy, virgin fuel oil.

VISCOSITY INDEX: The viscosity index is an empirical number indicating the effect of change of temperature on the viscosity of an oil. A low viscosity index signifies a relatively large change of viscosity with temperature, and vice versa. By means of the viscosity index function, the steepness of the viscosity-temperature curve of the sample is interpolated between that of a Pennsylvania Oil (denoted as 100 VI) and that of a Texas Coastal Oil (denoted 0 VI), both of which reference oils have the same viscosity as the sample at 210°F.

VISTANEX: A trade name for polyisobutylene. The polymer is produced in commercial grades having molecular weights of 10,000 to 300,000.

VOLATILITY: The extent to which oils vaporize, also the ease with which a liquid is converted into a vaporous state.

WASHING: Process of contacting oils with solution, e.g., soda washing, etc.

WASTE-HEAT BOILER: A boiler using the heat from flue gases or heat exchangers.

WATER DISENGAGING DRUM: (See Drum - Water Disengaging).

WATER DRAW-OFF: The pipe near the bottom of a storage tank.

WATT-HOUR METER: A device which operates from the voltage and current components driving a gear train which registers kilowatts. Sometimes potential and current transformers must be inserted in the metering leads if the voltage and/or current to be measured are above a certain level.

WEARING RING: A ring used, especially in centrifugal pumps, separating rotating and stationary parts. Close clearance between the rings forms a throttle between high and low pressure areas within the pump. Capacity, head, and efficiency are all affected by changes in clearance between wearing rings.

WEAR PLATE: Sheet steel installed in lines or vessels to provide erosion protection. Formed to the contour of the line or vessel and normally positioned with clips. May be of stainless or carbon steel, usually 3/8" to 1" thick.

WEATHERED DISTILLATE: Pressure distillate from which the gases boiling below about 70°F have been allowed to evaporate.

WEATHERING: The loss of light material from a petroleum oil by evaporation due to exposure to the atmosphere.

WEEP HOLE: Small hole drilled in reinforcing pads of pressure vessel attachments to show leakage resulting from the failure of welds joining attachment and vessel.

WEIR: Wall or partition for maintaining a level of liquid; used in bubble trays and reboilers.

WELDNECK FLANGE: A type of pipe flange which is designed with the neck portion the same diameter as the pipe in order to permit welding the flange to the pipe and thereby provide a smooth internal surface.

WESTERN CRUDES: Crude oils of a paraffinic nature produced in the mid-continent sections of the United States. Lubricating oils made from these crudes are distinguished by many of the desirable characteristics of the Pennsylvania-type paraffin crudes, but to a somewhat lesser extent.

WESTPHAL BALANCE: A balance in which the buoyancy of a float is balanced by sliding weights. It is used for determining the specific gravity of liquids, mineral fragments, etc.

WET GAS: A gas containing a relatively high proportion of hydrocarbons recoverable as liquids.

WHITE OILS: Generic name applied to highly refined, colorless, hydrocarbon oils, of low volatility, and covering a wide range of viscosities. They are widely used for the lubrication of food and textile machinery.

WHITE PRODUCTS: An obsolescent term applied to the more volatile petroleum products, such as gasoline and kerosene. Its use should be avoided since it can be so easily confused with "white oils".

WORKING PRESSURE: Maximum pressure at which equipment may be safely operated under specified conditions of temperature, etc.

X-RAY: Highly penetrating radiation similar to gamma rays. Unlike gamma rays, X-rays do not come from the nucleus of the atom but from the surrounding electrons. They are produced by electron bombardment.

YIELD: The amount of a desired product (frequently naphtha) or products obtained in a given process expressed as a percentage of the feed stock. There are many "yields" each of which should be specifically defined when used.

ZYGLO: A device used for the detection of defects where visual inspection by ordinary means is difficult. A fluorescent penetrant and ultra-violet light are used to reveal surface defects.

SHb-203

ABBREVIATIONS & SYMBOLS

A. C. S.	- American Chemistry Society
A. I. Ch. E.	- American Institute of Chemical Engineers.
A. I. E. E.	- American Institute of Electrical Engineers.
A. P. I.	- American Petroleum Institute
A. S. C. E.	- American Society of Civil Engineers.
A. S. M. E.	- American Society of Mechanical Engineers
A. S. T. M.	- American Society of Testing Materials
B. S. +W.	- Bottom sediment + water (See Definition)
B. t. u.	- British thermal unit (See Definition)
C. D.	- Calendar day
C. F. R.	- Coordinating Fuel Research
C. F. R.	- Capital Funds Request (See Definition)
C_n^4	- Normal hydrocarbon
C. P. C.	- Card programming calculator (650 C. P. C.)
ΔP	- Differential pressure (dp)
DIP	- Di-isobutyl phenol
DIPS	- Di-isobutyl phenol sulphide
D+L	- Distillation + loss
d/p	- Differential converter (See Definition)
F. B. P.	- Final boiling point
F. O. E.	- Fuel oil equivalent (See Definition)
g. p. m.	- Gallons per minute
I. B. P.	- Initial boiling point
$iC_4 =$	- Isobutylene
IPY	- Inches per year (See Definition)
LPG	- Liquefied petroleum gas
M	- Thousand
$\overline{M}$ or MM	- Million
MEK	- Methyl ethyl ketone
MOV	- Motor operated valve
MTC	- Manufacturing Technical Committee
N. A. C. E.	- National Association of Corrosion Engineers
NP	- Nonyl phenol
NPS	- Nonyl phenol sulphide
P. B. M.	- Project basis memo (See Definition)
P. C. Naphtha	- Prime Cut Naphtha
pH	- Symbol for degree of acidity (0-7) or Alkalinity (7-14)
P. O. P.	- Professional Orientation Program
p. p. m.	- Parts per million
r. p. m.	- Revolutions per minute
R. V. P.	- Reid vapor pressure
S. A. E.	- Society of Automotive Engineers
SBOH	- Secondary butyl alcohol
S. D.	- Stream Day
T. C.	- Technical Committee
T. E. L.	- Tetra-ethyl lead
U. S. P.	- United States Pharmacopoeia
V. G. O.	- Virgin Gas Oil
V. L. P. C.	- Vapor Liquid Partition Column (Chromotography)
W/Hr/W	- Pounds of oil per hour per pound catalyst hold up in reactor
705 E. D. P. M.	- I. B. M. 705 Electronic data processing machine

APPENDIX B.

COMMONLY-USED REFINING TERMINOLOGY

Alkylate: The product obtained by the acid catalyzed coupling of light olefins, usually propylene and butylene, with isobutane. Alkylate is a high octane gasoline blending component.

Amorphous fluid cracking catalyst: An amorphous catalyst, as defined in catalytic cracking, is one which contains no crystalline molecular sieves. It generally shows no measurable crystallinity by X-ray diffraction.

Aniline Point: The temperature at which a 50/50 mixture of the sample and freshly distilled aniline become miscible. Usually correlates with aromatics content – the lower the temperature, the more aromatic the sample.

°API Gravity: Unit of weight.

API Gravity = (141.5/(Specific Gravity 60/60°F)) - 131.5.

API Gravity is an indication of the premium fuel product potential of a crude; therefore, the higher the API, the higher the H/C ratio and hence, the more valuable the crude

Apparent Bulk Density: The apparent bulk density of a catalyst sample is the partially aerated weight of the sample divided by the volume of the sample. This is determined by pouring a sample of catalyst through a standard funnel into a tared graduated cylinder and immediately weighing without further compacting.

Barrels: Unit of measurement - there are 42 gallons in a petroleum barrel.

BPSD: Barrels per stream day.

BPCD: Barrels per calendar day (Barrels per year/365).

Battery Limits: The periphery of the area surrounding any process unit.

Bitumen: That portion of petroleum, asphalt and tar products which will dissolve completely in carbon disulfide, CS_2.

Blocked Operation: Operation of a unit, *e.g.*, a crude unit, under periodic change of feed or internal conditions in order to obtain a required range of raw products. Blocked operation may be required to meet critical specifications of finished products, *e.g.*, lubes, selected types of coke, *etc.*

Bottoms: In general, the higher boiling residue which is removed from the bottom of a fractionating column.

Bright Stock: Heavy (high viscosity, from vacuum tower bottoms) lube oils from which asphaltic compounds and waxy paraffins have been removed. Bright stock is a feed to a lube oil blending plant.

Bromine Number: A test which indicates the degree of unsaturation in the sample.

Bunker Fuel Oil: The heaviest fuel oils sold, often used to "bunker" ships or as power plant fuel.

C/O (Catalyst-To-Oil-Ratio): The weight ratio of the catalyst circulation rate to the combined feed rate. A measure of the number of effective catalytic sites each oil particle is exposed to; hence severity of catalytic action. Usually considered to be a dependent variable.

Catalyst: A substance that enhances a chemical reaction without itself being chemically changed.

Cetane Index: An approximation of cetane number based on API gravity and mid-boiling point (API Gravity x 50% TBP).

Cetane Number: A measure of the ignition quality of a diesel fuel, relative to that of a standard reference fuel. Higher numbers indicate better quality over the range of about 30-65.

Clay Treating: An elevated temperature and pressure process usually applied to thermally cracked naphthas to improve stability and color. The stability is increased by the absorption and polymerization of reactive polyunsaturates, traces of condensed aromatics, *etc.* in the cracked naphtha.

Cloud Point: A standard laboratory test which measures the temperature in °F at which an oil sample develops a haze from solid waxy crystallites. A rough indicator of wax content.

Coke: A mixture of high-molecular weight, hydrogen-deficient polymers and carbon formed in the reactor, plus any unstripped oils present on the catalyst as it enters the regenerator.

Conradson Carbon Residue (CCR): The weight percent of carbonaceous material remaining after a standard laboratory destructive distillation of the sample. CCR is an indication of the heavy fuel oil and asphalt potential of crudes. A value of about 0.25 or lower usually indicates a feed that has a low coke forming tendency.

Condensate: The liquid produced when hydrocarbon vapors are cooled.

Contaminants: Heavy metals (Ni, Cu, V, Fe), sulfur, nitrogen and oxygen are naturally occurring contaminants in crude oil.

Cracking: The breaking down of higher molecular weight hydrocarbons to lighter components by the application of heat. Cracking in the presence of a suitable catalyst produces an improvement in the product yield and quality over simple thermal cracking.

Cut: Same as fraction. Boiling temperature range of a product.

Cycle Oils: Middle distillate oils available for, but not necessarily used as, recycle in FCC for further processing.

Cylinder stock: Viscous petroleum oils obtained as residues in the distillation of crude petroleum. Used for preparation of bright stock and steam cylinder oils.

Deasphalted Oil (DAO): Heavy distillate, such as vacuum bottoms, which has been solvent extracted for removal of high molecular weight (asphaltic) compounds and metal contaminants. Often the solvent is propane, and the product is known as Propane Deasphalted Oil (PDA oil). Propane deasphalting, also called Propane Decarbonizing, is often used to increase the feed to a cat cracker by removing the paraffinic material from vacuum bottoms and including it in cat cracker feed.

Decanted Oil (DO): The clear overhead product that is decanted from the fractionator bottoms in the slurry settler of an FCC unit. Slurry settler bottoms, containing catalyst fines are continuously recycled to the FCC reactor. Decanted oil is normally blended or sold directly as heavy fuel oil. DO is also termed clarified slurry oil (CSO).

Deep-Hydrogenation: Very high pressure hydrogenation which hydrogenates significant amounts of aromatics to their corresponding naphthenes.

Desalting: A process for removal of brine from crude oil (usually an electrolytic settling system) prior to primary distillation.

Dewaxing: The removal of wax from lubricating oils, by chilling and filtering, by a solvent process, or catalytically.

Diesel Fuels: Light fuel oils, usually boiling in the range of 375-650°F, with specifications on cleanliness, ignition quality, low-temperature fluidity and volatility.

Diesel Index: An approximation of the cetane number of diesel fuel. DI = (Aniline Point x API Gravity)/100. Higher numbers are indicative of better burning quality.

Doctor Test: A method for determining the presence of mercaptan sulfur in petroleum products. This test is used for products in which a "sweet" odor is desirable for commercial reasons, especially naphthas.

Dry Gas: H_2, C_1, C_2 product - usually used as fuel gas.

End Point: Upper temperature limit of a distillation.

Endothermic Reaction: A reaction in which heat must be added to maintain reactants and products at a constant temperature. Cracking and reforming reactions are endothermic.

Exothermic Reaction: A reaction in which heat is evolved. Alkylation, polymerization, oxidation, and hydrogenation reactions are exothermic.

Equilibrium Catalyst: The circulating catalyst in the fluid catalytic cracking (FCC) unit is termed "equilibrium" catalyst. In a strict sense it is not at "equilibrium" until it reaches a consistent level of activity, surface properties and metals on catalyst, as controlled by the regular fresh catalyst addition rate and equilibrium catalyst removal rate (losses and withdrawals).

FBP: The final boiling point of a cut in Fahrenheit degrees, usually on an ASTM distillation basis.

Fixed Bed: A static bed of catalyst particles, *e.g.* beads, extrudates, *etc.*

Fixed Carbon: The organic portion of the residual coke obtained on the evaporation to dryness of hydrocarbons products in the absence of air.

Flash Point: Standard laboratory test that measures the oil temperature at which the vapor above the sample will flash if subjected to a flame.

Fluidized Bed: A bed of catalyst aerated to or just above the point where all particles are in free but suspended motion in the aerating medium.

Free Carbon: The organic matter in tars which is insoluble in carbon disulfide, CS_2.

Freeze Point: Temperature at which a liquid solidifies, *i.e.*, hydrocarbon crystals are formed.

Fresh Catalyst: Unused catalyst as purchased from the manufacturer.

Fuel Oils: Any of a large number of heavier distillate products, usually boiling above 430°F.

Fuel Oil Equivalent (FOE): The heating value of a standard barrel of fuel oil, equal to 6.05×10^6 B.T.U. On a yield chart, dry gas and refinery fuel gas are usually expressed in FOE barrels.

FVT: The final vapor temperature of a cut, in Fahrenheit degrees. Boiling ranges expressed in this manner are usually on a crude assay true boiling point basis.

Gas Oil: That material boiling within the general range of 330-750°F. This range usually includes kerosene, diesel fuel, heating oils, and light fuels oils. Actual initial and final cut points are determined by the specifications of the desired products.

Gasoline: Usually the cat-cracked product boiling in the range of C_5-430°F (TBP). Also called "Debutanized Gasoline" or "Stabilized Gasoline." May also be expressed as cut to other end points or to a 10# Reid vapor pressure gasoline.

Gum: Heavy polymers or resins formed in light petroleum products during heating or exposure to oxygen in storage. A variety of standard laboratory tests are used to measure gum-forming tendencies of petroleum products.

Hard Facing: An extra hard material (metal or ceramic) used in critical areas, such as FCC slide valves, to decrease wear and extend run times.

Heart Cut Recycle: That unconverted portion of the catalytically cracked material which is recycled to the catalytic cracker. This recycle is usually in the boiling range of the feed and by definition, contains no bottoms. Recycle allows less severe operation and suppression of the cracking of desirable products.

Heavy Cycle Oil (HCO): Usually refers to the 650°F$^+$ gas oil recycled to the cat cracker. Can also be taken to a heavy fuel product, such as No. 6 (industrial).

Heavy Virgin Naphtha (HVN): Naphtha distilled directly from the crude, usually fed to catalytic reforming for octane improvement. The usual boiling range is 200-410°F.

Hydrogenation: A high pressure, high temperature catalytic process for sulfur and nitrogen removal and saturation of olefinic or aromatic bonds.

Hydrogen Transfer: An intermolecular transfer of hydrogen — usually via hydride ions. A typical example is the transformation of olefins — in the presence of a strong acid catalyst — into hydrogen-rich paraffins and hydrogen deficient products such as aromatics and coke.

IMP: Initial boiling point of a cut, usually on an ASTM distillation basis.

IVT: Initial vapor temperature of a cut in Fahrenheit degrees, usually based on a crude assay distillation.

Isomerate: The product of an isomerization process.

Jet Fuels: Light to middle distillate products. Most grades include material boiling in both the gasoline and kerosene range (160-450°F) and have specifications relating to burning quality, freezing point and gum formation.

Kerosenes: Middle distillate products usually boiling in the range of 350-500°F with specified burning properties.

Kinematic Viscosity: A measure of a fluid's resistance to flow. Determined by measuring the time it takes a fixed volume of fluid to flow through a capillary tube.

Light Cycle Oil (LCO): A product from the cat cracker boiling in the range of approximately 430-650°F. LCO is usually blended into No. 2 domestic heating oil and diesel fuels.

Light Ends: Light gaseous products, usually C_4 and lighter compounds.

Light Virgin Naphtha (LVN): A light solvent-type naphtha distilled from the crude, usually boiling about C5-215 F. May be used as a solvent or included in the gasoline pool following desulfurization. Usually has a relatively good octane.

Lining: A protective coating on equipment internals, used to minimize the effects of erosion or heat (see Refractory).

Liquefied Petroleum Gas (LPG): C_3, $C_3^=$, C_4, $C_4^=$ or mixtures of these; stored under moderate pressure to ensure liquidity; clean burning fuel.

Mid Boiling Point: That temperature, usually based on a crude assay distillation, at which one-half of the material of a cut has been vaporized.

Mid Per Cent Point: The vapor temperature at which one-half of the material of a cut has been vaporized. Mid per cent point is often used to characterize a cut in place of temperature limits.

Middle Distillates: Atmospheric crude unit cuts boiling in the range of 300-700°F. The exact cut is determined by the specifications of the products.

Motor Octane Number: Indicates the knocking characteristics of gasoline as determined in a laboratory Cooperative Fuel Research (CFR) engine by a standardized test method (ASTM Manual of Engine Test Methods). The motor test method can be conducted in the same laboratory engine as the research test method (See Research Octane Number) by making certain adjustments to the motor. Different operating variables are employed in the motor method including a higher engine speed of 900 rpm (*vs.* 600 rpm). For a description of the general test method used in both tests and differences in the levels of octane, see Research Octane Number.

Naphthas: Any of an enormous number of light petroleum distillates, usually in the boiling range of C_5-450°F.

Naphthenes: A general term applying to any of the cyclic, saturated compounds found in petroleum; cycloparaffins.

Neutralization Number: The quantity of acid or base which is required to neutralize all basic or acidic components present in a specified quantity sample. This is a measure of the amount of oxidation that has occurred to a product while in storage or in service.

Octane Number: A measure of the antiknock properties of a gasoline, relative to that of a standard reference fuel.

Overcracking: Cracking of hydrocarbon molecules beyond the degree desired.

Penetration (Asphalt): Method for determining the consistency of asphalt. A weighted needle is positioned at the surface of the sample and allowed to penetrate, by gravity, for a specified time. The penetration is measured in tenths of a millimeter. 0=Hard, 250=Soft.

Pipestill: A heater or furnace containing tubes through which oil is pumped while being heated or vaporized. Pipestills are fired with waste gas, natural gas, or heavy oils, and by providing for rapid heating under conditions of high pressure and temperature, are useful for thermal cracking as well as distillation applications.

Plug Flow: Catalyst or fluids moving concurrently at equal velocities or at least with a relatively flat velocity profile.

Polymer Gasoline: The product obtained by the acid-catalyzed polymerization of light olefins ($C_3^= + C_4^=$). Although a simpler process than alkylation, the product is only about 80 octane. It is not currently used, therefore, where alkylation capacity permits better use of light olefins.

Polymerization: The combination of two or more molecules to form a molecule of higher molecular weight. Propylenes and butylenes are the primary feed material for refinery polymerization processes which use solid or liquid phosphoric acid catalysts.

Pore Volume: The void volume in an individual microsphere of catalyst. The pore volume is usually determined by either nitrogen adsorption or by water saturation and is reported in cubic centimeters per gram.

Pour Blending Index (PBI): An empirical quantity related to pour point which allows volumetric blending of pour points of various blend components. This method of blending is most accurate for blending of similar fractions of the same crude.

Pour Point: A standard laboratory test which measures the estimated temperature at which a cooled oil sample will still move or "pour". Pour point is 5°F higher than the temperature the sample stops flowing. A rough indicator of wax content.

Raffinate: The residue recovered from an extraction process. One extraction process is the SO_2 extraction of raw kerosene. The SO_2 raffinate is relatively free of aromatics and other impurities which have poor burning characteristics. Furfural extraction to produce lubestocks is another extraction process.

Reconstituted Crude: A crude to which has been added some other specific crude fraction for the purpose of meeting some product volume unattainable with the original crude.

Reduced Crude: A crude whose API gravity has been reduced by distillation of the lighter lower boiling constituents, *i.e.*, an atmospheric resid.

Reformate: Product from a catalytic reformer, usually a 90-105 octane aromatic naphtha boiling in the gasoline range. Specific reforming processes often add their trade name to the product.

Refractory: Insulation placed on the insides of vessels to prevent damage by high temperatures.

Refractory Feed: A feed that is difficult or impossible to crack catalytically. Recycle to the cat cracker is more difficult to crack than the fresh feed, hence it is a refractory feed. Polynuclear aromatics are examples of refractory molecules.

Reid Vapor Pressure: A laboratory test which measures the vapor pressure of a naphtha, usually gasoline, at 100°F. Important for starting characteristics of motor fuels, safety in transport and storage, and tendency to cause vapor lock in gasoline feed systems.

Research Octane Number: Measrues the knocking characteristics of gasoline as determined in a laboratory Cooperative Fuel Research (CFR) engine by a standardized test method (ASTM Manual of Engine Test Methods). Both the research test method and the motor method (See Motor Octane Number) use the same motor but certain adjustments must be made to the motor to comply with each test. Also, different engine operating variables are used for each test; for example, the motor speed used in the research test is 600 rpm compared to 900 rpm in the motor test. The octane number of a gasoline sample is found by blending n-heptane (0 octane) and isooctane (100 octane) in the proper proportions to produce the same knock intensity in the motor as the sample. The percent of isooctane in the blend is then taken as the octane number. Generally, higher octane numbers are found by the research compared to the motor method for the same gasoline sample. Increased differences in octane are found by the 2 methods when large proportions of olefins and aromatics are contained in the gasoline.

Residuum (Resid): The heavy, high boiling material remaining after a distillation (can refer to product of atmospheric or vacuum distillation).

Road Octane Number: The road octane number of a gasoline is determined in specially equipped automobiles for this purpose under actual road conditions. Actual road testing is the best way of obtaining the true knock characteristics of the gasoline. It has been found that the road octane number correlates much more closely to the motor octane number than the research octane. For example, Riegel of Du Pont reported the following:

1970 Cars – Automatic Transmission
Road Octane = 0.208 R + 0.792 M + 4.01
R = Research Octane   M = Motor Octane

Selectivity: The term selectivity is applied to describe the ability of a catalyst to optimize desired yields. For example, in FCC, a catalyst having "good selectivity" means one that produces high gasoline yields, low coke yields and low gas yields (currently desirable products). The catalyst is then said to have good gasoline, coke and gas selectivity. Certain catalysts may also be described as being "light olefin selective," meaning they enhance yields of $C_3^= + C_4^=$ for alkylation feed.

Sensitivity: The difference between the unleaded "research" octane number and the unleaded "motor" octane number of gasoline or its components (*e.g.* alkylate, reformate, *etc.*) is called sensitivity. Gasoline high in olefin content has a high sensitivity.

Service Factor: A quantity which relates the actual on-stream time of a unit to the total time available for use. Service factors include both expected and unexpected unit shutdowns.

Severity: The degree of intensity of the operating conditions of a process unit. This usually can be related to temperature/time exposure. Severity may be indicated by research octane number of the product, per cent yield of the product, or operating conditions alone.

Slack wax: The wax extracted from light to heavy neutral lubes by solvent dewaxing.

Slurry Oil: The FCC's fractionator bottoms oil/catalyst slurry that is recycled from the bottom of the slurry settler to the reactor riser. The catalyst is concentrated as it settles in the bottom of the slurry settler. Often a slip stream of HCO is used as an aid in flushing the concentrated fines slurry to the riser.

Smoke Point: The point is measured in a kerosene lantern type apparatus. A reservoir of fuel is fitted with a wick that can be cranked up or down to vary the flame size and wick length. The smoke point is a measure of how far the wick can be cranked up before the smoke is visible above the flame. The smoke point is equal to wick length in millimeters. Smoke point is an indication of aromaticity of oils, *i.e.*, the lower the smoke point, the more aromatics in the sample.

Softening Point: Temperature at which an object with standard weight and shape will start to sink into asphalt.

Sour or Sweet Crude: a rather general method for classifying crudes according to sulfur content.

Sour Crude: a crude which contains reactive sulfur in amounts greater than 1%; a crude which contains 0.05 cu. ft. or more of hydrogen sulfide (H_2S) per 100 gal., except West Texas crude, which is always considered sour regardless of its hydrogen sulfide content; a crude oil containing hydrogen sulfide and other sulfur compounds. Arabian crudes are high sulfur crudes which are not considered sour because they do not contain highly reactive sulfur compounds.

Space Velocity (Volume): The vol./hr. (at constant conditions) of feed to a reactor, divided by the volume of catalyst in the reactor. Abbreviated as V/Hr./V or VHSV. Usually used as a variable in fixed bed processing, such as reforming or hydrotreating.

Space Velocity (Weight): The lbs/hr of total feed (fresh feed plus recycle) divided by the total pounds of catalyst holdup in the reaction zone. Abbreviated as W/Hr./W or WHSV.

Specific Gravity: Weight of the compound/Weight of water at the same temperature.

Spindle Oil: Low viscosity lubricating oil for lubrication of relatively high speed machinery.

Stability (Catalyst Stability): The ability of a catalyst to withstand the physical and chemical deactivation that occurs during use. The type of stability is usually specified; *i.e.*, thermal or hydrothermal stability.

Straight-Run: A virgin material cut directly from the crude, without intermediate processing. A straight-run naphtha (SRN) and a virgin naphtha are synonymous.

Surface Area: The total surface area of a catalyst sample, including the area inside the pores. The surface area is determined by nitrogen adsorption and is reported in square meters per gram.

Sweet Crude: as evident from the definitions of sour crude, a sweet crude contains little or no dissolved hydrogen sulfide and relatively small amounts of mercaptans and other sulfur compounds.

Sweetening: Any of the many processes that remove sulfur from petroleum products.

Tail Gas: light gases, C_1-C_3 and hydrogen, produced as a by-product of refinery processing.

Theoretical Plate: a theoretical contacting unit useful in distillation calculations. Vapors and liquid leaving any such unit are to be in equilibrium under the conditions of temperature and pressure which apply. An actual fractionating tray or plate is generally less effective than a theoretical plate. The ratio of the number of theoretical plates required to perform a given distillation separation to the number of actual plates used gives the tray efficiency of the fractionator.

Thermal Cracking: A high temperature, non-catalytic cracking process, now used only to a minor extent.

Topping: removal of the light products from crude oil by distillation (usually through gasoline boiling range), leaving in the bottoms product all heavier constituents.

Torch Oil: Torch oil (often No. 6 fuel oil or hot decanted oil when available) is primarily burned to heat the catalyst in the FCC regenerator to the proper temperature during start-up, before feed introduction. In some cases, however, it is used on a continuous basis as a means of supplying heat to the system in order to maintain a desired regenerator temperature (and/or reactor temperature and catalyst circulation rate). This practice always causes some thermal deactivation of the catalyst, and if the torch oil is not properly dispersed through spray nozzles, the total unit inventory can be badly and permanently damaged.

Treat Gas: light gases having a high hydrogen content which are used in refinery hydrotreating processes such as catalytic reforming and hydrodesulfurization. The treat gas for hydrodesulfurization is usually off-gas obtained from catalytic reforming.

True Boiling Point (TBP) Distillation: A multiple-plate, high reflux laboratory fractionation, which actually measures the true boiling points of the components contained in an oil sample. Often requires a vacuum distillation with temperatures corrected to atmospheric pressure.

Tube Still: see Pipestill.

Vapor Pressure: A measure of a liquid's volatility. It is the pressure that must be kept on a liquid to keep the liquid from vaporizing.

Virgin Products: Those products separated from the crude oil by distillation only.

Viscosity: the property of liquids which causes them to resist instantaneous change of shape or instantaneous rearrangement of their parts due to internal friction. Viscosity is generally measured as the number of seconds, at a definite temperature, required for a standard quantity of oil to flow through a standard apparatus. Common viscosity scales in use are Saybolt Universal, Saybolt Furol, Kinematic, Absolute (cp) and Redwood I.

Volatility Factor: an empirical quantity which indicates good gasoline performance, volatility-wise. It involves actual automobile operating conditions and climatic factors. Volatility factor is generally defined as a function of RVP, % off at 158°F, and % off at 212°F The factor is an attempt to predict the vapor lock tendency of a gasoline.

Waste Heat Boilers: Heat exchangers which use the sensible heat of flue gases for steam generation.

Wax: High boiling straight-chain or slightly branched chain hydrocarbons, solid at room temperature, with melting points in the range of 105-155 F.

Weight Hourly Space Velocity: (See Space Velocity) .

Zeolite Fluid Cracking Catalyst or Molecular Sieve Fluid Cracking Catalyst: A fluid cracking catalyst, containing a crystalline alumino-silicate of the "X" or "Y" type. These compounds are also referred to as zeolites or molecular sieves.

APPENDIX C.

REFINERY ACRONYMS

AHGO	Atmospheric Heavy Gas Oil
API	API Gravity
APS	Average Particle Size
ART	Average Reactor Temperature also Asphalt Residual Treating
ASTM	American Society for Testing and Materials (Test Methods)
ATF	Automatic Transmission Fluid
ATM	Atmospheric
BB	Butene/Butane
BBL	Barrel
BPD	Barrels per Day
BPCD	Barrels Per Calendar Day
BPSD	Barrels Per Stream Day
BS	Bright Stock
CCR	Conradson Carbon Residue or Continuous Catalytic Reformer
CFR	Combined Feed Ratio
CGO	Cracked Gas Oil
CHD	Catalytic Hydrodesulfurization
CI	Cetane Index
CN	Cetane Number
C/O	Catalyst To Oil Ratio
CSO	Clarified Slurry Oil
CW	Cooling Water
DAGO	Deasphalted Gas Oil
DCF	Discounted Cash Flow
DEA	Diethanolamine
DGA	Diglycolamine
DI	Diesel Index
DIPA	Diisopropanolamine
DWO	Dewaxed Oil
DP	Differential Pressure
EB	Ethyl Benzene
EP	End Point
ERT	Equivalent Residence Time

FBP	Final Boiling Point
FCC	Fluid Catalytic Cracking
FOE	Fuel Oil Equivalent
GASCON	Gas Concentration Unit
GC	Gas Chromatography
G+D	Gasoline Plus Distillate
GPM	Gallons Per Minute
HAGO	Heavy Atmospheric Gas Oil
HC	Hydrocarbon
HCGO	Heavy Coker Gas Oil
HCO	Heavy Cycle (Catalytic Cracked) Oil
HDC	Hydrocracker
HDF	Hydrofinisher
HDS	Hydro-Desulfurization
HDT	Hydrotreater
HDT/FCC	Hydrotreating/Fluid Catalytic Cracking
HDW	Hydrodewaxing
HF	Hydrofluoric Acid
HFO	Heavy Fuel Oil
HGO	Heavy Gas Oil
HN	Heavy Neutral
HOC	Heavy Oil Cracking
HOD	Heavy Gas Oil Desulfurization
HP	High Pressure
HP/HDT	High Pressure Hydrotreating
HPS	High Pressure Separator
HTS	High Temperature Separator
HVGO	Heavy Vacuum Gas Oil
HVN	Heavy Virgin Naphtha
HVY	Heavy
IBP	Initial Boiling Point
ISOM	Isomerization
LCGO	Light Cycle (Catalytic Cracked) Gas Oil or Light Coker Gas Oil
LCO	Light Cycle Oil
LETGO	Light East Texas Gas Oil
LFO	Light Fuel Oil
LGO	Light Gas Oil
LHDC	Lube Hydrocracking
LHDT	Lube Hydrotreating
LHSV	Liquid Hourly Space Velocity
LN	Light Neutral
LNG	Liquid Natural Gas
LP	Low Pressure
LPG	Liquefied Petroleum Gas

LT	Light
LSRN	Light Straight Run Naphtha
LV	Liquid Volume
LVGO	Light Vacuum Gas Oil
LVN	Light Virgin Naphtha
MAIN COLUMN	Distillation Column following FCC Reactor
MBPCD	Thousand Barrels Per Calendar Day
MBPD	Thousand Barrels Per Day
MBPSD	Thousand Barrels Per Stream Day
MCB	Main Column Bottoms
MDDW	Mobil Distillate Dewaxing unit
MDEA	Monodiethanolamine
MDO	Marine Diesel Oil
MEA	Monoethanolamine
MEK	Methyl Ethyl Ketone (dewaxing process)
MHAP	Mobil Heavy Aromatics Processing
MHTI	Mobil High Temperature Isomerization
MIDW	Mobil Isomerization Dewaxing
MIL SPEC	Military Specification
MLDW	Mobil Lube Dewaxing Process
MMSCF	Million Standard Cubic Feet
MMSCFD	Million Standard Cubic Feet Per Day
MOG	Mobil Olefins to Gasoline
MOGD	Mobil Olefins to Gasoline and Distillates
MP	Medium Pressure
MPHC	Medium Pressure Hydrocracking
MSDB	Mobil Material Safety Data Bulletin
MTBE	Methyl Tertiary Butyl Ether
MTG	Methanol To Gasoline process
MTO	Methanol To Olefins
MTDP	Mobil Toluene Disproportionation
MVGO	Medium Vacuum Gas Oil
MVPI	Mobil Vapor Phase Isomerization
MWI	Mobil Wax Hydroisomerization
NCS	Naphthenic Cylinder Stock
NGL	Natural Gas Liquids
OCTANES:	
FEON(R-100)	Front End Octane Number
MON	Motor Octane Number
RON	Research Octane Number
OVHD	Overhead
PA	Pump Around
PCS	Paraffinic Cylinder Stock
PDA	Propane Deasphalting process

PET	Paraethyltoluene
pH	Degree of Acidity (0-7) or Alkalinity (7-14)
PONA	Paraffin/Olefins/Naphthenes/ Aromatics
PPB	Parts Per Billion
PPM	Parts Per Million
PrTr	Pretreater
PSIA	Pounds per Square Inch Absolute
PSIG	Pounds per Square Inch Gauge
PtR	Catalytic Reformer
RAFF	Raffinate
RCC	Reduced Crude Conversion
RDC	Rotating Disc Contactor
RDS	Resid Desulfurization
RESID	Residuum
RPM	Revolutions Per Minute
RSH	General Formula for Mercaptan Sulfur
RVP	Reid Vapor Pressure
SCFB	Standard Cubic Feet per Barrel
SCFD	Standard Cubic Feet per Day
SD	Stream Day
SDA	Solvent Deasphalting Process
SDW	Solvent Dewaxing
SG	Specific Gravity
SNB	Solvent Naphthenic Bright Stock
SNG	Substitute or Synthetic Natural Gas
SNN	Solvent Naphthenic Neutral
SPB	Solvent Paraffinic Bright Stock
SPN	Solvent Paraffinic Neutral
SRLGO	Straight Run Light Gas Oil
SSC	Shape Selective Cracking
STB	Syn Tower Bottoms
SUS	Saybolt Universal Seconds
TBA	Tertiary Butyl Alcohol
TBP	True Boiling Point
TCC	Thermofor Catalytic Cracking Process
T/D	Tons Per Day
TDI	Temperature/Dosage Interchange
TK	Tank
TPR	Throughput Ratio
TPSD	Tons Per Stream Day
TV	Total Volatility
VAC	Vacuum
VAC BTM	Vacuum Bottoms

VB	Visbreaking
VGO	Vacuum Gas Oil or Virgin Gas Oil
VHGO	Vacuum Heavy Gas Oil
VI	Viscosity Index
VPBI	Vapor Pressure Blending Index
WCP	Whole Crude Properties
WHSV	Weight Hourly Space Velocity

General Profile

The U.S. Petroleum Industry: Past as Prologue, 1970-1992, Energy Information Administration, September, 1993. (DOE/EIA-0572)

Petroleum: An Energy Profile, Energy Information Administration, August, 1991. (DOE/EIA-0545(91)

U.S. Industrial Outlook 1994, Department of Commerce.

1992 Census of Manufacturers Preliminary Report Industry Series: Petroleum and Coal Products, Bureau of the Census, June 1994. (MC92-I-29A(P))

Process Descriptions

Petroleum Refining - Technology & Economics, Gary & Handwerk, 3rd Edition, Marcel Dekker, Inc., New York, N.Y., 1994.

Petroleum Refining for the Non-Technical Person, 2nd ed., William L. Leffler, PennWell Publishing Company, Tulsa, Oklahoma, 1985.

Handbook of Petroleum Refining Processes, Meyers, R.A., McGraw-Hill Book Company, New York, 1986.

Petroleum Refining Distillation, Watkins, R.N., Gulf Publishing, Inc., Houston, TX, 1979.

Petroleum Refinery Enforcement Manual, U.S. EPA Office of Enforcement, by PEDCo Environmental Inc., Arlington, Texas, March 1980. EPA-340/1-80-008..

Release Profiles

Compilation of Air Pollutant Emission Factors, 3rd ed., Ch. 9, William M. Vatavuk, August 1977.

Assessment of Atmospheric Emissions from Petroleum Refining, R.G. Wetherold, Radian Corporation, Austin, Texas and U.S. EPA, Office of Research and Development, Washington, DC, April, 1980. (EPA-600/2-80-075e)

Petroleum Industry Environmental Performance, Third Annual Report, American Petroleum Institute, Washington, DC, 1995.

Petroleum Refinery Enforcement Manual, U.S. EPA Office of Enforcement, by PEDCo Environmental Inc., Arlington, Texas, March 1980. EPA-340/1-80-008.

Hazardous Waste Generation: 1. Petroleum Refining, U.S. EPA, Office of Solid Waste, January 1994.

Amoco - U.S. EPA Pollution Prevention Project, Yorktown, Virginia, Project Summary, U.S. EPA, January 1992.

The Generation and Management of Wastes and Secondary Materials in the Petroleum Refining Industry: 1987-1988, American Petroleum Institute, February 1991. (API Pub. no. 4530)

Generation and Management of Wastes and Secondary Materials: Petroleum Refining Performance, 1989 Survey, American Petroleum Institute, June 1992. (API Pub. no. 303)

Generation and Management of Wastes and Secondary Materials: Petroleum Refining Performance, 1990 Survey, American Petroleum Institute, August 1993. (API Pub. no. 324)

Generation and Management of Wastes and Secondary Materials: Petroleum Refining Performance, 1991 Survey, American Petroleum Institute, May 1994. (API Pub. no. 329)

Toxics Release Inventory, Public Data Release, 1992, U.S. EPA, Office of Pollution Prevention and Toxics, April, 1994. (EPA 745-R-94-001)

Dioxin and Furans - A Primer: What They Are and How to Measure Them, American Petroleum Institute, Washington, DC, March 1990.

Refinery Wastewater Priority Pollutant Study - Sample Analysis and Evaluation of Data, American Petroleum Institute, Washington, DC, December 1981.

Environmental Design Considerations for Petroleum Refining Crude Processing Units, American Petroleum Institute, February 1993. (API Pub. no. 311)

Pollution Prevention

Hazardous Waste Minimization: Part V Waste Minimization in the Petroleum Industry, Leeman, J.E., JAPCA 38, no. 6, June 1988.

Waste Minimization in the Petroleum Industry a Compendium of Practices, American Petroleum Institute, November 1991. (API Pub. no. 3020)

Amoco - U.S. EPA Pollution Prevention Project, Yorktown, Virginia, Project Summary, U.S. EPA, January 1992.

546-222

222

Case Study: Identifying Pollution Prevention Options For a Petroleum Refinery, Balik, J.A., and Koraido, S.M., Pollution Prevention Review, Summer 1991.

New Catalyst Designs Meet Environmental Challenges of the 1990's, Corbgett, R.E., Oil & Gas Journal, October 1, 1990.

Dry Scrubber Reduces SO_2 in Calciner Flue Gas, Brown, G.W., Roderick, D., and Nastri, A., Oil & Gas Journal, February 18, 1991.

Innovative Improvements Highlight FCC's Past and Future, Avidan, A.A., Edwards, M., Owen, H., Oil & Gas Journal, January 8, 1990.

Pollution Prevention: Strategies for Petroleum Refining (Fact Sheet), Center for Hazardous Materials Research (CHMR), Pittsburgh, PA.

Pollution Prevention Opportunities in Petroleum Refining (Fact Sheet), U.S. EPA Region III, Philadelphia, PA, October, 1990.

Pollution Prevention Opportunities Checklists, County Sanitation Districts of Los Angeles County, January 1991.

Regulatory Profile

Sustainable Environmental Law, Environmental Law Institute, West Publishing Co., St. Paul, Minn., 1993.

Issues Affecting the Refining Sector of the Petroleum Industry, Hearings Before the Committee on Energy and Natural Resources, United States Senate, Washington, DC, May 19, 1992, Cheyenne, WY, May 28, 1992, U.S. GPO, Washington, DC, 1992.

Costs to the Petroleum Industry of Major New and Future Federal Government Environmental Requirements, American Petroleum Institute, Washington, DC, October 1993. (API Discussion Paper #070R)

U.S. Petroleum Refining: Meeting Requirements for Cleaner Fuels and Refineries, Volumes I-VI, National Petroleum Council Committee on Refining, U.S. Department of Energy, August 1993.

U.S. Petroleum Strategies in the Decade of the Environment, Williams, Bob, Penn Well Books, Tulsa, OK, 1991.

Environmental Related Issues Taking Their Turn in Restructuring Industry, Williams, Bob, Oil & Gas Journal, January 22, 1990.

Clean Air Act Complicates Refinery Planning, Scherr, R.C., Smalley, G.A., and Norman, M.E., Oil & Gas Journal, May 27, 1991.

Clean Air Amendments Put Big Burden on Refinery Planners, Scherr, R.C., Smalley, G.A., and Norman, M.E., Oil & Gas Journal, June 10, 1991.

U.S. Regs Cause Refiners to Rethink Wastewater Systems, Norman, M.E., Kapoor, S., Smalley, G.A., and Daniel, B.M., Oil & Gas Journal, June 1, 1992.

U.S. Refiners Choosing Variety of Routes to Produce Clean Fuels, Ragsdale, R., Oil & Gas Journal, March 21, 1994.

CHAPTER 7

AUDITING GAS MONITORING SYSTEMS

After a CEM system has been installed and certified, the plant management and control agency expect valid data from the system. Unless a CEM system QA program is instituted by the plant, this expectation cannot be met. A QA program is a management program that assures that QC activities, such as preventive maintenance, calibration activities, and periodic audits, are performed. This chapter will focus on one aspect of QA, the audit, while leaving the detailed discussions of QA programs for Chapter 12. CEM systems audit procedures will be discussed in this chapter and in Chapter 10 (Auditing Transmissometer Systems).

An audit is a review of the CEM system by a team or individual not responsible for its day-to-day operations. Gas monitoring systems can be audited as part of an agency source inspection, an internal plant CEM QA program (such as that mandated by 40 CFR 60, Appendix F), or as part of a corporate environmental audit. Each of these activities will have different objectives, but they do have one principal objective in common—determining how well the system works.

Two basic sets of audit procedures can be applied to continuous gas monitoring systems: (1) the systems audit and (2) the performance audit. A systems audit is a qualitative evaluation that would normally be conducted by a state agency inspector or a corporate environmental auditor. The operational status of the monitoring system is evaluated, and records and data are reviewed. This is not a hands-on audit, but an inspection of system operations and system management practices.

A performance audit is a quantitative evaluation and is more detailed than a systems audit. It would normally be conducted by a trained agency inspector, a source testing contractor, or plant QA personnel. The performance audit involves testing the system using EPA manual reference methods, alternative reference methods, certified cylinder gases, or other audit materials (such as calibrated filters or standard solutions). This audit requires a set of audit equipment and materials and is a hands-on activity. Its purpose is to provide a quantitative assessment of problems that might affect the accuracy of the system.

In auditing, the use of the word "inspector" often becomes confusing. A CEM system operator will routinely inspect the system but cannot audit it, because an auditor is someone who is independent from the system's routine operation. Agency personnel who visit a plant to review control equipment performance and CEM system operations are commonly termed "agency inspectors," but they are actually auditors who obtain an independent assessment of plant environmental compliance. The thoroughness of the audit will depend on how much the auditor knows. An understanding of the material in this manual, combined with experience gained in the field, should enable the auditor to note problem areas and inconsistencies in a CEM installation.

8HB-225

SYSTEMS AUDIT PROCEDURES

Systems auditing is a skill that requires a good technical background, good interpersonal skills, and "sleuthing" capabilities. Auditing can be tedious, particularly when reviewing data and records and when attempting to corroborate conflicting data. It can also be intimidating. Meeting with personnel at various levels, from the technician to the plant manager or corporate vice president, is stressful, especially when the audit is seen as intrusive. But a well-conducted systems audit will give plant management and the control agency an indication of how the CEM program is operating. It will also give an indication of the level of confidence that can be given to the data.

Agency inspections of system procedures can be conducted on several levels; the CEM systems audit corresponds to a Level II inspection (e.g., Nazzaro, 1986). The list below illustrates the relationship of a Level II inspection to other enforcement inspection levels.

Inspection Levels in Agency Enforcement Programs

- Level I – Excess Emissions Report Review
- Level II – CEM Systems Audit
- Level III – Performance Audit
- Level IV – Relative Accuracy Testing

A CEM systems audit incorporates an examination of all major parts of the monitoring program and includes (1) a tour of the CEM system installation to review the system configuration and condition; (2) an evaluation of the CEM system operational status; and (3) a review of data and records.

The audit constitutes a formal, systematic review of the CEM system status, and it should not be conducted in conjunction with other administrative business at the facility (unless it is part of an overall facility inspection). The audit begins with an initial briefing and continues with a facility tour, a review of records and data, discussions with plant personnel, and an exit briefing. The auditor should take notes that are sufficiently detailed to support the findings that will be reported later in the audit report.

The Initial Briefing

The purpose of the initial briefing is to introduce the auditor to the plant personnel and address the purpose and extent of the audit activity. The auditor should verify administrative details of the audit. Offices that the auditor can use should be identified, a telephone should be available, and access to facility files and personnel should be clarified. If free access to the files is not permitted, facility personnel should provide documents on request. Materials, such as facility maps, documentation, and QA plans that had been requested earlier should be made available at this time. If the materials are not supplied at this point, the auditor should be informed where and when they can be obtained.

The auditor should also confirm who the audit host is and who is conducting the facility tour. Generally, the facility's environmental manager will be responsible for the needs of the auditor, but he can delegate responsibility for the tour or inspections to others who are more conversant with the operations of the CEM system.

CEM System Site Tour

The tour of the CEM system installation should familiarize the auditor with the system and its operations. All aspects of the installation, from probe to final data output, should be inspected. The auditor should have a basic understanding of the system prior to the tour, preferably by reviewing agency records, such as the initial PST report, excess emissions reports, or a "Phase 1" report that might be required before CEM system installation. Alternatively, the plant can provide information prior to the audit visit or during the initial briefing.

Some auditors prefer to review plant records first so that they know what to look for before taking the tour. This option, however, decreases the momentum established at the initial briefing and could reduce the accessibility of plant personnel who might otherwise have devoted the entire day to the audit. Both the plant and the CEM system should be operating during the audit period. Instrument technicians should be available to answer questions and to demonstrate features of the system operating under normal conditions.

There are many items to address on the tour, and checklists are often developed to assist new auditors or to refresh the memory of experienced auditors. The checklist for the system tour should provide an assessment that responds to questions, such as those listed in Table 7-1. Not all items will be relevant to a particular CEM installation, but the example questions and suggestions are provided to assist the auditor in the development of agency-specific or site-specific checklists.

Table 7-1. CEM System Configuration And Condition – Questions To Be Answered On A Tour Of The CEM System Installation

System Configuration

1. Is the system configuration the same as it was when it received initial, or Phase 1, approval?
2. Is the system configuration the same as it was when it was certified for monitoring after passing PSTs?
3. Are there any modifications to the system that might significantly affect its performance?
4. Are there any major components that have been replaced since the PST or since the last audit? Are the analyzers the same (check serial numbers)?

System Condition - Stack/Duct Installation Points

(Note: Request plant personnel to open protective coverings, instrument cabinets, etc., when feasible.)

1. What are the access and site conditions?
    a. Is the site difficult to reach? Is the elevator working? Would maintenance personnel be willing to inspect the site once a day, once a week, or never?
    b. Is the site protected between liner and chimney or catwalk? Can maintenance personnel perform repairs at the site during inclement conditions?

Continued on next page

SHB-227

Table 7-1. CEM System Configuration And Condition – Questions To Be Answered On A Tour Of The CEM System Installation (cont.)

---

   c. Does the site show evidence of being visited? Is there dust or fly ash on the railings or hand holds?

   d. Is the temperature higher or lower since the last audit?

   e. Is vibration at the location higher or lower since the last audit?

   f. What is the stack static pressure? (Use a piece of paper and see if it is sucked in or blown out.)

   g. Are there puddles of water at the site? Does it rain on the apparatus, or does water drip onto the system?

   h. Has fly ash sifted into piles near the installation.

   i. What is the condition of the ambient air? Is it laden with blowing fly ash? Can you smell SO_2 or other gases? Are the ambient pollutants affecting the CEM installation?

2. How does the probe or monitor installation look? Is it clean, well-maintained, or dirty?

   a. Are there significant quantities of dust or fly ash covering the unit?

   b. Are bolts rusted tight on the mounting flange? Is there evidence that the probe or unit has been recently removed?

   c. Is the unit corroded?

   d. What is the condition of plastic or rubber components, such as gaskets, heat-traced line protective coverings, hoses, electrical cables, etc.?

3. How does the probe look? (Sometimes it might be possible to look at the probe through another port.)

   a. Is the probe black or impacted with particulate matter?

   b. Is agglomerated, sticky particulate matter adhering to the probe?

   c. Is the probe sagging?

   d. Is the probe oscillating with the stack flow?

4. What is the condition of stack-mounted instrumentation?

   a. Are the filters for blowers (in situ gas monitors or transmissometers) clean? Is a supply of air being provided to the windows?

   b. Are any protective shutters tripped?

Continued on next page

Table 7-1. CEM System Configuration And Condition – Questions To Be Answered On A Tour Of The CEM System Installation (cont.)

   c. What is the status of any warning lights or operation indicators at the site?

   d. For J-boxes or meters at the site, record meter values and note times to correlate the information with previous records or data recorded in the control room.

5. Are calibration gas or audit gas cylinders located at the probe site?

   a. If so, record cylinder number and tag information – parts per million/percentage values, type of certification, gas vendor, date of analysis. What confidence is there in the stability of cylinder gases used over 6 months? Over 1 year?

   b. Record regulator pressures for each cylinder (tank pressure and supply pressure). Also note original tank pressure.

   c. Are the regulators corroded? Are proper fittings used for acid gases?

   d. What is the condition of the gas supply lines and fittings? Is the same type of tubing being used as that during the last audit or last PST? Are the fittings mangled or corroded, or do they show other indications of abuse?

6. If possible, observe a gas calibration cycle and a probe blowback cycle at the installation site.

7. What else can you observe? Is garbage or paper strewn about the site? Are there tools, instrument manuals, and source test apparatuses at the installation?

System Condition - Umbilical Lines and Electrical Cables

(Note the following when walking from the probe stack/duct installation to the CEM system analyzer shelter or CEM system room.)

1. Is there a minimum slope of 5° from the probe to conditioning system?

2. Are there any loops or kinks in the umbilical line?

3. Does the umbilical coil back on itself or touch itself or another umbilical line at any point?

4. Are there any unheated sections (e.g., where two umbilicals are spliced together, after the probe assembly, or just before the conditioning system)?

5. Are electrical cables properly routed and protected?

6. Are the cables located near or bundled with power lines, electric motors, or equipment generating strong electromagnetic fields?

7. For both heated and unheated lines, what is the condition of the line from the port to the conditioning system? Is it corroded, brittle, or dirty? Has it been run over by a forklift, spliced, or otherwise repaired?

Auditing In The CEM Shelter Or In The Control Room

The CEM system installation tour will most likely begin or end in the CEM shelter or in the plant control room. Most of the auditor's time should be spent in one of these rooms so that he or she can ask further questions about the system and its operational procedures.

The auditor should determine the proper methods of the system's operations from either the manufacturer's written instructions, or preferably, the standard operating procedures provided in the plant QA manual. At this time, it is often convenient for the plant environmental engineer or CEM system operator to explain the entries in the instrument maintenance log and describe the routine system maintenance procedures. Maintenance activities performed by plant personnel should be cross-checked in the maintenance log and QA manual to determine if established procedures are being followed. For the part of the audit conducted in the CEM system shelter or in the control room, the audit checklist should provide an assessment that responds to questions, such as those listed in Table 7-2.

Table 7-2. CEM System Room/Shelter – Questions To Be Answered During A Systems Audit Of The CEM Room Or Shelter

---

System Condition - Conditioning System (for Extractive Systems)

1. Trace the path of the umbilical line or sample line to the conditioning system or analyzers. Attempt to understand how the system works at this point. In particular, note the following:
   a. Does sample gas enter the conditioning system under pressure or under vacuum?

   b. What is the technique used for removing water from the sample gas?

   c. How is condensed water removed from the conditioning system? What is the probability of pollutant gas being absorbed in the condensed water? Is algae growing in the coolant?

   d. Locate the drain pipe for the condensed water. If the pipe drains to the outside, can the outlet freeze during the winter?

   e. Does the system incorporate a moisture-breakthrough sensor? Does the sensor work? How do you know?

   f. Can you see condensed liquid in any of the teflon lines?

   g. Is the tubing neatly or haphazardly arranged? Are there indications of ad hoc plumbing changes?

   h. Are the fittings, valves, etc., corroded or leaking?

   i. What is the status of the fine particulate filter? Is the filter clean or dirty? How often is the filter replaced?

   j. What is the condition of the sample pumps? Are they corroded, noisy or leaking? When were the diaphragm bearings, etc., last replaced? (verify in the maintenance log).

Continued on next page

Table 7-2. CEM System Room/Shelter – Questions To Be Answered During A Systems Audit Of The CEM Room Or Shelter (cont.)

---

k. Note the system gas flow (rotameter) readings and pressure readings. Are they consistent with readings obtained during the last audit? Are they consistent with readings specified in the operating or QA manual?

l. Is a manifold used for gas distribution to different analyzers?

m. In flow-through systems, where does the dump-line exhaust?

System Condition - Monitor Control Panels/Monitors

1. What is the status of the control panel lights/indicators, alarms, etc., for each analyzer?
2. Record panel meter readings exhibited by each analyzer.
3. Record settings for zero/span control dials for each analyzer (for comparison with historical data).
4. Record values for panel-operated test parameters, such as lamp voltages, automatic gain controls, etc., if procedures do not interfere with analyzer operations and data recording.

System Operational Procedures

1. Who has responsibility for the following:
   a. system operation?
   b. calibration?
   c. system preventive maintenance?
   d. system corrective maintenance?
   e. auditing?
   f. reporting?
2. Ask the following questions:
   a. How many hours a week are spent operating and maintaining the system?
   b. What system operation has given the most trouble since the last audit?
   c. How good has the CEM system vendor been in emergency service response? In spare parts delivery?

Continued on next page

Table 7-2. CEM System Room/Shelter – Questions To Be Answered During A Systems Audit Of The CEM Room Or Shelter (cont.)

---

3. Ask the operator to perform a system calibration. Note the following:
   a. the familiarity of the operator with procedures.
   b. how the operator determines that the system is in calibration (which data are used — meter, strip chart, or computer output?).
   c. how the operator annotates the data (in a logbook, strip chart, on the computer output, or not at all).
   d. how it is determined that the system is or is not in calibration (are quality control charts used?).
4. Record the calibration data and obtain copies of the strip chart record and/or computer output, if possible.
5. Cross-check observed procedures with written procedures given in the plant CEM system QA manual, when the time is available.

Review Of Records And Data

Records and previous data should be reviewed in a location that is free from interruptions. Several hours should be devoted to this activity. Depending on the complexity and condition of the CEM installation and the skill and patience of the auditor, the review could take even longer.

EPA requires that a source retain records for two years. It is recommended that the auditor review the data record for the past 30 days and also review the maintenance records for the past three months. If possible, the data record should cover a period for which an excess emissions report (EER) has been submitted to the agency. The auditor should review data over the period in which excess emissions were reported, and note if the data correspond, or note if any annotations are provided. The auditor should then determine the zero and span values obtained closest to the time of any excess emissions. When reviewing the data record, the auditor should also look for the following:

- Missing data
- Unusually noisy or flat data
- Inconsistent trends in readings
- Annotations for monitor and source shut-down time
- Annotations for excess emissions
- Printed fault or warning codes

Review, if possible, both instantaneous strip chart data and the computer printouts. The data from the strip chart and printouts should agree. After a calibration check, however, many computer systems will automatically correct subsequent data. This is a computer correction and does not involve the adjustment of the analyzer zero or span potentiometer. In such cases, the strip chart data and analyzer meter readings will not be corrected and will differ from the computer printed adjusted readings. The auditor should determine how the strip chart data and computer printed data are used by the plant and if plant personnel are aware of the differences between the data.

If the source has developed a CEM system QA plan, the plan can be used as a tool in conducting the review of data and records. The auditor should follow the plan, determine if each of the QC procedures in being performed, and ask for corroborating data documenting that the procedures were performed in the last quarter or year. Documentation might include inspection sheets, logbook entries, management reports, or test reports. This is where the auditor will find the greatest gaps in the QA program and where suggestions can be made for improving the operation and maintenance of the monitoring system.

The Exit Briefing

A formal or informal reporting of the audit findings (exit briefing) should be conducted before the auditor leaves the facility. Each audit finding should be discussed in reference to specific regulatory requirements or in terms of potential problems or liabilities. Evidence or references should be available to support a finding or observation. If a finding is disputed, the auditor should be willing to compromise, but only if adequate alternate information is provided. Achieving resolution for questioned items might require further investigation after the meeting, and in such cases, the discussion should be tabled at the briefing.

If the audit is performed periodically, it is necessary to address progress or lack of progress since the previous audit. This is readily done by reviewing the findings of the last audit and noting how the issues have been resolved. If progress has been good, the review will take some of the edge off the present findings and observations. If there has been no progress, the review will emphasize the problems of the CEM system and provide an impetus for resolution by the next audit.

The Audit Report

The audit report organizes and coordinates information gathered during the audit in a usable manner. It is the compilation of factual information and professional judgment resulting from the audit. The report also serves to record the procedures used in gathering the data and gives factual observations and evaluations from the audit. Information in the report must be accurate, relevant, complete, objective, and clear. A discussion of general topics should be avoided, and all compliance issues should be directly linked to regulatory requirements.

Tips For Conducting A Systems Audit

Systems audits are conducted to determine how well the system is operating and to obtain some assessment of the reported data quality without conducting independent performance tests. The auditor is actually a detective who is attempting to find clues (through observations and discussions) that will indicate system performance. Plant personnel will cast the best possible light on their operations, and if reasonably astute, will not volunteer negative information. It is the job of the auditor to find out what is not said. The following is a list of some general auditing techniques:

1. Be professional.

2. Be sensitive to the management levels and responsibilities of plant personnel. Always proceed through proper channels.

3. Maintain objectivity. The over-cooperative engineer might have a grudge against managemen and want the auditor to discover problems that do not exist.

4. Ask as many questions as possible. Ask questions continually (e.g., while walking, during coffee breaks, lunch). Do not be afraid to ask "dumb" questions. Answers to such questions can be revealing and also indicate the level of knowledge of facility personnel.

5. If you do not get what you ask for, ask again. If information or data is still not forthcoming, go up a level in management.

6. Compare what is said to what is observed. Question any discrepancies immediately and obtain resolutions by the end of the audit.

7. Do not be distracted. Long coffee breaks and lunches decrease time available for auditing.

8. Develop a knowledge of CEM systems. Maintaining an attitude that gas analyzers are merely "black boxes" will result in a nonconstructive exercise.

9. Take as many notes as possible while the audit is being conducted.

10. Refer to the source operating permit, state CEM regulations, and applicable federal regulations. Compare what is written to what is observed. Check the accuracy of schematics and the consistency of procedures. Incorporate salient features of the requirements in the checklist.

11. Do not be constrained by a checklist. Lengthy checklists make an auditor look foolish. Checklists are most useful at the end of the audit to determine if any points were missed.

12. Use QA plans, written Standard Operating Procedures (SOPs), and instruction manuals to determine if procedures are being followed. If they are not, ask when the written procedures will be changed to reflect actual practice.

13. Prepare a summary of findings and observations as soon as possible after the audit, preferably on the same day the audit is conducted.

14. If possible, allow plant personnel to review an audit summary of findings and observations before leaving the plant. This will help to minimize misperceptions by the auditor and will reduce later correspondence when each party attempts to justify his actions (this point is particularly important for the corporate environmental auditor).

15. Be firm. If something is wrong, report it. Failure to report a problem can result in additional problems and could cast doubt on the auditor's objectivity and capability.

For a more quantitative assessment of data quality, the performance audit can be conducted following the systems audit or as part of a regular schedule of a [illegible] activities.

THE PERFORMANCE AUDIT

Performance audits are conducted on a regularly scheduled basis as part of a QA program (such as that mandated by EPA Appendix F [EPA, 1990]), or when the findings of the systems audit indicate that information of a more quantitative nature is necessary to evaluate data accuracy. A performance audit is defined as " . . . an independent assessment of the accuracy of the data . . .. The audit should be a true assessment of the measurement process under normal operation of the system — that is, without any special preparation or adjustment of the system." (EPA, 1977b)

The most common method of conducting a performance audit of a gas monitoring system is to challenge the system with certified audit gases. This cylinder gas audit (CGA) provides an independent assessment of the system, but it does not always assess the accuracy of the data (in terms of EPA enforcement inspection levels, conducting a CGA would correspond to a Level III inspection). The use of optical filters for electro-optical analyzers, standard solutions for electrochemical systems (typically ion-selective electrode analyzers), or the use of electronic signals can provide a similar level of assessment. These latter methods are commonly used in Europe, but have been discouraged in the United States, which prefers CGAs.

More independent techniques of performance auditing involve using other test methods, such as the following:

- Testing using portable inspection monitors.
- Testing with instrumented mobile vans.
- Conducting abbreviated relative accuracy tests using EPA manual or alternate reference methods, (the relative accuracy audit [RAA]).
- Redoing the relative accuracy test (the relative accuracy test audit [RATA]).
- Determining stack emissions using continuous remote sensing instrumentation.

Such testing is more involved and expensive, because it requires additional resources. The fourth alternative, redoing the relative accuracy tests, constitutes Level IV of EPA's enforcement inspection scheme and is an annual requirement for sources regulated under Appendix F.

The CGA

As mentioned above, the CGA audit is the most frequently conducted performance audit procedure. It is conducted by challenging the CEM system with an audit gas that is traceable to NIST (National Institute of Standards and Technology) standard reference materials. These are commonly called Protocol 1 gases and will be discussed later in this chapter. The audit gases are introduced at the sampling probe and should pass through all components of the sampling system.

Conducting The CGA

An Appendix F CGA is conducted by challenging the CEM system with two audit gases. One has a value of 20 percent to 30 percent of the span, and the other has a value 50 percent to 60 percent of the span. The CEM system is alternately challenged three times with each audit gas. Sufficient time is allowed for each injection until the concentration reading stabilizes. For integrating instruments, it may be necessary to monitor several measurement cycles to determine when the reading is stabilized. Audit readings must not be included in the facility emission averages. The CEM system operator should place the data acquisition system in an alternate mode while the audit is being conducted.

An auditor might modify Appendix F procedures to obtain further system data. Also, state or regional QA guidelines can require other procedures (Peeler, 1990). Typical procedural variations include those listed on the next page.

- Using a zero gas in addition to two audit gases.
- Using an audit gas at a concentration level that corresponds to the emissions standard.
- Using an audit gas that corresponds to the average stack gas concentration of the pollutant.
- Generating variable gas concentrations using a dilution system.
- Challenging the system only twice with each gas.
- Challenging the analyzer with audit gas at the analyzer calibration port.

The first and last variations above are particularly useful in CEM system troubleshooting. It should be noted that a cylinder of zero gas might not be necessary; for example, an NO_x audit gas reading can serve as a zero reading for an SO_2 channel.

Challenging an analyzer at its calibration port is a simple method of checking the audit gas against the span gas used to calibrate the analyzer. If the audit gas reading obtained on the analyzer differs widely from its certified value, it might indicate that the span gas has deteriorated or its tag value is incorrect. If the probe audit results are unsatisfactory, it might be useful to check the audit gases at the analyzer to aid in troubleshooting the system.

Using audit gas concentrations different from those specified in Appendix F is a matter of different regulatory requirements or technical preference (e.g., Butler, 1987; 1990). Using an audit gas corresponding to the average pollutant concentration readings can give additional confidence in the emissions measurements, if the audit results are satisfactory.

Extractive System CGAs

The method used to introduce gas at the probe depends on the design of the probe and the monitoring system. Techniques for probe calibration checks (probe cal) for extractive systems are illustrated in Figure 7-1.

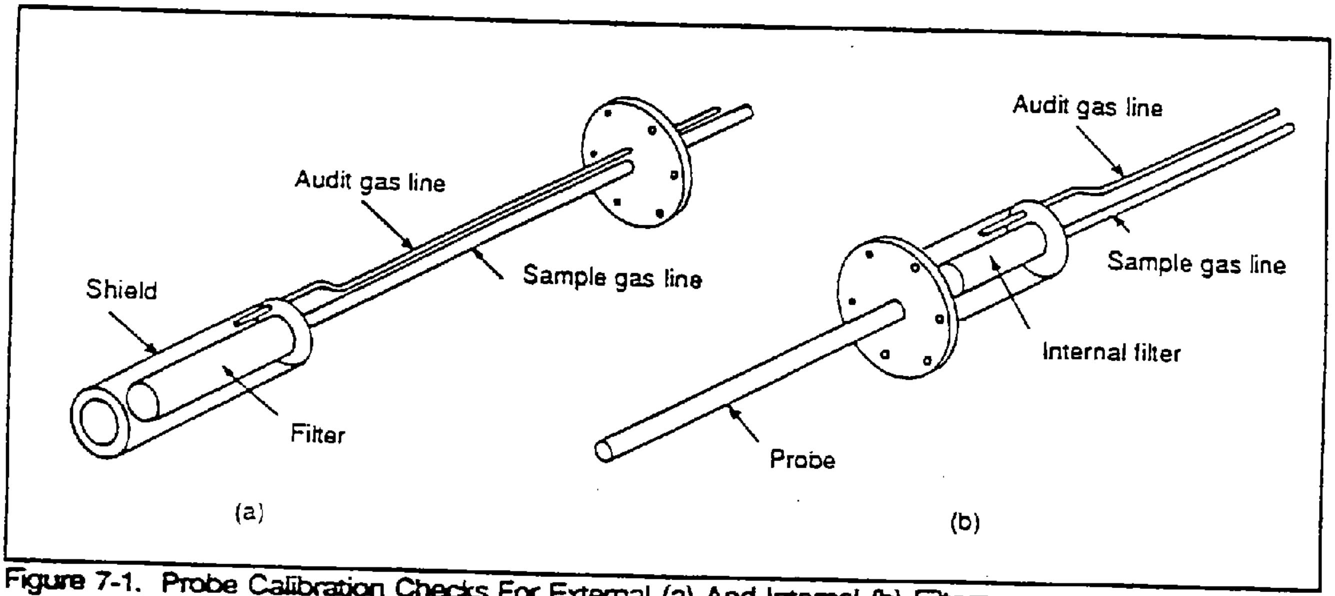


Figure 7-1. Probe Calibration Checks For External (a) And Internal (b) Filters

SHB-236

236

The injection of audit gas at the probe of direct (non-dilution) extractive systems can often be difficult and could require large volumes of gases. Audit gas must be provided at a rate necessary to overcome the absolute static pressure of the stack gas at the probe. At this pressure, stack gas will be flushed away from the probe so that an undiluted audit gas concentration can be obtained.

In practice, gas can be injected at the probe of the external filter (Figure 7-1a) or at the internal filter (Figure 7-1b) of the direct probe. The cylinder gas flow rate is increased until a maximum, stable reading is obtained. Excess gas is exhausted into the stack as the extractive system withdraws sample gas through the probe at its normal flow rate. A probe cal can be conducted at an external filter if a probe sheath is used, but large volumes of gases are necessary to flush out stack gas. A more effective method is to flood the annulus around the internal probe filter, as shown in Figure 7-1b. This might require less calibration gas because the space is more confined.

A probe CGA is relatively easy for a dilution probe. As shown in Figure 7-2, the inner space of the dilution probe can be flooded with audit gas. Because this space is smaller than that encountered in most direct extractive systems, and since the sampling rate is typically low (e.g., 50 cc/min), the volume of audit gas required is correspondingly smaller.

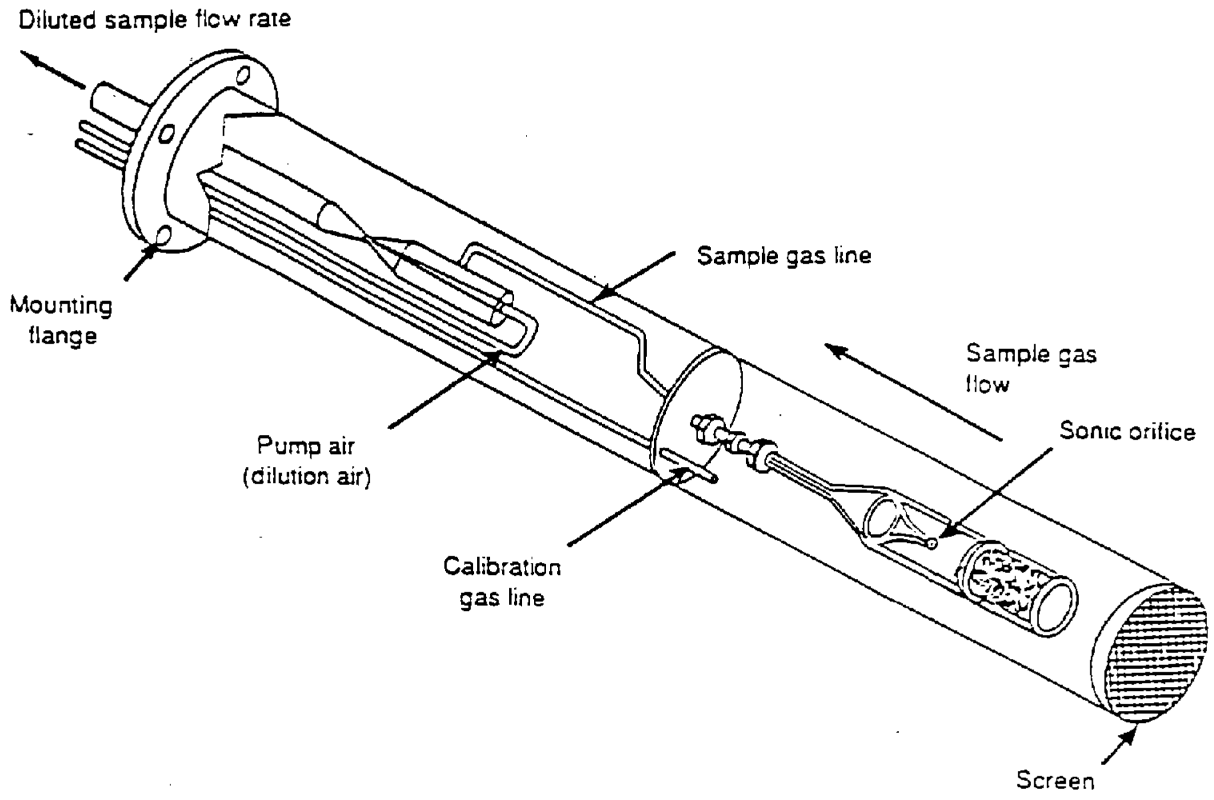


Figure 7-2. Dilution Probe

The techniques discussed above have been referred to as probe vent audit techniques (Reynolds, 1989). Another technique, the external atmospheric vent audit, is used when the probe system cannot be flooded with audit gas. This less complete check of the probe system can be conducted by using a three-way valve and a rotameter, as shown in Figure 7-3 on the next page. In this method, the probe system is essentially shut off and audit gas is vented through a rotameter. The sample system withdraws the audit gas (which is essentially at atmospheric pressure) at the valve. Care must be exercised to supply enough gas to vent through the rotameter, otherwise ambient air will dilute the sample. If a three-way valve is not part of the installed system, the auditor should ask the CEM system operator to disconnect the sample line at the probe and connect the audit sample line and rotameter directly to the line. This technique does not check the probe and probe filter, but it can assist in evaluating the integrity of the sample line. For CEM systems that pull gas through the sample line under vacuum (negative pressure), the check should not be conducted without the vented rotameter. The system will be pressurized, and the audit will not help in checking leaks in the line.

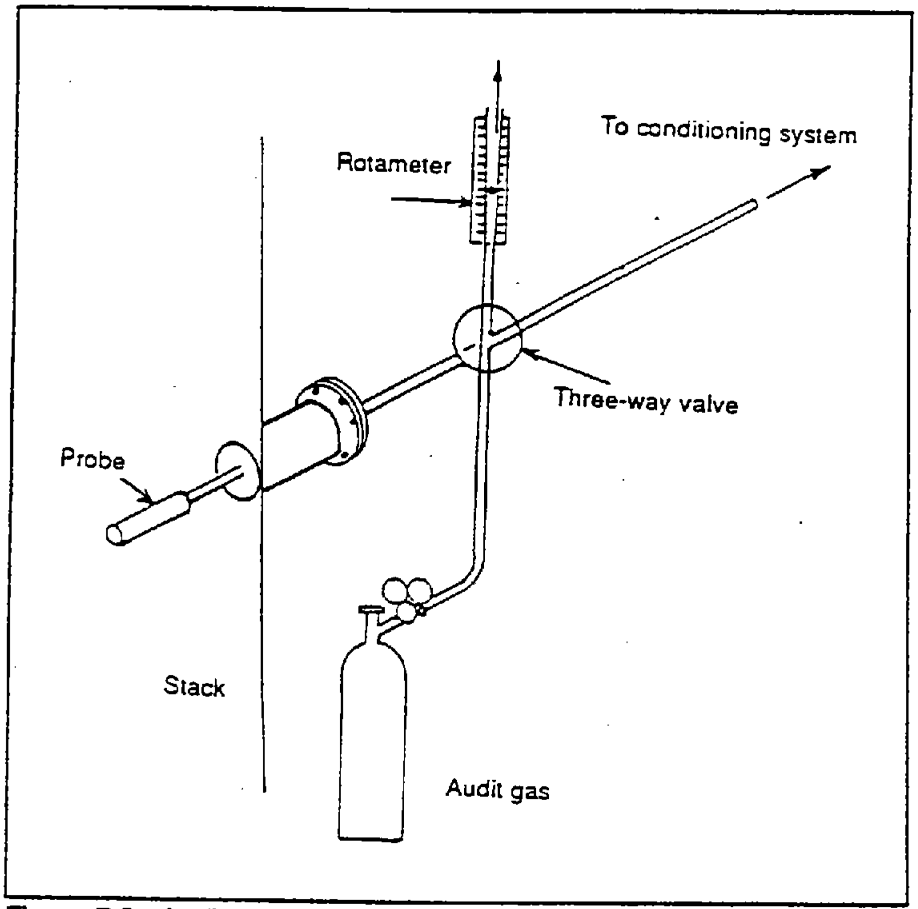


Figure 7-3. Audit Method For Probes That Cannot Be Flooded—The External Atmosphere Vent Technique

In Situ System CGAs

Performing a cylinder gas audit on a point in situ analyzer is similar to conducting a probe vent audit for an extractive system. Audit gas can be used to flood the sample chamber to a pressure greater than the stack static pressure, as shown in Figures 7-4 and 7-5.

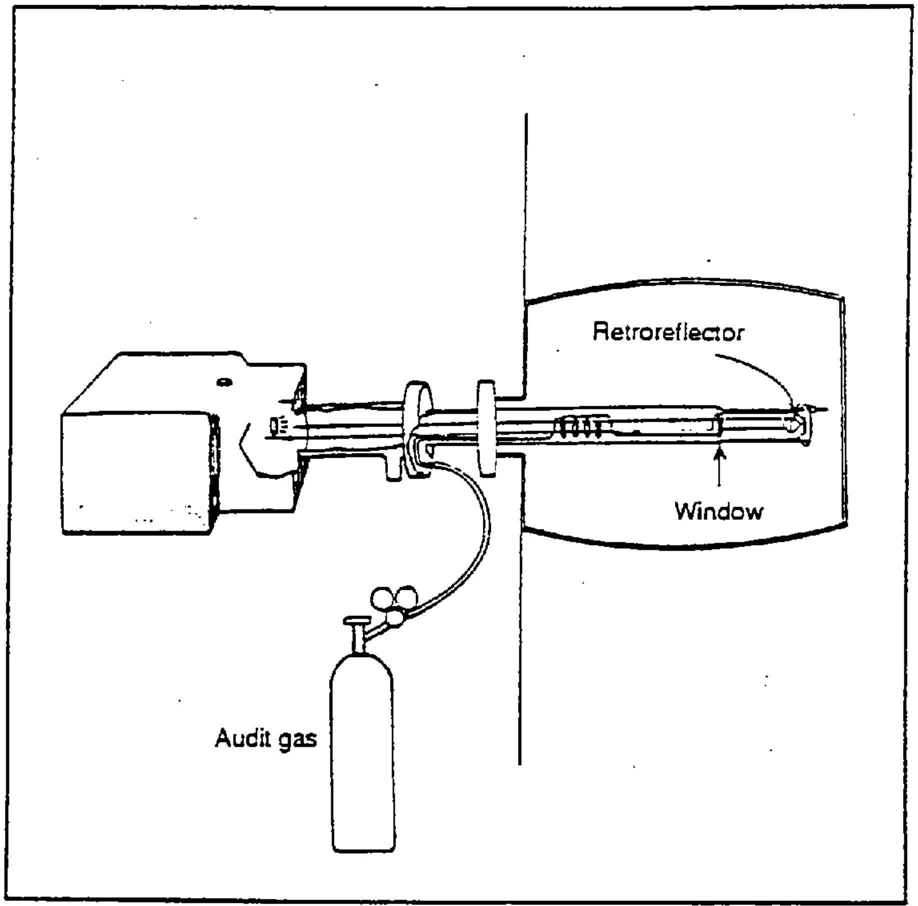


Figure 7-4. CGA Audit For A Point In Situ Analyzer

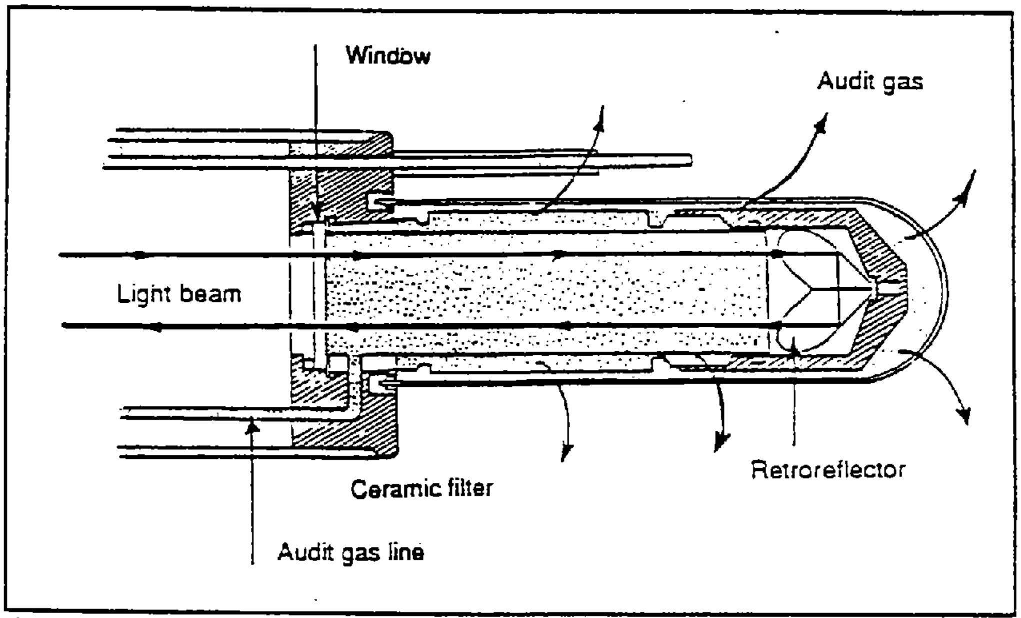


Figure 7-5. A Magnified Version Of A Probe Calibration For A Point In Situ Analyzer

SAB-239

It is possible to over-pressurize the chamber in analyzers that incorporate a ceramic filter to prevent fouling from particulate matter. At higher pressures, the audit gas concentration will be higher than true concentration and lead to incorrect readings. The audit gas flow rate should be increased 0.5 ppm over the manufacturer's recommended value to determine if such an effect is occurring (see Reynolds, 1989 for detailed procedures).

A problem occurs when the ceramic filter becomes blinded by impaction with particulate matter. After the audit gas flow is terminated, it will be a long time before the stack gas pollutant concentration returns to its normal value. The problem is easily recognized with a probe calibration check, and recommendations should be made to replace or clean the filter as soon as possible. A CGA can also be conducted on an in situ path analyzer if a flow-through gas cell is incorporated into the measurement system (Figure 7-6 shows one such design).

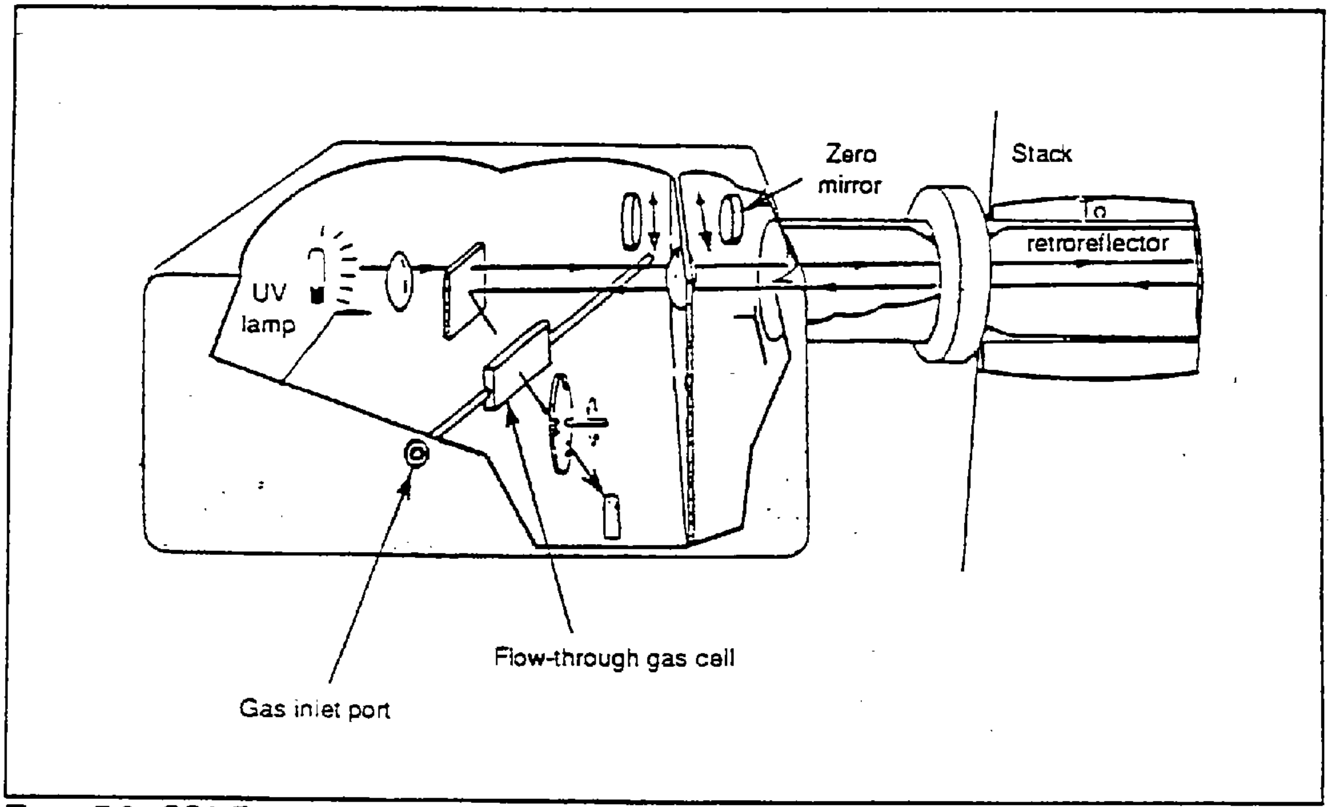


Figure 7-6. CGA For A Double-Pass In Situ Path Analyzer

In a double-pass system, the zero mirror will reflect the measuring light beam through the gas cell and back to the detector. The flow-through gas cell serves as a pseudo-stack. Cylinder gases at higher concentrations (percentage instead of parts per million) are necessary to obtain an optical depth that corresponds to the measurement pathlength. For example, if the analyzer monitors a gas concentration of 600 ppm of SO_2 over a total distance of 10 m in a stack, the optical depth will be 600 x 10 = 6000 ppm-m. If a flow-through gas cell has an internal measurement path of 1 cm (0.01 m), a cylinder gas would have to have a concentration of 6000/0.01 = 600,000 ppm for equivalent optical depth. The 600,000 ppm corresponds to a concentration of 60 percent.

SHB-240

Different techniques can be used to gain more audit information. For example, multiple flow-through cells can be stacked together. One lower-value audit gas can then be used to obtain multiple audit readings as each cell is filled in sequence.

Meaningful cylinder gas audits on single-pass in situ path monitors are more difficult to perform. Since that the stack gas is continually monitored unless a zero pipe is used, a flow-through gas cell will give an incremental reading added onto the stack gas values. Data resulting from these measurements becomes difficult to interpret when the stack gas concentrations are varying rapidly. A zero pipe avoids this problem, but by closing the pipe and flushing the stack gas with ambient air, other variables can be introduced, such as contaminated zero air or system misalignments.

Another technique that has been used in single-pass units is to block off the measurement light beam and use an auxiliary light source to send a beam through the cell. Obviously, this scheme does not check all of the normally operating active components of the system. It will serve to check the detector and primary electronics, however.

CEM system vendors frequently state that in situ path analyzers do not meet Appendix F requirements since a cylinder gas audit cannot be conducted on them. This is not true. Path analyzers that incorporate flow-through cells can be challenged with audit gases and meaningful information can be obtained from the results.

Audit Gases

Cylinder gases used for calibrating and auditing CEM systems have improved significantly over the past 20 years. In the early 1970s, it was not uncommon to find pollutant gas concentrations differing from the tag values by more than 10 percent, even when the producer stated accuracy was between 2 percent and 5 percent of the pollutant value. This led to considerable uncertainty in CEM system measurements and often led to the failure of initial PSTs. Because accurate standards are needed in any measurement program, steps were taken by EPA to improve the quality of cylinder gases.

In 1978 EPA published a traceability protocol that could be used to reference a prepared cylinder gas to NBS (National Bureau of Standards, now NIST) Standard Reference Materials (SRM). The protocol was subsequently revised in 1987 (see EPA, 1977a, Section 3.04). Gases prepared under this protocol are known as Protocol 1 gases. Due to the limited supply and high cost of the standard reference materials, intermediate standards can also be used by the gas vendor when preparing Protocol 1 gases. An intermediate standard can be either a Certified Reference Material (CRM) Standard (Hughes, 1981), or a Gas Manufacturer's Intermediate Standard (GMIS) (see EPA, 1977a). Table 7-3 summarizes the differences between these standards.

SHB 241

Table 7-3. Differences Between Standard And Certified Gases

SRM	Standard reference materials	• Prepared and sold by NIST
CRM	Certified reference materials	• Prepared by the gas vendor • Referenced directly to a SRM • Nominal concentration within ± 1% of an SRM concentration • Analyzed after preparation • Analyzed again, 30 days after first analysis • Two samples analyzed by independent laboratory
GMIS	Gas manufacturer's intermediate standard	• Prepared by the gas vendor • Referenced to a SRM or CRM • Nominal concentration within 0.3 and 1.3 times the concentration of the SRM • Must be assayed three times over 3 months • Assays must agree to within 1.0% • Must be recertified every 3 months
Protocol 1 Gas		• Prepared by the gas vendor • Referenced to a SRM, CRM, or GMIS • Nominal concentration between 0.3 and 1.3 times the concentration of the SRM, CRM, or GMIS • Assays must agree to within 1.5% • Reactive gases must be reassayed after 7 days

All the gases are assayed using analyzers that have been calibrated with certified gases. Calibration procedures, linearity responses, and adjustment procedures are strictly defined in Protocol 1. When purchasing a Protocol 1 gas, the buyer should obtain a certificate from the vendor that contains the following:

- Cylinder identification number.
- Certified concentration.
- Balance gas in the mixture.
- Cylinder pressure at certification.
- Date of certification.
- Expiration date of certification.
- Reference standard data (SRM or CRM number/cylinder number).
- Statement that certification followed procedures of Protocol 1.
- Lab and analyst identification.
- Gas analyzer identification, date of last multipoint calibration.
- All analyzer readings used for the certification and calculations used.
- Chronological record of all certifications.

Certification data should be reported to three significant digits. The certification applies for a maximum period of 18 months for most gases contained in aluminum or stainless steel cylinders. For other cylinder materials and NO_2/air mixtures, the certification period is only six months. Also, if the cylinder gas pressure drops below 100 psi (700 kilo pascals [kPa]), the Protocol 1 gas should not be used. If sufficient gas remains after 18 months, the gas can be recertified, but the recertified value must be within 5 percent of the original certified value.

When contracting or conducting a CGA, attention should be paid to obtaining the certification information. Since the QA results are intended to be ultimately traced to NIST standards, a report will not be complete without the documentation given above.

Other Performance Audit Techniques

As mentioned earlier, the CGA is not completely independent of the monitoring system. In fact, most CEM installations can pass EPA-established criteria for the CGA easily. In many cases, the exercise is merely a comparison between the audit gases and the system span gases, particularly if the daily calibration check is conducted at the probe.

Redoing the relative accuracy test is the ultimate audit technique, because the regulatory acceptance of the CEM system is based on the results of this test. As mentioned earlier, this is required once a year for Appendix F-affected sources. In cases where a repeat of the test is mandated by an agency enforcement action, it would constitute a Level IV inspection. Other performance audit procedures can be used as part of a plant QA program, however. Although the methods might not be specified by the agency, their application can provide additional levels of confidence in the data for plant personnel.

Testing Using Portable Inspection Monitors

A number of portable inspection monitors are commercially available. The monitors are generally lightweight and operate using electrochemical cells. Oxygen analyzers in this class are particularly useful and can provide accurate short-term measurements. The pollutant gas analyzers often have relatively long response times (5 to 15 m) and can drift on a long-term basis. These analyzers can be useful in uncovering stratification problems or in helping to resolve gross differences between installed CEM systems and manual test methods.

Testing Using Instrumented Mobile Vans

Most commercial stack testing companies and a few corporate environmental organizations use instrumented test vans or trailers to perform CEM relative accuracy tests and audits (Peeler, 1981; Chapman, 1990; and Noland, 1990). These vans usually will incorporate instrumentation whose quality is equivalent to installed CEM systems. Data obtained from such systems can be of high quality if the requirements of reference methods (such as 6C and 7E) are met.

Testing With Abbreviated Relative Accuracy Tests

An RAA can be conducted by reducing the number of runs that are normally conducted in a relative accuracy test. Instead of performing nine runs, as is required in a reference method, only three runs are necessary in an RAA. The effect of reducing the number of runs on the statistical acceptability of the data has been discussed in detail by Jernigan (1986).

SHR-247

Reducing the number of runs can save time, but not necessarily a great deal of expense. Because much of the cost associated with a stack test or audit program is associated with travel, QA, and reporting, a few hours saved at the site will not save much money.

The Use Of Remote Sensors

Remote sensing instrumentation showed considerable promise in the research and evaluation work conducted in the 1970s (although most systems were expensive and required special skills to operate). Progress was being made in developing less expensive, portable units, but development essentially ended in the 1980s.

Remote sensing is receiving renewed interest in the 1990s due to an increasing interest in measuring toxic air pollutants (EPA, 1990). FTIR and differential optical absorption spectroscopy (DOAS) are two techniques that are being applied in numerous ways. Also, with the increasing flux of electro-optical engineers from the defense industries, other sophisticated remote monitoring systems might be expected in the future. Perhaps by the year 2000, the auditor might need only to set up instrumentation at the plant gate and monitor the emissions independent of plant constraints.

REFERENCES

Butler, A. T. 1987. A Method for Quick Validation of Continuous Emission Monitoring Systems. *Proceedings–Transactions of the Pulp and Paper Institute (TAPPI) Environmental Conference*, pp. 199-208. Atlanta: Pulp and Paper Institute.

Butler, A. T. and Willenberg, J. M. 1990. A Method for Quick Validation of Continuous Emission Monitoring Systems. *Proceedings - Specialty Conference on Continuous Emission Monitoring - Present and Future Applications*, pp. 350-359. Pittsburgh: Air and Waste Management Association.

Chapman, J. 1990. Examination of a Transportable Continuous Emission Monitoring System. *Proceedings - Specialty Conference on Continuous Emission Monitoring - Present and Future Applications*, pp. 327-337. Pittsburgh: Air and Waste Management Association.

Hughes, E. E. 1981. Certified Reference Materials for Continuous Emission Monitoring. *Proceedings - Continuous Emission Monitoring: Design, Operation and Experience*, pp. 187-196. Pittsburgh: Air Pollution Control Association.

Jernigan, J. R. 1986. Assessment of the Equivalency of Three-Run Accuracy Audits Versus Six-Run Relative Accuracy Audits for Characterizing CEMs Performance. *Transactions - Continuous Emission Monitoring - Advances and Issues*, pp. 332-342. Pittsburgh: Air Pollution Control Association.

Nazzaro, J. C. 1986. Continuous Emission Monitoring System Approval, Auditing and Data Processing in the Commonwealth of Pennsylvania. *Transactions - Continuous Emission Monitoring - Advances and Issues*, pp. 175-186. Pittsburgh: Air Pollution Control Association.

Noland, S. and Reynolds, W. E. 1990. Design and Operation of a Transportable Emission Monitoring System Utilizing Dilution Probe Technology. *Proceedings - Specialty Conference on Continuous Emission Monitoring - Present and Future Applications*, pp. 136-147. Pittsburgh: Air and Waste Management Association.

Peeler, J. W. and Deaton, G. D. 1981. Field Testing of a Transportable Extractive Monitoring System for SO_2, NO/NO_x, CO, and CO_2. *Proceedings - Continuous Emission Monitoring: Design, Operation and Experience*, pp. 176-186. Pittsburgh: Air Pollution Control Association.

Peeler, J. W. 1990. *Guidelines for CEMs Performance Specifications and Quality Assurance Requirements for Municipal Waste Combustion Facilities.* Northeast States' Consortium for Air Use and Management (NESCAUM) - U.S. EPA, Contract No. 68D90055 (obtain by writing NESCAUM, 85 Merrimac St., Boston, MA 02114).

Reynolds, W. E. 1989. *Field Inspector's Audit Techniques: Gas CEMs which Accept Calibration Gases.* EPA-340/1-89-003.

U.S. Environmental Protection Agency (EPA). 1977a. *Quality Assurance Handbook for Air Pollution Measurement Systems–Stationary Source-Specific Methods.* Vol. III. EPA-600/4-77-027b.

——. 1977b. *Quality Assurance Handbook for Air Pollution Measurement Systems–Ambient Air - Specific Methods.* Vol. III. EPA-600/4-77-027a.

U.S. Environmental Protection Agency and the Air and Waste Management Association. 1990. *Measurement of Toxic and Related Air Pollutants - Proceedings of the 1990 EPA/A & WMA International Symposium.* EPA-600/9-90/026.

BIBLIOGRAPHY

American Society for Testing and Materials. 1975. *Calibration in Air Monitoring.* Philadelphia.

Caron, A. L. and Hoy, D. R. 1987. A Short-Term Evaluation of Stability of a Dynamic Dilution System Proposed to Challenge TRS Emission Monitors on Kraft Emission Sources. *Proceedings–Transactions of the Pulp and Paper Institute (TAPPI) 1987 Environmental Conference*, pp. 209-215. Atlanta: Pulp and Paper Institute.

Decker, C. E., et al. 1981. Analysis of Commercial Cylinder Gases of Nitric Oxide, Sulfur Dioxide, and Carbon Monoxide at Source Concentrations. *Proceedings - Continuous Emission Monitoring: Design, Operation and Experience*, pp. 197-209. Pittsburgh: Air Pollution Control Association.

Floyd, J. R. 1979. Quality Assurance Audit Techniques for Validating Data from Continuous Emission Stack Monitoring (CEM) Systems. Air Pollution Control Association Meeting Paper. Cincinnati. 79:20.5.

Floyd, J. R. 1980. Application and Results of Quality Assurance (QA) Audits and Other Novel Techniques to Continuous Emission Monitoring (CEM) Programs. Air Pollution Control Association Meeting Paper. Montreal. 80:70.3.

Host, J. T., Gilman, B. H. and McMillan, T. S. 1981. San Diego Gas & Electric's CEM QA Program-A Practical Approach. *Proceedings - Continuous Emission Monitoring: Design, Operation and Experience,* pp. 210-220. Pittsburgh: Air Pollution Control Association.

Hughes, E. and Mandel, J. 1981. *A Procedure for Establishing Traceability of Gas Mixtures to Certain National Bureau of Standards (NBS) Reference Materials.* EPA-600/7-81-010.

Hughes, E. E. 1982. Certified Reference Materials for Continuous Emission Monitoring. *Journal of Air Pollution Control Association* 32:708-711.

Logan, T and Rollins, R. 1984 Quality Assurance for Compliance Continuous Emission Monitoring Systems: Evaluation of Span Drift for Gas CEMs. Quality Assurance in Air Pollution Measurements. Air Pollution Control Association/American Society for Quality Control Specialty Conference Proceedings. Pittsburgh.

Nolen, S. L., Ryan, J. V. and Bridge, R. 1987. Real-Time Monitoring of a Hazardous Waste Incinerator with a Mobile Laboratory. Air Pollution Control Association Meeting Paper. New York. 87

Reynolds, W. E. 1984. Development and Evaluation of SO_2 CEM QA Procedures. Quality Assura Air Pollution Measurements. Air Pollution Control Association/American Society for Quality Cc pp. 752-760. Pittsburgh.

Rollins, R., Logan, T. J. and Midgett, M. R. 1985. An Assessment of the Long-Term Precision of Continuous Emission Monitors. Air Pollution Control Association Meeting Paper. Detroit. 85:51.2.

Van Gieson, J. and Paley, L. R. 1984. *Summary of Opacity and Gas CEMs' Audit Programs.* EPA-340/1-84-016.

von Lehmden, D. J. and Walsh, G. W. 1990. Appendix F DARs for CEMs at Subpart D Facilities. *Proceedings - Specialty Conference on Continuous Emission Monitoring - Present and Future Applications,* pp. 103-119. Pittsburgh: Air and Waste Management Association.

Walsh, G. 1989. *Data Assessment Reports for CEMs at Subpart Da Facilities.* EPA-600/3-89-027.

Wright, R. S., Decker, C. E. and Barnard, W. F. 1986. Performance Audit of Inspection and Maintenance Calibration Gases. Air Pollution Control Association Meeting Paper. Minneapolis. 86:46.4.

Wright, R. S., et al. 1986. Analysis of EPA Protocol Gases Used for Calibration and Audits of Continuous Emission Monitoring Systems and Ambient Air Analyzers - Results of Audit 6. *Transactions - Continuous Emission Monitoring - Advances and Issues*, pp. 343-355. Pittsburgh: Air Pollution Control Association.

Wright, R. S., Eaton, W. C. and Decker, C. E. 1987. *NBS/EPA Certified Reference Material Performance Audit Program: Status Report 2.* EPA-600/S4-86/045.

Wright, R. S., et al. 1987. Performance Audits of EPA Protocol Gases and Inspection and Maintenance Calibration Gases. *Journal of Air and Waste Management Association* 37:384-385.

Wright, R. S, et al. 1989. Accuracy Assessment of EPA Protocol Gases in 1988. *Journal of Air and Waste Management Association* 39:1225-1227.

U.S. Environmental Protection Agency (EPA). 1982. *Performance Audit Procedures for* SO_2, NO_x, CO_2 *and* O_2 *Continuous Emission Monitors.* CEM Report Series No. 5-371-7/82.

——. 1984. *Air Compliance Inspection Manual.* EPA-340/1-84-020.

——. 1985. *Air Pollution Source Inspection Safety Procedures Student Manual.* EPA-340/1-85-002a.

U.S. Government Printing Office. 1989. *Code of Federal Regulations - Protection of the Environment.* 40 CFR 60, Appendix A.

Relative Accuracy. "The absolute mean difference between the gas concentration or emissions rate determined by the CEM system and the value determined by the reference methods (RM) plus the 2.5[%] error confidence coefficient of a series of tests divided by the mean of the [reference method] tests or the applicable emission limit."

How these values are determined will be discussed in the section on procedure. The actual specifications that are to be met are provided in Table 6-3.

Table 6-3. Performance Specifications For Gas-Measuring CEM Systems

PS	Gases	Calibration Drift	Relative Accuracy
2	SO_2, NO_x	2.5% of span	20% of RM value in units of the standard 10% of applicable standard (for stds >130 ng/J)[a] 15% of applicable standard (for stds >86 <130 ng/J)[a] 20% of applicable standard (for stds <86 ng/J)[a]
3	O_2, CO_2	0.5% of span	20% of RM value or 1.0% (whichever is greater)
4	CO	5% of span for 6 of 7 test days	10% of RM mean value in units of the standard 5% of applicable emission standard (whichever is greater)
5	TRS	5% of span for 6 of 7 test days	20% of RM mean value in units of the standard 10% of the applicable standard (whichever is greater)
7	H_2S	5% of span for 6 of 7 test days	20% of RM mean value in units of the standard 10% of the applicable standard (whichever is greater)

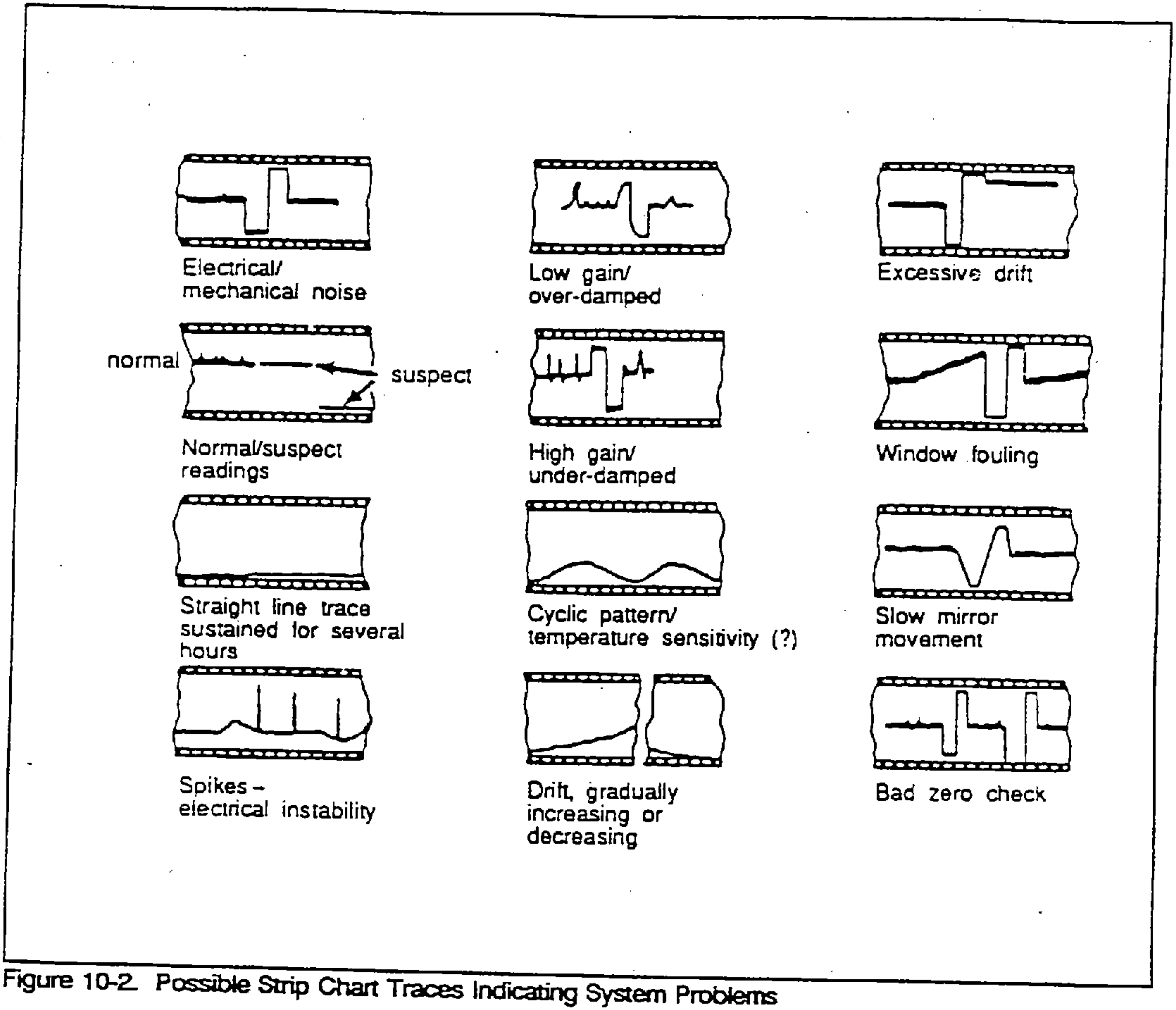
[a] ng = nanogram; J = joule.

Calibration Drift

There are several important points to understand about calibration drift. First, the span value for calibration drift is defined as the upper limit of a gas concentration measurement range specified for affected source categories in the applicable subparts of 40 CFR 60.

The span value is not found in the performance specifications but in the subparts of 40 CFR 60 that address the source category where the CEM system is required (i.e., Subpart D, Da, and Db for FFFSG, Subpart BB for Kraft Pulp Mills, and Subpart P for Petroleum Refineries). For example, in Subpart Db for Industrial-Commercial-Institutional Steam Generating Units span values for NO_x CEM systems are given in paragraph 60.48b. The span values are incorporated in Table 6-4.

SHB 249



Electrical/ mechanical noise

Low gain/ over-damped

Excessive drift

Normal/suspect readings

High gain/ under-damped

Window fouling

Straight line trace sustained for several hours

Cyclic pattern/ temperature sensitivity (?)

Slow mirror movement

Spikes – electrical instability

Drift, gradually increasing or decreasing

Bad zero check

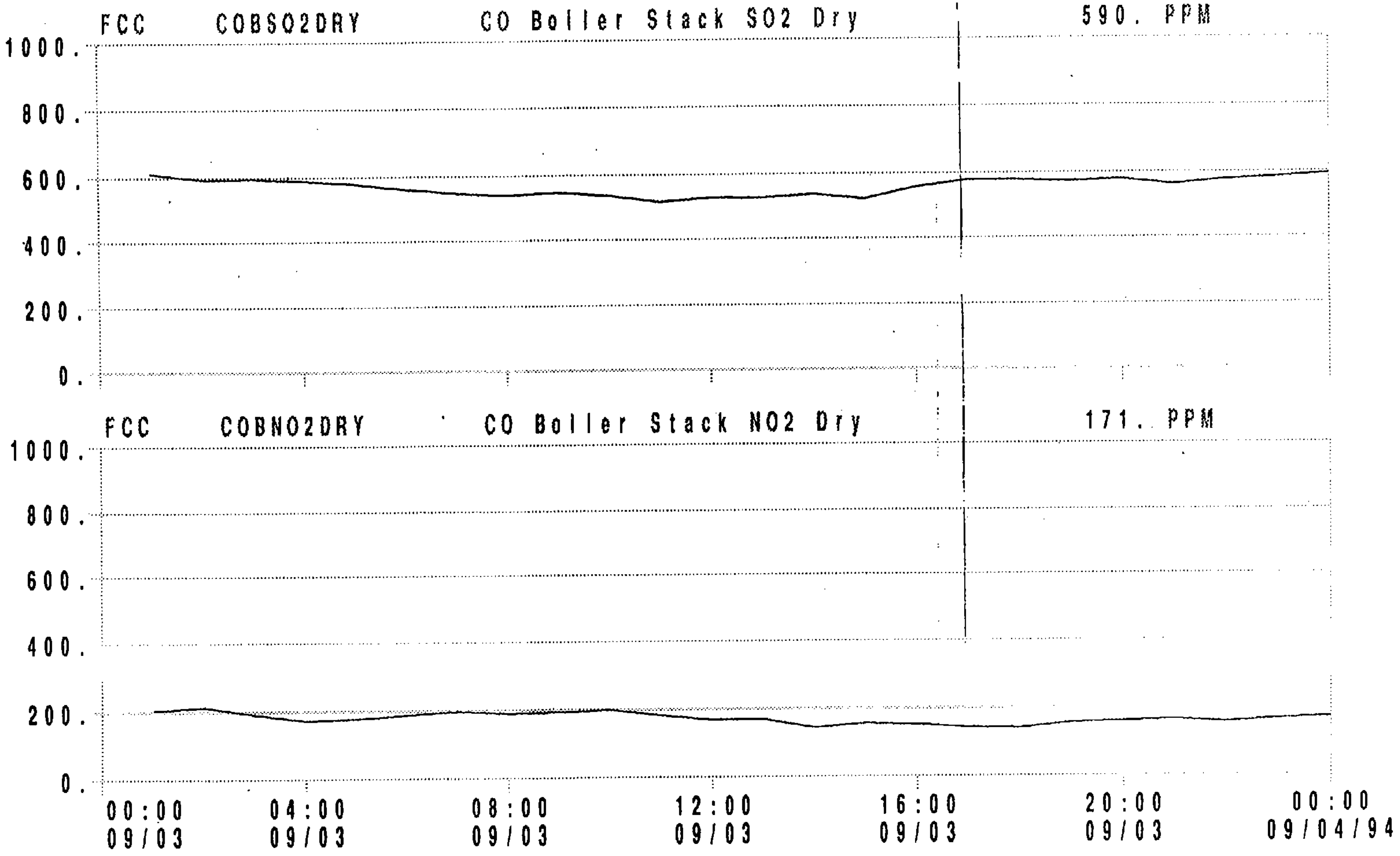
Figure 10-2. Possible Strip Chart Traces Indicating System Problems

The strip chart record also gives many clues to the quality of the source monitoring program. If the pen is not inking (the pen does not have the proper amount of ink or the ink is smearing), if the paper is jammed, or if the chart speed is too slow to provide intelligible data, the data might not be accurate. A working strip chart should be properly annotated, and the record of the daily zero and calibration tests should be easily read. Figure 10-3 on the next page gives an example of a properly annotated record.

Inspectors seldom find a well-annotated chart, and the full-scale-chart value, the degree of offset, and the chart speed will most likely have to be determined. A good technique to use, prior to inspection, is to fashion a rubber stamp that incorporates blanks for the information required, including the organization's logo, and a place for a signature, date, and time.

Evaluating a computer record will require assistance from the CEM operator. It is difficult to examine a printout (or even to obtain one) without some assistance. When reviewing the data, the inspector should look for the zero and span values first; this will provide some orientation to the format. If there are any printed fault codes, it is advisable to examine them; it might be useful to have the codes printed out in the data acquisition system documentation.

1 DAY OF 1 HOUR AVERAGE DATA



SHB-253

If the mean difference is outside this ran , it does not necessarily mean that the transmissometer readings are incorrect; data from two diss iar methods are being compared, and discrepancies can occur for any of the following reasons:

Method 9 Problems	Transmissometer Problems
• water vapor or acid gases condensing at plume exit, but not in the stack	• improper instrument calibration
	• incorrect stack-exit correlation value
• poor contrast conditions (cloudy sky, limited light)	• dirty optics
• poorly trained observer	• misalignment
	• particulate stratification at monitoring location

The contribution of the problems between Method 9 observations and transmissometer data can be approximated. A scheme is given in the Inspection Guide for generating "corrected" data.

Evaluation Of Transmissometer System Operational Status

The operation of the transmissometer system can be checked by inspecting (1) the data acquisition system (strip chart recorder, computer); (2) system fault lamps; (3) the zero and span values; and (4) instrument-specific diagnostic criteria.

The Data Acquisition System. If a CEM system has a strip chart recorder, it is usually used to record opacity values from the transmissometer. A strip chart record can reveal various kinds of information and gives a g d indication of how well the system is being maintained. If only a computer printout is available. audit will be more difficult. It is harder to detect trends, noise, and other system proble s from digi a, although system fault codes are often helpful. Figure 10-2 on the next page illustrates some of t problems that can be identified from the strip chart record.

These strip chart traces indicate a number of problems, such as temperature effects, vibration, and sticking zero mirrors. Some of these chart indications are obvious. A sustained reading of a zero value does not generally mean that the air pollution control equipment is working exceptionally well; it often means that no signal is coming out of the transmissometer.

SHB-25

Table 4-3. Portable VOC Detection Instrument Performance Specifications (U.S. EPA, 1992b)

Flame Ionization Analyzers

		Method 21 Criteria							
		Meets Leak Definition							
Manufacturer	Model	500 ppmv	10,000 ppmv	5% Definition at Leak Level	Intrinsically Safe	Response Time (sec)	0.25-in. o.d. Probe	Sample Flow (L/min)	Comments
The Foxboro Company	OVA 88	no	yes	yes	no	2	yes	2.0	
	OVA 108	no	yes	yes	yes	2	yes	2.0	
	OVA 128	yes	no	yes*	yes	2	yes	2.0	6
Heath Consultants, Inc.	DP-III	yes	yes	yes	no*	3	yes	2.0	2
	DP-II	yes	no	no	no*	3	yes	2.5	3
	PF-II	yes	no	yes*	no*	2	yes	0.7	4,6
MSA/Baseline Industries, Inc.	GasCorder FID	no	no*	no*	no*	3	yes	0.5	5
Sensidyne, Inc.	Portable FID	yes	yes	yes	no*	3	yes	1.25	1
Thermo Environmental Instruments, Inc.	710	yes	no	no	no	5	yes	1.5	
	712	yes	yes	yes	no	5	yes	1.5	

* = See Comments.

Comments:

1. Working on making intrinsically safe instrument.
2. Plans are under way to make DP III intrinsically safe.
3. Plans are under way to make DP II intrinsically safe.
4. Currently being modified to be intrinsically safe.
5. Will reach market 9/91 and will be redesigned to meet Class I, Division 1 and 2 standards by approximately 12/92.
6. Five percent definition at 500 ppmv leak level.

Flame Ionization Analyzers

Manufacturer	Model	Calibration Gas	Maximum Range (ppmv)	Battery/Fuel Life (hr)	Dimensions (In.) and Weight (lb)	Temperature (Celsius)	Price* ($)	Comments
The Foxboro Company	OVA 88	Methane	0-100,000	8	9 x 12 x 4, 11	10 to 40	4,400	1
	OVA 108	Methane	0-10,000	8	9 x 12 x 4, 12	10 to 40	6,600	2
	OVA 128	Methane	0-1,000	8	9 x 12 x 4, 12	10 to 40	6,600	3
Heath Consultants, Inc.	DP-III	Methane	0-10,000	8	3.5 x 7 x 10, 7	-20 to 48	3,200	7
	DP-II	Methane	0-1,000	8	11 x 7 x 9, 9	-20 to 48	4,000	8
	PF-II	Methane	0-5,000	10	3 x 10 x 9, 6.3	-20 to 48	2,500	9
MSA/Baseline Industries, Inc.	GasCorder FID	Methane	0-10,000**	8	17 x 11.2 x 8, 18.5	5 to 35	6,800	10
Sensidyne, Inc.	Portable FID	Methane	0-10,000	15	14.5 x 4.6 x 9.3, 6.5	-5 to 40	4,800	6
Thermo Environmental Instruments, Inc.	710	Methane	0-2,000	8	10 x 4 x 8.5 (Case)	0 to 40	5,800	4
	712	Methane	0-20,000	8	6.5 x 6.1 x 4 (Gun) 14 total	0 to 40	5,800	5

* = Approximate base unit price 8/91.
** = See Comments.

Comments:

1. The OVA 88 is primarily for natural gas leak detection. Logarithmic analog scale.
2. Generally accepted as the industry standard. Logarithmic analog scale.
3. GC option ($1,200) for qualitative analysis. Three scales 0-10, -100, -1,000. Linear analog scale.
4. Three scales 0-200, -2,000, -20,000. Digital readout.
5. Three scales 0-2,000, -20,000, -200,000. Digital readout.
6. Two scales 0-1,000, 0-10,000. Analog scale.
7. Five scales maxima of 10, 50, 100, 1,000, and 10,000.
8. Five scales maxima of 10, 50, 100, 500, and 1,000.
9. Three scales 0-50, 0-500, 0-5,000. Analog scale.
10. Dedicated air and hydrogen cylinders. Data logging capabilities.

ɪe 4-3 (continued)

Photoionization Analyzers

ıufacturer	Model	Method 21 Criteria: Meets Leak Definition: 500 ppmv	Method 21 Criteria: Meets Leak Definition: 10,000 ppmv	Method 21 Criteria: 5% Definition at Leak Level	Method 21 Criteria: Instrinsically Safe	Method 21 Criteria: Response Time (sec)	Method 21 Criteria: 0.25-in. o.d. Probe	Sample Flow (L/min)	Comments
ı Systems,	IS-101	yes	no	no	yes	3	yes	0.17	
	DL-101-2	yes	no	no	no*	3	yes	0.25	1
	DL-101-4	yes	no	yes*	no*	3	yes	0.25	1,4
∧/Baseline	GasCorder PID	yes yes	no*	yes*	no*	3	yes	0.5	3,4
A mational	Photon	yes	no	yes*	no*	3	yes	0.5	1,4
ıtex Sensing :hnology, Inc.	Scentogun	yes	no	yes*	no	2	yes*	0.1	2,4
ırmo ironmental ɾuments, Inc.	580-S	yes	no	yes*	yes	2	yes	0.4	4
	580-B	no	no	no	no	2	yes	0.4	

See Comments.

ımments:
Class I, Division 2 certified.
Meets Method 21 probe size criteria only when used with optional extension.
Will be redesigned approximately 12-18 months after it reaches the market (9/91) to meet Class I, Division 1 and 2 requirements.
Five percent definition at 500 ppmv leak level.

Photoionization Analyzers

ɪanufacturer	Model	Calibration Gas	Maximum Range (ppmv)	Battery/Fuel Life (hr)	Dimensions (in.) and Weight (lb)	Temperature (Celsius)	Price* ($)	Comments
ɪu Systems, :.	IS-101	Benzene, Isobutylene	0-2,000	8	8 x 5 x 9, 10	-15 to 40	5,000	1
	DL-101-2	Benzene	0-2,000	8	8 x 3 x 6, readout 4	40 max	4,900	2
	DL-101-4	Benzene	0-2,000	8	8 x 3, probe 3 8 x 3 x 6, readout 4	40 max	5,500	3
ƷA/Baseline	GasCorder PID	Benzene	0-2,000**	8	17 x 8 x 8, 10	5 to 35	5,000	7
ƷA ɛrnational	Photon	Isobutylene	0-2,000	8	16.9 x 3.8 x 5.8, 7	0 to 40	5,000	5
ɪntex Sensing ːchnology, Inc.	Scentogun	Benzene	0-2,000	6	9 x 6 x 4, 4	None supplied	3,750	6
ɪermo ɪvironmental struments, Inc.	580-S	Benzene	0-2,000	8	6.75 x 5.75 x 10, 7.5	5 to 40	5,300	4
	580-B	Benzene	0-2,000	8	6.8 x 5.8 x 10, 6	5 to 40	4,400	4

= Approximate base unit price 8/91.
= See Comments.

ɔmments:
Basic instrument is PI-101. The HW-101 (Hazardous Waste) is Class I, Division 2 certified. Analog readout, three scales.9.5, 10.2, 11.7 eV lamps.
DL-101-2 has two modes of operation, data logging capabilities, digital readout, 9.5, 10.2, 11.7 eV lamps.
DL-101-4 has four modes of operation, data logging capabilities, digital readout, 9.5, 10.2, 11.7 eV lamps.
4. Digital display, data logging capabilities, optional bar code reader interface.
5. Digital display, data logging capabilities, 10.6 eV lamp.
6. Digital display, 10.6, 11.5 eV lamps.
7. Dilution system available. 8.4, 9.6, 10.2, 10.6, 11.8 eV lamps. Data logging capabilities.

158

Table 4-3 (c

Manufacture
AIM USA
Arizona Instrument
Bacharach, I
CEA Instruments,
The Foxboro Company
Gas Tech, In
McNeil International

* = See Com

Comments:
1. Internal lit
2. No s
3. Sca a
4. Four scal given).
5. Meets Me
6. BASEEF
7. Intrinsical
8. Submittec
9. Leak defi

Manufactu
AIM USA
Arizona Instrument
Bacharach,
CEA Instrument Inc.
The Fo Compa

Table 4-3 (continued)

Infrared, Electrochemical, and Solid State Analyzers

		Method 21 Criteria							
		Meets Leak Definition							
Manufacturer	**Model**	**500 ppmv**	**10,000 ppmv**	**5% Definition at Leak Level**	**Instrinsically Safe**	**Response Time (sec)**	**0.25-in. o.d. Probe**	**Sample Flow (L/min)**	**Comments**
AIM USA	1300	yes	yes	yes	yes	1	yes*	1.5	5
	3300	yes	yes	yes	yes	1	yes*	1.5	5
Arizona Instrument	Jerome 431X	no	no	no	no	13	yes	0.750	3
	Jerome 631X	no	no	no	no	6	yes	0.150	4
Bacharach, Inc.	TLV sniffer	yes	yes	yes	yes	<30	yes	1.75	
	MV-2	no	no	no	no	5	yes	N/A	2
CEA Instruments, Inc.	Gaseeker GS4	yes	yes	no	yes*	<10	yes	0.3	6
The Foxboro Company	MIRAN 1Bx	yes	no	yes*	yes	Compound dependent	no	30	1
Gas Tech, Inc.	1238	yes	no	yes*	yes*	<10	yes	0.47	7
	4320	yes	no	yes*	yes*	<10	yes	1.0	7
	GP-116	no	yes	yes	no*	5	yes	2.0	8
McNeil International	Gasurveyor 4	yes	no	yes*	yes	5	yes	0.5	

* = See Comments.

Comments:
1. Internal library of approximately 115 compounds.
2. No sample flow given.
3. Scale reads in milligrams per cubic meter.
4. Four scales 1-1000 ppbv, 0.1-1.0 ppmv, 1-10 ppmv, and 10-50 ppmv. Response time varies by scale and mode setting (survey mode times given).
5. Meets Method 21 criteria only when used with optional sample pump attachment.
6. BASEEFA certification is pending.
7. Intrinsically safe Class I, Division 1, Groups C and D.
8. Submitted for UL safety approval.
9. Leak definition at 500 ppmv.

Infrared, Electrochemical, and Solid State Analyzers

Manufacturer	**Model**	**Calibration Gas**	**Maximum Range (ppmv)**	**Battery/Fuel Life (hr)**	**Dimensions (in.) and Weight (lb)**	**Temperature (Celsius)**	**Price* ($)**	**Comments**
AIM USA	1300	Methane	0-50,000	7.5	18 x 2 dia, 4.5	0 to 50	1,200	5
	1300	Benzene	0-50,000	7.5	18 x 2 dia, 4.5	0 to 50	2,200	5
Arizona Instrument	Jerome 431X	N/A	0-0.999 (mg/m^3)	6	6 x 13 x 4, 7	0 to 40	5,900	4
	Jerome 631X	N/A	0-50	6	6 x 13 x 4, 7	0 to 40	9,900	4
Bacharach, Inc.	TLV sniffer	Hexane	0-10,000**	8	9 x 3.75 x 6.6, 5	10 to 49	1,840	2
	MV-2	N/A	0-1.0 (mg/m^3)	4	11.4 x 4.8 x 4.4, 6	N/A	3,300	3
CEA Instruments, Inc.	Gaseeker GS4	Methane	0-10,000	10	3 x 6 x 6, 0.3	-10 to 50	1,200	6
The Foxboro Company	MIRAN 1Bx	**	**	4	27 x 9 x 11, 28	5 to 40	17,100	1

ble 4-3 (continued)

Infrared, Electrochemical, and Solid State Analyzers (continued)

anufacturer	Model	Calibration Gas	Maximum Range (ppmv)	Battery/Fuel Life (hr)	Dimensions (in.) and Weight (lb)	Temperature (Celsius)	Price* ($)	Comments
as Tech, Inc.	1238	Hexane	0-1,000	8	12 x 3.8 x 5.5, 8	-12 to 49	1,300	7
	4320	Hexane	0-2,000	8	12 x 3.8 x 5.5, 8	-12 to 49	2,600	8
	4320	Hexane	0-2,000	8	12 x 3.8 x 5.5, 8	-10 to 40	<5,000	9
cNeil ternational	Gasurveyor 4	**	0-1,000	15	7 x 3.8 x 4.1, 3.5	-20 to 50	1,900	10

= Approximate base unit price 8/91.
= See Comments.

omments:
1. Infrared. Internal library of approximately 115 compounds. Calibration ranges from 0-10 ppmv to 0-2,000 ppmv. Digital readout. Infrared instrument.
2. Range can be expanded to 0-100,000 ppmv with 10:1 dilution probe option.
3. Mercury vapor detector only. Digital readout.
4. Digital readout, data logging capabilities, software optional.
5. Digital readout with data logging capabilities. PC software optional.
6. Logarithmic LED scale, not defined enough at 95% for Method 21.
7. Analog meter, also reads 0-100% LEL combustibles.
8. Analog meter, also reads 0-100% LEL combustibles, 0-25% oxygen, 0-100 ppmv H S, and 0-300 ppmv CO .
9. Digital readout, data logging system with integral bar code pen. 25,000 and 50,000 ppmv ranges available.
0. Electronically calibrated.

roviding data that can be related to EPA's data ollected using an organic vapor analyzer (OVA) alibrated to methane.

everal initial steps must be taken to document the iability of a device that fails to meet the Method 21 equirements. First, a laboratory program must emonstrate the response of the monitoring instrument o the compounds being measured. This response ust be documented. The second step is relating the nstrument response (i.e., screening value) to actual oncentrations to develop an instrument response urve. The screening value response curve must be eveloped for the entire screening value range and ocumented so that screening values taken in the field an be adjusted to actual concentrations. Third, the esting program should be sufficiently well documented o demonstrate how the instrument will be used in the screening program. For example, if the response time f the candidate instrument exceeds the Method 21 erformance specification, the test plan should reflect dded screening time at each potential leak point to be screened. Once this laboratory demonstration is ompleted and the screening value correction curve is established, the screening can begin.

4.3 Screening Protocols

4.3.1 Calibration

Before screening begins, the monitoring instrument must be calibrated (U.S. EPA, 1988, p. 3-22). The VOC analyzer is assembled and started up according to the manufacturer's instructions. After the appropriate warmup period, the person performing the test should introduce zero gas into the sample probe, and set the instrument meter readout to zero. He or she then should introduce the calibration gas into the sample probe, and adjust the instrument meter readout to correspond to the calibration gas value. If the meter readout cannot be adjusted to the proper value, a malfunction of the instrument is indicated, and corrective measures should be taken before the instrument is used. The operator's manual for each instrument might help determine the cause of the malfunction. Also, verifying that the calibration gas contains the rated concentration of gas might be appropriate.

4.3.2 Procedure for Screening Equipment

The mechanics of the screening operation outlined in Reference Method 21 are summarized in the following discussion (U.S. EPA, 1992a). The operator places the probe inlet at the surface of the leak interface where leakage could occur. (The leak interface is the boundary between the process fluid and the atmosphere.) The probe must be perpendicular, not tangential, to the leak interface so that inaccurate readings do not result. Then the probe should be moved along the interface periphery while the instrument readout is observed. If the meter reading increases, the operator moves the probe slowly along the interface where leakage is indicated until the maximum meter reading is obtained. The probe inlet should be left at this maximum reading location for approximately two times the instrument

SHB- 260

---

response
recorded

The instr
of in
exc 1
generate
also must
to allow
the instrur
with a
concentra
measurer
instrumen

Fouling o
be avoide
as a prob
In areas
tubing ca
a filter. (T
filter in p
dirty, the
avoid sc
unavoida
at least
recomme
by rappin
are wet
solution
solution
tran
should b
procedur
such as
pressure
VOC lea
lines, or

4.3.2.1

For valve
between
the oper
exits the
circumfe
recorded
the pack
along t
assembl
all point
mainten
also Fi
illustrati

4.3.2.2

For fl
of the fl

LOCATION:
FAX #: 415/928 8560
MESSAGE: Relative Response Chart.

LOCATION:
FAX #:
PHONE #:

DOX # 84668

ALIGN ARROWS WITH TOP OF DOCUMENT

NEW UPDATED CENTURY RELATIVE RESPONSE CHART

(Tear out and save!)

3/26/90

CENTURY RELATIVE RESPONS .RT

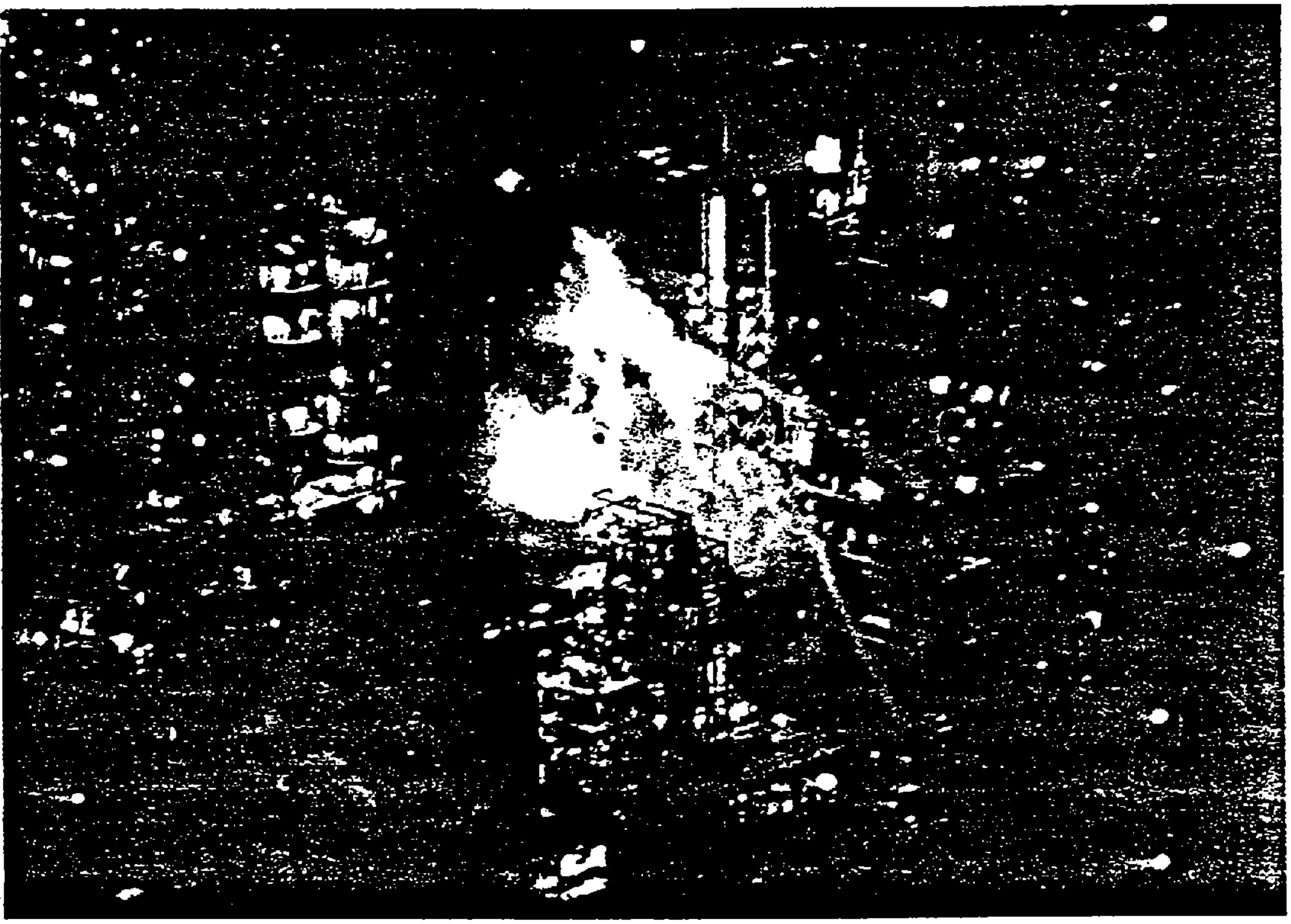
COMPOUND	RELATIVE RESPONSE % (AS METHANE)	COMPOUND	RELATIVE RESPONSE % (AS METHANE)	COMPOUND	RELATIVE RESPONSE % (AS METHANE)
ACETALDEHYDE	25	O-DIETHYLBENZENE	75	METHYL ACRYLATE	40
ACETIC ACID	80	DIETHYL ETHER	18	METHYL CHLORIDE	78
ACETONE	60	DIETHYL KEYTONE	80	METHYL CYCLOHEXANE	100
ACETONITRILE	70	DIMETHYL ANILINE	45	METHYL CYCLOPENTANE	80
ACETYLENE	225	DIMETHYL ETHER	21	METHYL ISO-BUTYL KETONE	100
ACROLEIN	27	DIMETHYL FORMAMIDE	34	METHYL METHACRYLATE	50
ACRYLIC ACID	11	DIMETHYL HYDRAZINE	20	4-METHYL-2-PENTANONE	100
ACRYLONITRILE	70	DIMETHYL SULFIDE	20	METHYLENE CHLORIDE	80
ALLYL ALCOHOL	30	DIOXANE	30	METHYL ETHYL KETONE (2-BUTANONE)	80
ALLYL CHLORIDE	50	DIPROPYLAMINE	110	METHYL PROPYL KETONE (2-PENTANONE)	65
AMMONIA	N/F	EPICHLOROHYDRIN	60	METHYL ISO-PROPYL KETONE	90
ANILINE	30	ETHANE	80	METHYL TERT BUTYL ETHER	62
BENZENE	150	ETHANOL	25	4-METHYL-2-BUTANONE	80
BENZYL CHLORIDE	60	ETHANOL AMINE	N/F	MONOMETHANOL AMINE	N/F
BIPHENYL	N/F	2 ETHOXY ETHANOL	22	MONOMETHYL HYDRAZINE	78
BROMOETHANE	75	ETHRANE	150	NAPTHALENE	48
1-BROMOPROPANE	75	ETHYL ACETATE	65	NITROBENZENE	88
BUTANE	63	ETHYL ACRYLATE	40	NITROMETHANE	34
1,3, BUTADIENE	32	ETHYL BENZENE	100	1-NITROPROPANE	60
N-BUTANOL (BUTANOL)	65	ETHYL BROMIDE	75	2-NITROPROPANE	70
ISO-BUTANOL (2 METHYL PROPANOL)	70	ETHYL BUTYRATE	70	NONANE	90
SEC-BUTANOL (2 BUTANOL)	65	ETHYLCHLORIDE	55	OCTANE	80
TERT-BUTANOL (2 METHYL-2 PROPANOL)	105	ETHYLENE	85	PENTANE	65
BUTENE	53	ETHYLENE DIAMINE	N/F	PENTANOL	40
2-BUTOXY ETHANOL	44	ETHYLENE DIBROMIDE (1,2 DIBROMOETHENE)	60	PHENOL	54
N-BUTYL ACETATE	80	ETHYLENE DICHLORIDE (1,2 DICHLOROETHANE)	50	PHTHALIC ANHYDRIDE	N/F
N-BUTYL ACRYLATE	60	ETHYLENE GLYCOL	N/F	PIPERIDINE	70
2-BUTYL ACRYLATE	70	ETHYLENE OXIDE	70	PROPANE	70
N-BUTYL FORMATE	50	ETHYL FORMATE	40	PROPANOIC ACID	32
2-BUTYL FORMATE	60	ETHYL METHACRYLATE	70	1-PROPANOL	41
N-BUTYL METHACRYLATE	60	ETHYL PROPIONATE	65	2-PROPANOL (ISOPROPANOL)	65
2-BUTYL METHACRYLATE	50	FORMALDEHYDE	N/F	PROPYL ACETATE	75
CARBON DISULFIDE	N/F	FREON 11	10	PROPYL BROMIDE (BROMO PROPANE)	78
CARBON TETRACHLORIDE	10	FREON 12	16	N-PROPYL ETHER	65
CELLASOLVE ACETATE	44	FREON 13	15	N-PROPYL FORMATE	60
CHLOROBENZENE	100	FREON 21	72	PROPYLENE	N/F
CHLORODIFLUOROMETHANE (FREON 22)	40	FREON 22	70	PROPYLENE GLYCOL	N/F
CHLOROFORM	65	FREON 113	90	PYRIDINE	128
1-CHLOROPROPANE	75	FREON 114	110	STYRENE	80
2-CHLOROPROPANE	90	FREON 116	42	1,1,1,2-TETRACHLOROETHANE	100
CUMENE	70	HALOTHANE	30	1,1,2,2-TETRACHLOROETHANE	100
CYCLOHEXANE	85	HEPTANE	75	TETRACHLOROETHYLENE PERC.	70 %
CYCLOHEXANONE	110	HEXACHLORO 1,3 BUTADIENE	71	TETRAHYDROFURAN	40
DECANE	75	HEXANE	75	TOLUENE	110
O-DICHLOROBENZENE	60	HEXANOL	60	2,4 TOLUENE DI ISOCYANATE	N/F
P-DICHLOROBENZENE	113	HEXENE	70	TRICHLOROBENZENE	100
1,1 DICHLOROETHANE	80	ISOBUTENE (ISOBUTYLENE)	74	1,1,1-TRICHLOROETHANE	105
1,2 DICHLOROETHANE	80	ISOPENTANE	80	TRICHLOROETHYLENE	70
TRANS 1,2-DICHLOROETHYLENE	50	ISOPRENE	60	1,2,3-TRICHLOROPROPANE	73
DICHLOROMETHANE	100	ISO-PROPANOL (2-PROPANOL)	65	TRIETHANOL AMINE	N/F
1,2-DICHLOROPROPANE	90	ISOPROPYL ACETATE	71	TRIETHYLAMINE	70
1,3-DICHLOROPROPANE	80	MALEIC ANHYDRIDE	N/F	VINYL CHLORIDE	35
DICYCLOPENTADIENE	48	METHANE	100	VINYLIDENE CHLORIDE	40
DIESEL FUEL	*F	METHANOL	12	M-XYLENE	111
DIETHANOL AMINE	N/F	2-METHOXYETHANOL	14	P-XYLENE	116
DIETHYLAMINE	75	METHYL ACETATE	41	O-XYLENE	116

Relative Response Factors were generated at TWA concentrations or 60 ppm whichever is less.
N/F = NOT FEASIBLE, *F = FEASIBLE BUT RESPONSE DATA NOT AVAILABLE

$$\text{ACTUAL CONCENTRATION} = \frac{\text{MEASURED CONCENTRATION}}{\text{RELATIVE RESPONSE (AS A DECIMAL)}}$$

Large Property Damage Losses in the Hydrocarbon-Chemical Industries
A Thirty-year Review

Sixteenth Edition
David Mahoney, Editor



MARSH &
McLENNAN
M&M Protection Consulta

SHB-263

Table of Contents

Introduction

Sixteenth Edition
David Mahoney, Editor

This sixteenth edition reviews 100 large property damage losses that occurred in the hydrocarbon-chemical industries over the last 30 years. Although nearly all of the losses involved fires or explosions, this edition includes several losses that resulted from natural hazards events. Offshore and marine transportation losses are excluded from this publication, except for those losses involving marine vessels moored at a plant dock. Of all the property damage losses that occurred in the hydrocarbon-chemical industries during this period, we have selected 100 large losses that have sufficient data available for a complete account of each incident.

The 100 large losses in this edition represent approximately $7 billion in property damage, stated in January 1, 1995, dollars. The loss amounts were trended using an inflation index for petroleum equipment published by Industrial Risk Insurers, thus allowing a comparison of events on a constant dollar basis over the 30-year period. The loss amounts include property damage, debris removal, and cleanup costs; however, the costs of business interruption, extra expense, employee injuries, and liability claims are excluded.

Increased regulatory, safety, and environmental concerns have, in many cases, increased the cost of permits, debris removal, and cleanup associated with large property damage losses. These concerns relate to asbestos abatement, PCB removal, or cleanup of spilled oil or chemicals following a fire, explosion, or other loss event. These direct, on-premises cleanup costs traditionally have been considered part of the property damage loss and, to the extent insurance is applicable, are paid by property insurance underwriters.

This edition includes eight new losses compared with the fifteenth edition, our last publication of 100 large property damage losses. Five of the new losses occurred in 1994 and one in each of the years 1993, 1991, and 1989. The five losses in 1994 totaled $354,000,000 in property damage with an average value of $70,800,000 per loss. Of these five losses, the two largest losses involved petrochemical plants and totaled $224,400,000 in property damage. Additionally, these two losses represented 63 percent of the total property damage for the five losses in 1994. The remaining three new losses in 1993, 1991, and 1989 involved two refineries and a synthetic fuels plant and totaled $137,600,000 in property damage with an average value of $45,900,000 per loss. The other 92 large property damage losses listed in this edition for the years 1965 through 1993 represented $6.56 billion in property damage with an average value of $71,300,000 per loss.

Three of the large property damage losses in this edition resulted from natural hazards events such as heavy rain, hurricane, and electrical storm. A petrochemical plant in Baytown, Texas, experienced $25,000,000 in property damage on October 17, 1994, from heavy rain and subsequent flooding; a refinery in St. Croix, Virgin Islands, experienced $62,000,000 in property damage on September 18, 1989, as a result of Hurricane Hugo; and a refinery in Deer Park, Texas experienced $68,000,000 in property damage on September 1, 1979, as a result of an electrical storm and subsequent ship explosion. The total trended property damage from these three losses is $215,300,000 with an average value of $71,800,000 per loss.

While Hurricanes Andrew and Iniki in 1992 resulted in catastrophic "general property" damage losses, these natural hazards events did not cause a single catastrophic loss in the hydrocarbon-chemical industries. However, the losses from these hurricanes had an adverse impact on the overall insurance market as discussed in the Insurance Broker's Perspective by John Lapsley, Managing Director, Marsh & McLennan, Inc. The subsequent decrease in insurance market capacity following these natural hazards events resulted in an indirect, undesirable effect on the insurance for the hydrocarbon-chemical industries.

The large property damage losses have been grouped by type of complex into one of five categories: Refineries, Petrochemical Plants, Gas Processing Plants, Terminals, and Miscellaneous. The Miscellaneous category includes six losses involving an industrial resin coatings plant, paint manufacturing plant, synthetic fuels plant, natural gas transmission compressor station, and two crude oil pipeline pump stations.

Acknowledgement

M&M Protection Consultants would like to acknowledge the significant input from the various sources interested in the prevention, mitigation, and analysis of large property damage losses that makes this publication possible. We will continue to rely on information provided from interested professionals as well as published sources, and we encourage readers to bring errors, omissions, or additional information to our attention.

Additional copies of this publication are available through M&M Protection Consultants.

An Insurance Broker's Perspective

By John J. Lapsley
Managing Director
Marsh & McLennan, Inc.

The year 1994 was friendly for insurers underwriting physical damage risks for onshore hydrocarbon processing risks. It was the fourth consecutive year of premium increases and coverage discipline. When examining large losses in this publication for the years 1991 through 1994, you could guess that underwriters made quite a gain during this period, especially in 1993 and 1994 when rates remained firm and energy portfolios ran free of catastrophes.

On the other hand, during the prior four year period, 1987 through 1990, premium levels were at their softest while large losses peaked. Many insurance markets unfortunately ceased underwriting energy business during this period and have not enjoyed the 1991 through 1995 improvement.

It is difficult to state whether underwriting this class throughout both periods was profitable as there are many other factors such as the availability of competitive catastrophe reinsurance, attachment point(s) of the risk transfer(s), and contribution of investment income. Generally, most markets express the view that over the long term, this business has made positive underwriting margins.

It should be noted that energy underwriting is a business segment of property & casualty insurance companies, reinsurance companies, and Lloyd's Syndicates. Our large loss publication lists only property damage losses in the hydrocarbon/chemical industry. In addition to these large losses the same markets have been absorbing an increasing amount of "general property" losses from an alarming sequence of natural catastrophes.

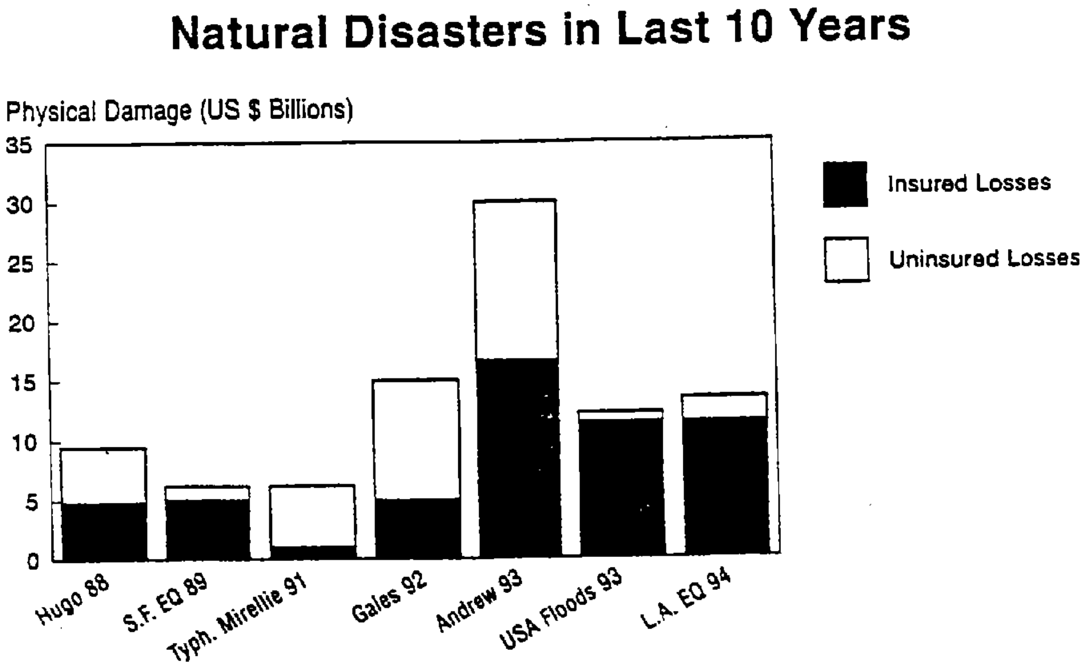


Fig. 1

Early reports on 1995 Kobe, Japan, earthquake indicate US $100 billion in damages. It is too premature to estimate the amount insured; however, the best guess is less than US $5 billion.

S4B-267

More importantly, at least to our clients, is the availability or supply of underwriting capacity. It is this factor which gives insight on how much of the risk can be transferred and how much pressure can be exerted by the market on the price. The following graphic illustrates a general trend of capacity.

Supply of Onshore Energy Capacity

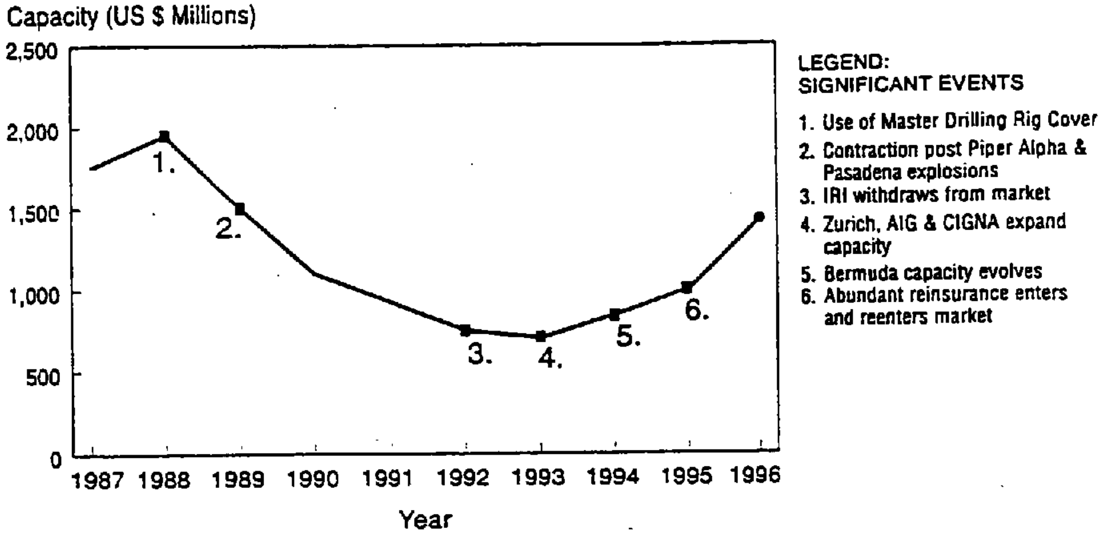


Fig. 2

The illustration assumes gross capacity available for fire and/or explosion risks at a market consensus premium. Capacities represent EML capacity usually available to major integrated oil companies considering the utilization of marine and non-marine underwriters for onshore risks.

O.I.L. is a mutual insurance organization made up of approximately 46 member energy companies. An additional $150 million of capacity was available for O.I.L. members until 1988 when the limit was increased to $300 million. Due to lack of reinsurance, the limit was reduced to $200 million in 1991 and has remained at that level.

In figure 2 the term EML (Estimated Maximum Loss) is used. The EML methodology is used by sophisticated markets to estimate the worst case loss scenario for hydrocarbon processing risks under normal conditions.

Another factor affecting capacity is the very conservative approach now adopted by underwriters when calculating EML's based on vapor cloud explosion. Prior to the property loss in Pasadena, Texas in 1989, EML's for a plant typically would be around 15 percent of the total site value. In the wake of the Pasadena incident, vapor cloud explosion methods were drastically revised with the result that today EML's of around 30 percent are common.

Not surprisingly, the insurance supply increases as rates rise and decreases as markets dry up following catastrophes and underwriting losses. In this regard, we believe capacities will continue to grow in 1995 and beyond at a faster pace with pricing stabilizing unless or until large losses again impact underwriters' earnings.

Losses, premiums, and capacities have been erratic in the insurance market for onshore energy assets. To a large extent these factors are out of individual risk managers' control and their decisions are basically made within the parameters set by these factors.

The protection of these assets and the prevention of loss incidents are somewhat in the control of our clients. In view of this issue, all the major underwriting groups have invested in engineering expertise as has Marsh & McLennan, Inc., through M&M Protection Consultants. Virtually, all major onshore energy insurance programs, especially those covering business interruption, now contain an engineering element. The engineering aspect both offers loss control advice to insureds and also assists underwriters assemble data to choose their risks and determine adequate premium levels.

In conclusion, markets and clients are now both benefiting from the good results. We must keep in mind that historically this specialized market segment is very fragile; in that poor underwriting results swiftly change supply of capacity and ultimately rating. To suggest the current softening is one large catastrophic loss away from hardening again is certainly a possibility. To this end, the brokers, clients, and underwriters should all be in concert so that as marketing becomes easier the attention to the engineering concerns should not be diminished.

07/24/94
Pembroke, United Kingdom
$77,500,000
$79,100,000
New this edition

A severe thunderstorm passed over the refinery between 7:20 a.m. and 9:00 a.m. on July 24. Lightning strikes resulted in a 0.4 second power loss and subsequent power dips throughout the refinery. Consequently, numerous pumps and overhead fin-fan coolers tripped repeatedly, resulting in the main crude column pressure safety valves lifting. Also, major process unit upsets occurred in other refinery units, including those within the fluid catalytic cracking (FCC) complex. This 90,000 barrel-per-day cracking complex, which includes the FCC unit, Butamer unit, alkylation unit, and an idle hydrogen plant, is a joint venture of two refining companies.

The refinery crude unit was shut down following ignition of vapor escaping from the main crude column pressure safety valves by a subsequent lightning strike. Except for the FCC unit itself, all units in the cracking complex were also shut down. However, a process upset in the FCC unit's gas recovery section ultimately led to a high liquid level in the on-plot flare drum and several shutdowns of the wet gas compressor together with other process anomalies.

As a result of the wet gas compressor shutdown, there was a large vapor load on the FCC flare system, which lead to a high liquid level in the on-plot flare drum. When the hydrocarbon liquid overflowed into the outlet line of this drum, the line ruptured due to mechanical shock. A pulsing leak appeared at the flare drum discharge elbow where the outlet line had ruptured and fallen to the ground. The hydrocarbon liquid and vapor mixture released from this flare system became an explosive mixture that drifted within the process area prior to being ignited by a heater. The explosion, which occurred at 1:23 p.m., was centered in the process area approximately 360 feet (110 meters) from the FCC on-plot flare drum.

Following the explosion, a number of isolated fires continued to burn at locations within the FCC, Butamer, and alkylation units. In view of the entrained hydrocarbons in damaged areas of the plant and a non-operative flare system, these small fires were allowed to burn out under controlled conditions with the last fire being extinguished on the morning of July 27. The fire fighting was handled by the refinery emergency services with assistance from the Dyfed County Fire Service.

As a result of this incident, an estimated 10 percent of the total refining capacity in the United Kingdom was lost until this complex was returned to service. The business interruption loss for this incident is estimated at $70,000,000, which reflects four and one-half months of downtime.

SHB-270

08/02/93
Baton Rouge, Louisiana
United States
$65,200,000
$68,500,000
New this edition

Operations were normal at this 421,000 barrels-per-day refinery when a fire occurred at 4:21 a.m. in the central unit of three delayed coker units, which have throughput capacities of 32,000 barrels-per-day each. Each unit consists of four 100-foot metal coke drums set about 40 feet above grade and topped with 100-foot high drilling derricks

Operators were in the process of switching feed from "D" drum to "C" drum and two contractors were preparing to cut the coke in "D" drum when a 45-degree elbow in the feed line ruptured, releasing hydrocarbon at the 40-foot level. This 6-inch diameter elbow was made of carbon steel instead of 5 percent chrome alloy steel, which was required by the design specifications because some of the pipes in this unit area reach temperatures up to 900 degrees F. An investigation indicated that the piping on each side of the ruptured elbow, which was fabricated and installed in 1963, was of the proper alloy steel.

The sustained, intense fire caused other pipes in the unit area to rupture, releasing additional hydrocarbons and involving the entire structure in fire. As a result of the fire, two of the drilling derricks were completely destroyed and the two remaining derricks were partially damaged. There was also significant damage to the coke drums, electrical, instrumentation, and associated equipment in the central unit.

Upon report of the fire, approximately 12 members of the refinery primary fire brigade arrived within minutes at the delayed coker unit. These brigade members were supplemented within 15 minutes by an additional 83 members from the refinery primary and volunteer fire brigades, and the fire brigade from an adjacent chemical plant. The Baton Rouge Fire Department went to the scene and was available to assist these fire brigades but did not actively fight the fire. These fire brigades battled an intense fire for nearly three hours until all sources of fuel were shut off. The small fires that continued to flare-up in the unit were completely extinguished by 6:00 p.m.

Because of this incident, the west coker unit was shut down for a period of three weeks for testing, and the east unit was shut down for a slightly longer period while investigators checked the piping in this unit for proper metals. The central unit may be shut down for a period of up to one year, which represents the time necessary to repair this unit.

11/9/92
La Mede, France
$260,000,000
$278,200,000

Operations were normal at this 136,000 barrels-per-day refinery when a vapor cloud explosion occurred in the 29,700 barrels-per-day fluid catalytic cracking (FCC) unit. The initial vapor cloud explosion and several subsequent lesser explosions could be heard in Marseille, approximately 18 miles from the refinery. An estimated 11,000 pounds of light hydrocarbons were involved in the initial explosion.

At approximately 5:17 a.m., a gas detection system in the FCC unit sounded an alarm, indicating a major gas leak in this unit. While the unit operator was contacting the security service to warn of this situation, the initial explosion occurred at approximately 5:20 a.m. The initial gas release is believed to have resulted from a pipe rupture in the gas plant, which is used to recover butane and propane produced in the FCC unit.

SHB-271

The explosions and subsequent fires devastated about two hectares of this refinery, which covers a total area of about 250 hectares. The FCC unit and associated control building were destroyed by this incident. Two new process units under construction, which were scheduled to come into operation in 1993, were seriously damaged. Outside the refinery, roofs were damaged in the nearby town of Chateauneuf les Martigues and windows were broken within a radius of 3,000 feet, with some windows broken up to six miles away.

The refinery fire brigade and over 250 fire fighters from three neighboring industrial sites and four nearby towns were used for more than six hours to bring this incident under control. Approximately 37,000 gallons of foam concentrate were used during the fire fighting effort. Some fires were intentionally left burning for a few hours after the incident was under control to allow safe depressurizing of the process units since the flare system was partially damaged by the explosions.

The business interruption loss associated with this incident is estimated at $180,000,000.

10/16/92
Sodegaura, Japan
$160,500,000
$171,700,000

An explosion and subsequent fire resulted in significant property damage at this 126,600 barrels-per-day refinery. The explosion occurred from a heat exchanger failure in the light oil hydrodesulfurization unit. The channel cover and lock ring of the heat exchanger were hurled into an adjacent factory, which was located approximately 650 feet from this plant. The channel cover and lock ring were each 60 inches in diameter, and weighed 4,000 pounds and 2,000 pounds, respectively.

The hydrodesulfurization unit was being restarted following catalyst exchanging work when plant personnel noticed that hydrocarbon was being released from the heat exchanger. Plant personnel were working to complete the additional tightening work required on the heat exchanger bolts due to thermal expansion when the explosion occurred at approximately 3:55 p.m. The subsequent fire was brought under control in two hours and 45 minutes by fire fighters using 15 fire trucks.

10/8/92
Wilmington, California
United States
$78,300,000
$83,800,000

An explosion originating in the hydrogen processing unit occurred at 9:43 p.m. in this 75,000 barrels-per-day refinery. Extensive damage resulted to the hydrocracker, hydrodesulfurization, and hydrogen processing units because of the explosion and subsequent fires, which were fueled by hydrocarbon released from a damaged process column and equipment. This explosion, which damaged nearby buildings and shattered windows several miles away, was recorded as a "sonic boom" at the California Institute of Technology in Pasadena, California, approximately 20 miles from this 350-acre refinery.

The explosion resulted from the rupture of a six-inch carbon steel 90-degree elbow (outside radius) and the release of a hydrocarbon/hydrogen mixture to the atmosphere.The vapor cloud ignited within seconds after the rupture at an undetermined point in the plant. A review of process data showed that there were no out-of-range or warning indications about the incident until after the time the elbow had failed. The Los Angeles Department of Water and Power delivers electricity to the refinery and about twelve hours before the incident thid refinery had a power outage. A review of the information showed that the power outage and restart were not a contributory cause of the incident. An inspection after the failure found the line at nearly full design thickness a short distance away from the failure. On these facts, it was concluded that the line failure was the result of the thinning of the Schedule 120 carbon steel elbow due to long term erosion/corrosion.

The fire fighting effort was coordinated by the refinery emergency response team, with the Los Angeles City Fire Department and Los Angeles County Fire Department using the Joint Incident Command System. The refinery emergency response team, under the observation of the Coast Guard, placed booms in the Dominguez Channel storm drain to stop oily water run-off generated by the fire fighting operations from reaching the Los Angeles Harbor. The fire was finally extinguished at 2:00 a.m. on October 11.

Because of this incident, the refinery's gasoline production was reduced to 35,000 barrels-per-day, which is approximately 70 percent of rated capacity, until repairs to the damaged process units were complete. In early May 1993, the repairs to these units were 95 percent complete.

12/10/91
North Rhine
Westphalia, Germany
$50,500,000
$54,500,000
New this edition

A pipe failure in the T-junctions area of a collector for an air cooler in the high pressure section of the hydrocracker unit resulted in a release of hydrocarbons and hydrogen, which subsequently ignited. A substantial part of this plant was destroyed by the explosion and subsequent fire. The cause of the pipe failure was attributed to an increase in erosion/corrosion behind the air cooler due to a plant process change.

Because of this incident, the hydrocracker unit was shut down for approximately seven months and a business interruption loss of nearly $90,000,000 was incurred at this plant.

Refineries

11/3/91
Beaumont, Texas
United States
$15,000,000
$16,200,000

At approximately 2 a.m., a fire occurred in a crude unit of this 310,000 barrels-per-day refinery. This fire resulted from a seal failure on a process pump in this unit. Before the pump could be shut down and isolated, the fire spread, resulting in damage to the piping, pumps, instrumentation, and fin-fan coolers for this unit.

To control and extinguish the fire, a fire fighting effort was required from the refinery fire brigade, municipal fire department, and fire brigades from nearby mutual-aid companies. The fire fighting effort brought the fire under control in three to four hours and achieved total extinguishment in approximately 10 hours. During the fire, water was drafted from the nearby Neches River and pumped into the refinery Inlet Canal to ensure an adequate water supply for the fire water pumps that take suction from this canal.

Because of this incident, the crude unit was shut down for approximately 30 days for repairs.

4/13/91
Sweeny, Texas
United States
$36,500,000
$39,400,000

A series of three explosions damaged the atmospheric residuum desulfurization (ARDS) unit and the adjacent hydrotreater at this 175,000 barrels-per-day refinery. The initial explosion occurred at approximately 2:25 p.m. and originated near the third reactor of the "B" train in the ARDS unit. This reactor, which was significantly damaged, had an 11-inch wall thickness and operated at approximately 2,000 psi of pressure. This 75,000 barrels-per-day ARDS unit was used to extract sulfur and heavy metals from crude oil in the refining process.

A downtime of approximately 17 months was required to replace the reactor and associated process equipment since there were relatively few suppliers capable of manufacturing or repairing this type of reactor. Additional factors in the length of downtime were the congestion of other process equipment near the damaged reactor and asbestos insulation in the ARDS unit. With respect to the restoration of the ARDS unit, approximately 36,000 barrels-per-day of throughput capacity was restored by December 1991 and 64,500 barrels-per-day by August 1992. The unit was back to full operating capacity by September 1992.

A business interruption loss of approximately $225,000,000 resulted from this incident.

3/3/91
Lake Charles, Louisiana
United States
$23,000,000
$24,800,000

An explosion and fire occurred at approximately 11:00 p.m. in a 50,000 barrel-per-day fluid catalytic cracking (FCC) unit, which was being brought on-line after a seven-week shutdown for maintenance. During the start-up, a drain valve at the bottom of a pressure vessel was improperly closed, letting water accumulate in the vessel. When superheated oil was allowed into the vessel and mixed with the water, a steam explosion resulted, rupturing the vessel. The oil released from this vessel ignited and fire engulfed the FCC unit.

After the explosion, plant operators isolated the involved FCC unit and two other FCC units at this refinery. The fire then burned itself out at approximately 1:30 a.m. The two other FCC units were brought back on-line since they were not damaged by the explosion or subsequent fire. The business interruption loss associated with this incident is estimated at $44,000,000.

Trended values in bold italic type

1/12/91
Port Arthur, Texas
United States
$25,500,000
$27,500,000

A fire occurred because of a seal failure on a pump for the crude unit atmospheric tower. Before the pump could be shut down and isolated, a second product release occurred, spreading the fire. Subsequently, an elevated reflux drum and several process lines overheated and ruptured, increasing the damage to the unit.

Because of this incident, the crude unit was shut down for six months, which resulted in a business interruption loss of approximately $76,000,000.

11/30/90
Ras Tanura,
Saudi Arabia
$32,000,000
$35,500,000

A fire at this 530,000 barrels-per-day refinery completely damaged two fractionating columns, which were used in the production of kerosene and diesel fuel. Because of this incident, the refinery was shut down for a two-week period for repairs. The refinery was then brought on line with a production capacity of 300,000 barrels-per-day. Since complete repairs for the fractionating columns will take additional time, it is unknown when the refinery will be operating at full capacity.

The business interruption loss associated with this incident is estimated at $20,000,000.

11/3/90
Chalmette, Louisiana
United States
$20,000,000
$22,200,000

At approximately 11:21 p.m., a vapor cloud explosion occurred in the hydrocracker unit of this 160,000 barrels-per-day refinery. A mechanical failure involving the shell of a heat exchanger in this unit resulted in the formation of a vapor cloud, which was ignited by a heater. The subsequent fires in this unit burned for 10 to 12 hours before they were extinguished by the refinery fire brigade with mutual aid assistance.

As a result of this incident, the hydrocracker unit was shut down for approximately three months for repairs. However, the fire damage was limited to the hydrocracker unit and the refinery was brought back online within one week.

4/1/90
Warren, Pennsylvania
United States
$25,000,000
$27,800,000

An operator was draining water from the debutanizer system of the fluid catalytic cracking (FCC) gas plant when liquefied petroleum gas (LPG) was suddenly released. The LPG release continued at this 65,000 barrels-per-day refinery since the operator panicked and left the FCC gas plant. Subsequently, an ignition occurred resulting in an explosion and fire.

Trended values in bold italic type

12/24/89
Baton Rouge, Louisiana
United States
$68,900,000
$77,200,000

An eight-inch pipeline operating at approximately 700 psi ruptured, releasing a mix of ethane and propane. The record low temperature of 10 degrees F is believed to have contributed to the rupture. After a few minutes, the resulting vapor cloud was ignited causing an explosion.

The explosion shattered windows up to six miles away and could be felt as far as 15 miles away. Seventeen additional pipelines, in a pipe rack containing 70 lines, were ruptured by the explosion. The resulting fire involved two large storage tanks holding approximately 3.6 million gallons of diesel, twelve small tanks containing a total of 882,000 gallons of lube oil, and two separator units.

The explosion resulted in the partial loss of electricity, steam, and fire water for the refinery since two power lines, two steam lines, and a 12-inch fire water line were located in this pipe rack. Upon the initial explosion, the lines for the dock fire pumps were damaged. Therefore, the water for fire fighting had to be supplied with the remaining plant fire pumps and municipal fire trucks taking draft from alternate sources.

Approximately 48,000 gallons of AFFF foam concentrate, 200 fire brigade members, and 13 pumper units were used during the fire fighting effort, which was successful in extinguishing the fire approximately 14 hours after the initial explosion.

Because of this incident, the refinery was completely shut down for three days and operated at reduced capacity for an additional three weeks.

9/18/89
St. Croix, Virgin Islands
$62,000,000
$69,400,000

Hurricane Hugo struck this refinery, causing extensive damage to fourteen of the 500,000 to 600,000 barrel storage tanks in the tank farm area, the administration building, and the company housing. The damage to process units, which were idled in preparation for the hurricane, was limited to the asbestos insulation on process columns and piping. A maximum wind speed of 192 mph was reported for this hurricane before the measuring device at the St. Croix airport was damaged.

Because of the damaged asbestos insulation, approximately 1,500 employees and contractors worked seven days per week for 15 weeks to remove the asbestos debris from the refinery at a substantial extra expense. Additionally, an outside contractor specializing in the construction of atmospheric storage tanks worked for more than one year rebuilding the 14 storage tanks damaged in the tank farm.

9/5/89
Martinez, California
United States
$48,200,000
$54,000,000

A fire or explosion occurred in a hydrotreater unit which was processing feedstock from the fluid catalytic cracking unit at the time of the incident. A failure occurred in a line downstream from a separator, resulting in the release of hydrogen and hydrocarbons in the unit. The cause of line failure, source of ignition, and process equipment involved is unknown at this time.

To control and extinguish the fire, a massive fire fighting effort was required from the refinery fire brigade, the fire brigades from nearby plants, and the municipal fire department.

4/10/89
Richmond, California
United States
$87,200,000
$97,600,000

A 2-inch line carrying hydrogen gas at 3,000 psi failed at a weld, resulting in a high pressure hydrogen fire. The fire resulted in flame impingement on the calcium silicate insulation of the skirt for a 100-foot high reactor in a hydrocracker unit. The steel skirt for this reactor, which was 10 to 12 feet in diameter and had a wall thickness of 7 inches, subsequently failed. The collapse of this reactor damaged fin-fan coolers and other process equipment, greatly increasing the size of the loss.

At the time of the loss, the hydrocracker unit was being shut down for maintenance and the reactor was in a hydrogen purge cycle. The initial hydrogen leak is believed to have resulted from the failure of an elbow to reducer weld in the 2-inch hydrogen preheat exchanger bypass line.

Because of this incident, approximately 25 percent of the refinery's throughput capacity, including the complete hydrocracker unit production, was lost for a period of five months. The repairs for this refinery were completed within two years.

6/8/88
Port Arthur, Texas
United States
$11,000,000
$12,700,000

A catastrophic failure of a 6-inch propane line and ignition of the resulting vapor cloud at a refinery tank pump station led to the subsequent failure of numerous other lines in the 50-foot-wide pipe trench. The intense fire quickly involved four 18,000 barrel, internal floating roof blending tanks containing raffinate, debutanized aromatic concentrate, and slop. Three of the tanks were lined up to piping in the trench and there was difficulty isolating the tanks and pipelines. Two empty spheroids were heavily exposed. The fire spread throughout the trench, which contained as many as 35 lines for a distance of 1,300 feet.

The refinery fire water system supplemented by 10,000 feet of 5-inch hose delivered 9,000 gpm of water to the fire area for foam production and exposure cooling. A very strong mutual aid response with foam supplies flown in from distances of up to 1,500 miles extinguished the fire 20 hours later.

5/5/88
Norco, Louisiana
United States
$254,700,000
$292,900,000

Operations were normal in a 90,000 barrels-per-day fluid catalytic cracking (FCC) unit when internal corrosion caused the failure of the outside radius of an 8-inch carbon steel elbow located 50 feet above grade in the depropanizer column overhead piping system. An estimated 20,000 pounds of C_3 hydrocarbons escaped through the resulting hole, forming a large vapor cloud during the 30 seconds between failure and ignition. Both the depropanizer column (operating at 270 psi at 130 degrees F) and the accumulator depressured through the opening.

Ignition of the vapor cloud probably was caused by the FCC charge heater. The initial blast destroyed the FCC control building and toppled the 26-foot-diameter main fractionator from its 15-foot-high concrete pedestal. The column separated from its 10-foot-high skirt before falling. Analysis of bolt stretching of towers in the blast path indicated overpressures as high as 10 psi.

The refinery immediately lost all utilities, including fire water and the four diesel fire pumps, greatly limiting the fire fighting effort for several hours. Steam pressure dropped abruptly due to severed lines. Twenty major line or vessel failures occurred in the FCC and elsewhere throughout the 215,000 barrels-per-day refinery. Blast damage throughout the plant was extensive, but was most severe in the 300-foot by 600-foot FCC unit. About 5,200 property claims were received for off-site damage at distances up to six miles. The FCC unit eventually was demolished and a new unit will be built.

A preliminary report stated that the failed elbow was located downstream of the injection point where ammoniated water was added to reduce depropanizer condensation or fouling. The elbow was a designated inspection point in the overhead piping system for taking ultrasonic thickness measurements during turnarounds. These inspections had constantly shown the expected corrosion rates of 0.05 mils per year. Measurements taken at the failed elbow and in the downstream piping after the explosion revealed unexpected high localized corrosion rates.

3/22/87
Grangemouth, United Kingdom
$78,500,000
$93,400,000

A 29,000 barrels-per-day distillate hydrocracking unit was undergoing start-up and was under hydrogen pressure and circulation with the hydrogen leak-off from the high pressure separator at 1,500 psi to the low pressure separator at 150 psi being regulated by two control valves in series. When the control valves were placed in manual mode, they opened fully and overpressured the low pressure separator whose relief valves were not sized for such an occurrence. The 30-foot high, 10-foot diameter separator exploded and disintegrated. One piece weighing three tons was thrown 3,300 feet.

Fire fighting was conducted by the refinery fire brigade and 23 outside pumpers, foam trucks, and other equipment. Within one and one-half hours, 31 foam and water streams were discharging 12,000 U.S. gpm on the fire. Sewers were unable to cope with the flow and hydrocarbons began bubbling up from drains in other parts of the plant. The drainage system also became blocked by large quantities of a heavy waxy material. Eventually, water covered a 380,000 square foot (8.7 acre) area. A total of 270,600 U. S. gallons of foam concentrate were used to blanket the hydrocarbon which was floating on the water. Final extinguishment was achieved approximately 19 hours after a nitrogen purge of the hydrocracking unit was initiated.

12/13/84
Las Piedras, Venezuela
$62,100,000
$78,200,000

A straight run of 8-inch line carrying hot oil from the high pressure separator to the low pressure stripper in a refinery hydrodesulfurizer fractured circumferentially in the parent metal in the heat zone about one and one-half inches from a weld. Hot oil at 700 psi and 650 degrees F sprayed across the roadway into the hydrogen units where ignition occurred. Intense fire around the pipeway in the hydrogen plant caused a 16-inch gas line to rupture, adding a second blowtorch to the fire. In successive order, more pipes ruptured with explosive force in adjacent areas.

The fire caused a crash shutdown of the entire 600,000 barrel-per-day refinery. After six and one-half hours, the fire was extinguished. Damage was extensive. The three hydrogen plants and the four HDS units were heavily damaged or destroyed. Four years after the plant was built and nine years before the loss, the line which failed was judged as having excessive vibration. It is believed that the hot oil line failed in fatigue, largely due to hydrogen embrittlement.

8/15/84
Ft. McMurray, Alberta
Canada
$76,000,000
$95,800,000

Erosion failure in a 10-inch slurry recycle oil line in an 82,000 barrels-per-day fluid bed coking unit released liquids near auto-ignition temperature. Vapors covered a large area and ignited almost immediately, resulting in a large area ground fire which led to the failure of six or seven more lines. The fire eventually extended over a 150 foot area with damage up in the unit structure to over 100 feet.

Metallurgical examination revealed that an 18-inch long piece of carbon steel pipe had inadvertently been inserted into the 5-chrome slurry recycle line during an earlier metals inspection.

The reactor fractionator, light gas-oil stripper, 15,000 horsepower air blower, pumps, pipe racks, etc., were severely damaged or destroyed.

About 2,700 barrels of hydrocarbon liquids were released from process equipment during the fire. Much of this was by gravity flow from ruptured lines, although pumps which could not be shut down contributed much of the flow. A 900 psig steam line, which supplied the turbine drivers of the compressors, ruptured, hampering the fire fighting efforts.

7/23/84
Romeoville, Illinois
United States
$191,000,000
$240,700,000

Just prior to the rupture of a 55-foot high 8-1/2 foot diameter monoethanolamine (MEA) absorber column, a refinery operator noted a 6-inch horizontal crack at a circumferential weld was leaking propane. As the operator attempted to close the inlet valve, the crack spread to about 24 inches. The area was being evacuated and the plant fire brigade were arriving when the column failed massively. Propane at 200 psig at 100 degrees F propelled most of the 20-ton vessel 3,500 feet where it struck and toppled a 138,000 volt power transmission tower.

The weld separation occurred along a lower girth weld joint made during a repair to the column 10 years earlier. The vessel was constructed of 1-inch thick SA 516 Gr 70 steel plates rolled and welded with full penetration submerged arc joints, but without post-weld heat treatment.

This explosion resulted in severe fires in the unsaturated gas plant, FCC, and alkylation units. After about one-half hour, a boiling liquid expanding vapor explosion (BLEVE) occurred in a large process vessel in the alkylation unit. One piece of this vessel traveled 500 feet shearing off pipelines before striking a tank in the water treatment unit. Another fragment landed in a Unifining unit over 600 feet distant causing a major fire there.

SHB-279

The first explosion, believed to be from an unconfined vapor cloud, broke windows up to six miles from the plant, caused extensive structural damage to refinery service buildings and disrupted all electric power at the refinery, rendering a 2,500 gpm electric fire pump inoperable. One explosion sheared off a hydrant barrel, resulting in a reduction of fire water pressure from the two 2,500 gpm diesel engine driven fire pumps, which were operating. The refinery's blast resistant control center, approximately 400 feet northeast of the absorber, sustained little structural damage.

An estimated 30 paid and volunteer public fire departments, together with equipment from refineries and chemical plants within a 20-mile radius, responded promptly. Many pumpers took suction from the adjoining canal and a nearby quarry. The pumpers and a 12,000 gpm fire boat eventually provided water at pressures sufficient for fire fighting.

8/30/83
Milford Haven, United Kingdom
$11,100,000
$14,500,000

The most likely source of ignition of this 600,000-barrel floating roof tank fire was incandescent carbon particles discharged from the top of a 250-foot high refinery flare stack situated 350 feet from the tank. The 256-foot-diameter by 66-foot-high tank, which contained 348,000 barrels of North Sea crude at the time of ignition, was arranged within a standard individual dike. It had a single mechanical seal and was equipped with a 12-inch high foam dam but no foam delivery lines or outlets. Reportedly, there were several cracks extending over 11 inches on the single plate floating roof. Inspections of the roof a few days before the fire revealed oil seepage onto the roof deck. There had been no oil transfer in the 24 hours preceding the fire.

When first noticed, fire involved about half the tank roof area. It progressively spread to the entire surface. Cooling water streams were positioned to protect two 138-foot diameter, 142,000-barrel fixed roof vacuum gas oil and fuel oil tanks situated 200 feet away. Oils were being pumped out of the three tanks in preparation for a major foam attack when, 12 hours into the fire, a violent boilover occurred in the crude tank. The ensuing fire covered four acres and destroyed or damaged much of the fire fighting equipment including two foam trucks. This was followed two hours later by a second less violent boilover. The major foam attack, which commenced 21 hours after ignition, continued for 14-1/2 hours before extinguishment was complete. The crude tank was destroyed, two fixed roof tanks badly damaged, and 132,000 barrels of crude oil consumed.

This fire involved the use of 44 pumpers, six elevating platforms, and 14 foam trucks from four nearby refineries and the public fire service. In addition, 66 commercial tankers and vehicles transported the 201,600 U.S. gallons of 3 percent and 6 percent foam concentrate.

4/7/83
Avon, California
United States
$49,000,000
$64,100,000

Rupture of a 12-inch recycle slurry line in a 47,000 barrel-per-day FCC unit resulted in immediate ignition of the slurry. The failure occurred in a pipe rack 12 feet above grade. The slurry line pressure was estimated to be between 120 and 160 psi at a temperature of 600 to 700 degrees F. Shortly thereafter, a 600 psi steam line failed a few feet from the slurry line. It hampered fire fighting efforts due to extreme noise levels and the vaporizing of liquid hydrocarbons. Water spray of a pump alley and strong refinery water supplies allowed containment of the fire to a 70-foot by 140-foot area of the FCC unit. The FCC reactor, regenerator, fractionator, as well as related piping instrumentation, and electrical equipment sustained severe damage.

8/20/81
Shuaiba, Kuwait
$100,000,000
$148,000,000

The cause of this refinery tank farm fire, which destroyed eight tanks and damaged several others, has not been disclosed. It appears to have originated at a pump manifold within the common dike serving six 160,000-barrel floating roof tanks containing petrochemical grade naphtha. Naphtha was being pumped into one of the tanks when the initial explosion and fire occurred.

About one-half hour into the fire, the seal of the first tank caught fire. This event was followed rapidly by two other seal fires. Fires spread progressively, eventually involving five of the six tanks in the group. The sixth tank was empty and sustained severe damage.

A strong fire fighting attack was initially made by the refinery fire brigade, later assisted by nearby industrial fire brigades, and military and public fire departments. As many as 75 pieces of mobile fire fighting equipment were used to supply up to 11,000 U. S. gpm of water and foam solution during the fire which lasted five days and twenty hours.

In spite of heavy protective water streams, a strong wind and radiated heat caused the fire to spread into an adjoining row of four 72,000-barrel floating roof tanks containing intermediate products and to a fixed roof 32,000-barrel slop tank. This took place 64 to 103 hours after the fire began.

Wind-driven flames caused the collapse of a heavily loaded unprotected steel pipe rack located between the two rows of three tanks. Water curtains set up between the tank groups and nearby process units at the 200,000 barrel-per-day refinery and petrochemical plant were effective. Damage was split 50-50 between liquid hydrocarbons and tanks and other equipment.

1/20/80
Borger, Texas
United States
$34,900,000
$56,900,000

A piping or vessel failure in a 16,800 barrels-per-day HF alkylation unit was the cause of this incident. Reportedly, water which accumulated in the flare system froze on contact with propane, forming an ice plug. Equipment in the alkylation unit overpressured and subsequently failed. A large vapor cloud explosion and the ensuing fire destroyed the alkylation unit and boiler plant, and resulted in varying degrees of damage to the crude, FCC, gas converter, reformer, and treating units.

Because of this incident, the entire refinery was shut down for repairs.

12/11/79
Geelong, Australia
$11,200,000
$19,900,000

An inboard roller bearing failure in a reduced crude pump operating at 570 degrees F in a refinery crude unit initiated the fractures of the motor shaft and pump bearing bracket. The pump casing then broke open allowing the release of hot oil which auto-ignited. Since the pump was only equipped with manually operated suction valves which could not be reached and the column had no isolation valve, the crude oil in the column was released fueling the fire.

Access to the fire area was difficult and the table-top above the pump allowed the rapid spread of fire over a wide area, eventually engulfing the entire pump house. Secondary pipe and flange failures contributed further fuel to the fire. The pump house, concrete structures, and fin-fans were destroyed in the fire, which was extinguished by the use of 12 hand lines and 15 portable monitor nozzles for 14 hours.

9/1/79
Deer Park, Texas
United States
$68,000,000
$120,400,000

Nearly simultaneous explosions aboard a 70,000 DWT tanker off-loading vacuum distillate and in an 80,000-barrel ethanol tank at a refinery occurred during a severe electrical storm. The ethanol tank was ignited when a plate section of the exploded tanker flew through the air and struck the tank, causing it to explode and burn.

The ship, tied up at the refinery dock, had discharged all but 50,000 barrels of its 128,000-barrel cargo when the explosion occurred. Unloading had been suspended minutes earlier because of a storm in the area. Explosions within the ship's holds spread 5,000 to 10,000 barrels of burning distillate on the water. This involved several nearby docks and four gasoline and crude oil barges.

The 120-foot diameter cone roof ethanol tank was about one-third full and burned itself out in about 14 minutes.

7/21/79
Texas City, Texas
United States
$23,000,000
$40,800,000

Liquid and gaseous hydrocarbons at 265 psi were released through failure of a 12-inch elbow in a line from a reflux accumulator serving the depropanizer overhead condensing system of a sulfuric acid alkylation unit. An estimated 4,000 to 5,000 gallons of liquids were discharged, forming a large vapor cloud which traveled about 640 feet downwind to a FCC unit. Ignition occurred an estimated two minutes after the initial release. The alkylation and FCC units, the CO boiler and control building sustained heavy structural damage. Four cooling towers and another control house were moderately damaged. Windows were broken one and one-half miles away.

SH5-282

10/3/78
Denver, Colorado
United States
$21,900,000
$41,900,000

Two weeks after the initial start-up of a new catalytic polymerization unit a pipe from the stabilizer reboiler failed and released propane gas. The resulting vapor cloud probably was ignited by a heater 300 feet from the point of release. The blast and ensuing fire destroyed the catalytic polymerization unit and heavily damaged other refining units.

5/30/78
Texas City, Texas
United States
$55,000,000
$105,100,000

Cause of this loss which started in a refinery alkylation unit tank farm is unknown. An unidentified failure led to the release of light hydrocarbons which spread to an ignition source. A rather intense fire followed in the tank farm. In less than five minutes, a 5,000-barrel sphere failed, causing a tremendous fireball and sending pieces of the sphere throughout the plant. Within the next 20 minutes, five 1,000-barrel horizontal bullets, fou 1,000-barrel vertical bullets, and one additional 5,000-barrel sphere failed from either missile damage or BLEVEs. Pieces of the tanks traveled in all directions, falling into a number of operating units and tank farms, starting more fires. Fragments also hit the fire water storage tank and electric fire pumps, leaving only the two diesel fire pumps operational.

10/17/77
Baton Rouge, Louisiana
United States
$9,500,000
$19,500,000

A new preheat furnace for a FCC unit was demolished by an explosion caused by an accidental short circuit created while the furnace instrumentation was being relocated to a new central control building. A adjoining furnace also serving a FCC unit was severely damaged by the explosion and resulting fire. The short circuit interrupted power supply for almost five minutes to instruments on both furnaces. Shutdown and control valves, used in series on both pilot gas and fuel gas on both furnaces, closed with loss of power. This extinguished all flames in both furnaces. When the fault was discovered and removed, power was restored immediately. This reopened the control valves to both furnaces and the shutdown valves on one furnace.

Gas re-entered the fire box and apparently was ignited by hot refractory. The shutdown valve on the second heater locked in a closed position, preventing gas re-entry and a similar explosion in the second heater. Th fire was contained within the furnace area, but lasted almost one and one-half hours.

9/24/77
Romeoville, Illinois
United States
$8,000,000
$16,200,000

Lightning struck a 190-foot diameter cone roof tank containing diesel fuel. Roof fragments thrown 240 feet struck a 100-foot diameter covere floating roof gasoline tank. A 180-foot floating roof gasoline tank at 80 feet distance was also struck by debris. The entire surfaces of the cone and internal floating roof tanks ignited immediately. The rim fire on the floating roof resulted in the roof sinking after about four hours. The two largest tanks were full; the smallest about half full. The two larger tanks and their contents were destroyed. The fire in the internal floating roof tank was extinguished after about two hours.

Extinguishment was by top-side and sub-surface foam application after about 46 hours. The refinery's five stationary fire pumps supplied up to 10,000 gpm of the estimated 14,000 gpm pumped during the fire. Thirty-five municipal and industrial fire departments, including a 12,000 gpm fire boat, assisted the refinery fire department. About 22,000 gallon of foam concentrate were consumed during the fire fighting effort.

10/14/75
Avon, California
United States
$6,300,000
$14,700,000

Two weeks after coming on-stream following repairs from a March 16 loss, a second major fire occurred in this 42,000 barrels-per-day fluid coking unit.

The unit had been operating normally since start-up when operators noticed a rapidly developing vapor cloud. Quick investigation revealed that the vapor was coming from the coker slurry quench recycle pump. Ignition occurred before the suction or discharge valves could be fully closed to isolate the pump. Immediately, remote operated valves were activated from the control room. These had been installed after and as a result of the first fire. None of the valves operated, since unprotected instrumentation lines had already been destroyed, and all control was lost.

Early in the fire, the bonnet of a 600 psi steam line blew off and the steam, acting as an atomizer, spread the fire considerably. Additional product lines ruptured contributing liquid and gaseous fuels to the fire, which burned for about an hour. Damage was extensive to all levels of the coker structure and pipe rack which adjoined the pump.

The investigation revealed that a monel bull plug on the pump blew out releasing slurry at 750 degrees F at 250 psi. The plug had been installed during original construction 19 years earlier and had since been untouched. Reportedly, the plug had been inserted only one and one-quarter turns.

8/17/75
Philadelphia,
Pennsylvania
United States
$13,000,000
$30,300,000

Crude oil was being off-loaded from a tanker at a refinery to a 60,000-barrel converted internal floating roof tank. Evidence suggests that while the tank had not actually overflowed at the time of the initial fire and explosion, it had been filled beyond the designed maximum fill height, and this caused rapid emission of volatile vapors from the tank vents. These vapors traveled to a boiler house and its stack. The hot surface of an uninsulated high temperature and high pressure steam pipe ignited the accumulated vapors. This caused a momentary overpressure of the stack that damaged it extensively. Flashback to the crude tank was immediate. Piping failures in the tank manifold released more crude oil outside the tank dike.

Within a brief time, an explosion occurred in the crude tank spilling additional oil into the dike. An adjoining tank containing No. 6 fuel oil became involved in fire and several pipelines in the dike failed. The fire burned for nine days before it was finally extinguished. During that time, it involved four tanks, the refinery administration building, and other less important facilities.

Fire fighting was conducted by 200 municipal fire fighters responding to 11 alarms and by several refinery fire departments. Three foam trucks and two pumpers were destroyed when fire flashed over oil-covered water. At times, as much as 13,000 gpm of fire water was pumped on the fire.

3/16/75
Avon, California
United States
$10,400,000
$24,200,000

After observing a high liquid level on the fresh feed drum of a large fluid coking unit, operators increased the pump-out rate, creating a vacuum and resulting in an implosion of the drum. Spilled hot oil ignited and burned for 11-1/2 hours. Loss of instrumentation was responsible for a second simultaneous fire on the sixth through eighth levels of the burner-auxiliary-air-heater gantry structure. The two fires originated 200 feet apart and did not join one another. Hot fuel gases were carried 100 feet further to the CO boiler where significant damage occurred.

8/24/73
St. Croix, Virgin Islands
$10,500,000
$30,000,000

A crack developed in a weld of a high pressure transfer line between the high and low pressure separators downstream of the reactor of a new hydrodesulfurizer. The unit was starting up at the time of the loss. The high pressure separator was operating at 850 psi and about 150 degrees F With failure of the Schedule 80 line, hydrogen and liquid hydrocarbons were released. These were ignited from an unknown source and burned for about three hours. During that period, the prevailing winds carried fire along 125 feet of pipe rack. Fin-fans elevated above the rack on one-hour rated fireproofed supports failed within 20 to 35 minutes, dropping the aerial coolers on the pipe rack. The system unloaded through the break since there was no way of shutting off the flow. Fire control and extinguishment was achieved by use of 20 hose streams and a fire water flow of about 7,000 gpm.

8/14/72
Billings, Montana
United States
$5,000,000
$15,300,000

An alkylation unit was being started up after shutdown because of an electrical outage. When adequate circulation could not be maintained in a deisobutanizer heater circuit, it was decided to clean the strainer. Workers had depressurized the pipe and removed all but three of the flange bolts when a pressure release blew a black material from the flange, followed by butane vapors. These vapors were carried to a furnace 100 feet away, where they ignited, flashing back to the flange.

The ensuing fire exposed a fractionation tower and horizontal receiver drums. These drums exploded, rupturing pipelines which added more fuel. The explosions and heat caused loss of insulation from the 8-foot by 122-foot fractionator tower, causing it to weaken and fall across two major pipe racks, breaking piping and adding more fuel to the fire. Extinguishment, achieved basically by isolating the fuel sources, took two and one-half hours.

The fault was traced to a 10-inch valve that had been prevented from closing the last 3/4-inch by a fine powder of carbon and iron oxide. Whe the flange was opened this powder blew out, allowing liquid butane to be released.

3/30/72
Rio de Janeiro, Brazil
$4,800,000
$14,600,000

The LPG storage area of this 256,000 barrels-per-day refinery included five 10,000-barrel spheres and 16 bullets. Protection consisted of fixed cooling water systems on the spheres and monitor nozzles and hydrants for the horizontal tanks.

Water was being drained from one of the spheres through a 2-inch pipe with a 2-inch gate valve pointing down at a height of 6 feet from ground level. The operator left with the drain valve fully open. When he returned, liquid LPG was pouring from the drain at 156 psi, and he was unable to reach the valve because of the cold zone and because the jet had dug a large hole in the crushed stone bed covering the ground. A very large vapor cloud developed spreading beyond the refinery boundary. It ignited and flashed back to the sphere. Flaming LPG from the drain hitting the ground was deflected back against the lower part of the tank. Cooling water was applied to all tanks. After 15 to 20 minutes, the relief valve opened at 239 psi discharging gas to atmosphere and it promptly ignited.

Despite the cooling water and open safety valve, the sphere exploded, causing a tremendous blast wave and leaving only a crater where the sphere had been. Nearby spheres and some bullets were thrown from their supports. Lines were broken, so that the fire spread throughout the storage area. Following the explosion, the fire developed beyond any possible control, causing the explosion of three more horizontal tanks and finally burning itself out.

All 21 storage tanks were destroyed. Many refinery buildings and facilities sustained blast damage. Two fire trucks were destroyed and another four were damaged.

12/5/70
Linden, New Jersey
United States
$27,200,000
$99,700,000

A 7-inch thick reactor of a wide-range hydrocracking unit being operated by computer at 2,500 psi failed explosively due to localized overheating. The blast caused widespread damage over a 300-yard radius including an adjoining catalytic cracker and crude pipe still where the roof of the control building collapsed. Other units were safely shut down from a blast-resistant control building which sustained minor damage. There were over 7,000 claims of property damage from outside the refinery.

1/20/68
Pernis, Netherlands
$28,000,000
$123,200,000

Frothing occurred when hot oil and water emulsion in a refinery slop tank reacted with volatile portions of hydrocarbonic slop, causing a violent vapor release and boil-over. The ensuing fire involved 30 acres of the approximately 200-acre refinery, then the second largest refinery in the world. Two wax hydrocrackers, a naphtha hydrocracker, a sulfur plant and 80 storage tanks were destroyed or damaged. Much of the property involved in this loss was idle or obsolete. Off-premises damage was reported as far as nine and one-half miles away.

8/8/67 **Lake Charles, Louisiana** **United States** $17,300,000 ***$80,800,000***	An estimated 17,500 gallons of isobutane released by failure of a valve on an underground pipeline was dispersed over an area of 300 feet by 800 feet before igniting. The resulting explosion and fire destroyed or heavily damaged two alkylation units, a delayed coking unit, a thermal cracker and a catalytic hydroforming unit. Two spherical tanks failed and numerous cone roof tanks were involved.
1/4/66 **Feyzin (Lyons), France** $18,100,000 ***$88,700,000***	Improper sampling procedures on a 48-foot diameter, 12,580-barrel butane sphere which was 3/4 full resulted in the uncontrolled release of liquid butane through a 2-inch connection. Ignition was believed to have been from a passing vehicle at a distance of 300 feet. Fire at the relief valves and at the base of the sphere burned about an hour before the tank failed massively. Pieces of steel up to 100 tons traveled about 1/4 mile. One fragment landed on a pipe rack, cutting 40 lines. Another piece cut the legs out from under an adjoining sphere causing it to topple and break its 8-inch connecting line. Hot spots developed on three nearby butane tanks, which subsequently ruptured.

Petrochemical Plants

12/13/94
Port Neal, Iowa
United States
$120,000,000
$122,400,000
New this edition

Shortly after 6:00 a.m., an explosion occurred in the ammonium nitrate process area of this plant. As a result of the explosion, the seven-story main process building was completely destroyed and a 30-foot wide crater was created. Additionally, metal fragments from the explosion punctured one of the plant's two 15,000-ton refrigerated storage tanks. The punctured tank released an estimated 5,700 tons of ammonia, causing the evacuation of approximately 2,500 people outside of the plant. Metal fragments also punctured a nitric acid tank, resulting in the release of approximately 100 tons of this material. The explosion tore metal siding from adjacent buildings, damaged three third-party electric generating stations, broke windows in buildings 16 miles away in Sioux City, and was felt over 30 miles away.

As a result of this incident, a business interruption loss estimated at $60,000,000 is expected to be incurred.

10/17/94
Baytown, Texas
United States
$25,000,000
$25,500,000
New this edition

Heavy rains, amounting to approximately 25 inches throughout the greater Houston area, resulted in extensive flooding from surface water as well as overflowing streams. Most of the water that flooded this 90-acre plant, located approximately 30 miles east of Houston, came from the overflow of Cedar Bayou that borders the north side of the plant. Flood water covered the entire plant in depths ranging from two to five feet.

Plant management anticipated the flooding and was successful in shutting down all six process units in an orderly manner. Additionally, plant personnel were successful in relocating the smaller and lighter property items to higher ground. This effort notwithstanding, the flood waters caused extensive damage, mainly to computers, electrical substations, switchgear, pumps, motors, and buildings. At least 350 electric motors varying in size from 5 to 20 horsepower were completely submerged and required replacement, while the larger electric motors up to 1,500 horsepower were disassembled, baked out, and repaired.

The plant was shut down for approximately two months as a result of this flooding. During this period, the ethylene, polyethylene, olefins, and acetylene black production was shut down, resulting in a business interruption loss estimated at $85,000,000.

08/08/94
Baton Rouge, Louisiana
United States
In excess of $25,000,000
New this edition

Operations at this 1.9 billion pounds-per-year ethylene plant were normal until a fire occurred at approximately 8:00 p.m. in one of the two ethylene trains at this plant. The fire, which was limited to the sponge fractionator column of the 1.5 billion pounds-per-year ethylene train, was brought under control early the next morning. Fire officials decided to allow the fire to continue to burn until it consumed the remaining hydrocarbon products in this train, which occurred on August 11.

As a result of this incident, both of the ethylene trains at this plant were shut down. Plant personnel were successful in placing the 400 million pounds-per-year ethylene train back in service within two weeks. The ethylene production from this plant accounts for about four percent of the total U.S. ethylene production and 25 percent of this company's production.

The exact property damage loss that resulted from this incident is unknown at this time. As a result of this incident, the larger ethylene train was shut down for nine weeks to replace coke-plugged tubes in the furnaces caused by the emergency shutdown.

05/27/94
Belpre, Ohio
United States
$100,000,000
$102,000,000
New this edition

At approximately 6:30 a.m., an abnormal chemical reaction occurred during the batch production of a thermoplastic rubber product resulting in an explosion at this plant. Because of the explosion, the reactor, process controls, appurtenances, control room, and building for this production were completely destroyed.

The fire then spread to involve part of the tank farm, resulting in the destruction of five atmospheric storage tanks. At approximately 12:30 p.m., the first of these four 1,000,000-gallon and one 500,000-gallon storage tanks containing styrene exploded. A fire fighting attack utilizing cooling water and foam hose streams was used to prevent the fire from involving other nearby storage tanks, two of which contained butadiene. The fire was extinguished at approximately 3:30 p.m.

7/28/92
Westlake, Louisiana
United States
$25,000,000
$26,800,000

At 7:10 p.m. a reactor in an urea manufacturing unit exploded, resulting in extensive damage at this chemical plant. The force of the explosion, which could be felt in areas up to 10 miles from the plant, drove 20 feet of the reactor support pedestal into the ground. The remaining 70 feet of the vessel failed catastrophically and fragments were propelled in all directions. Two pieces of the steel shell, each approximately 3-feet by 4-feet and weighing about 300 pounds, were found in the tank farm of a refinery located across an interstate highway and a railroad from the chemical plant. These two pieces traveled over 900 feet from their original site in the chemical plant.

The reactor, which was constructed in 1967, was 90 feet in height and 6 feet in diameter. This vessel was supported on a pedestal and had a 4-inch thick laminated shell. This shell consisted of 14 laminations, each approximately 3/8-inch thick, and a 1/2-inch thick stainless steel liner. The reactor was used in the conversion of carbon dioxide and ammonia and is believed to have been operating at design pressure and temperature (3,000 psi and 350 degrees F) at the time of the explosion.

This incident resulted from an improper weld on a bracket supporting a tray inside the reactor. The bracket was welded to the stainless steel liner. The improper weld resulted in a carbamate leak and subsequent corrosion of the containment vessel. Reportedly, the leak went undetected for some time because weep holes in the vessel were not adequately checked to detect ammonia and carbon dioxide coming out ahead of the carbamate. As the carbamate progressed outward through the weep holes, it hardened and eventually clogged the holes.

Because of this incident, the urea production at this plant was shut down for more than 12 months, the time necessary to replace the damaged process equipment. The business interruption loss for this incident is estimated at $20,000,000.

5/8/92
Tarragona, Spain
$13,000,000
$13,900,000

During normal operation of this ethylene plant, a leak was detected in the cooling/heating water jacket for the upper zone reactor tubes. The ethylene plant was immediately shut down at 12:45 p.m. and the pressure in the reactor was gradually reduced to 355 psi. Water was drained from the jacket and ethylene detectors were inserted to identify the location of the gas leak. Ethylene gas was reintroduced into the system and the pressure was gradually increased to 14,220 psi at 7:45 p.m. When the source of the leak was detected at 7:51 p.m., the operators started to reduce the pressure in the reactor and separators.

As the pressure in the reactor and separators started to decrease, a loud noise was heard in the control room. Operators believed the noise to be a large ethylene leak and actuated the emergency dump system which closed the ethylene and oxygen inlet valves of the reactor, released gas through the reactor vents, and closed the outlet valve of the high pressure separator. Almost immediately after the emergency dump system was actuated, an explosion occurred which was followed by fire.

The explosion caused substantial damage to equipment and buildings within a one-half mile radius of the plant and severely damaged the concrete containment bunker for the reactor and high pressure separator. The walls of the bunker remained standing, secured by the steel reinforcing, but had been bowed outwards. The damage patterns suggest that there were two simultaneous vapor cloud explosions, one within the bunker and one centered above the top of the bunker. The fire following the explosions was extinguished within 10 minutes as the flow of gas was shut off. Fire damage was observed on the top of the high pressure separator and at the bottom valves of the low pressure separator.

The initial release of ethylene gas during testing came from the high pressure separator lid, which was secured to the body by a series of studs and was sealed with a steel ring. The leakage was said to have been caused by differential thermal contraction of the seal and the lid/body assembly following the introduction of cold ethylene gas into the reactor and separators for test purposes. There was no evidence of fracture or mechanical failure on either the seal ring, lid, or body of the high pressure separator. Additional ethylene gas was released from the reactor and separators when the emergency dump system was actuated. The source of ignition for the ethylene gas was failure of insulation on electrical wiring for a remote operated dump valve. This valve would have been operated with electrical sparking during the emergency dump system actuation.

1/13/92
Alvin, Texas
United States
$32,300,000
$34,600,000

A vessel in a raw material process unit at this chemical plant ruptured during a cleaning operation at approximately 7:21 p.m. This vessel was a centrifugal feed tank with an 8,200-gallon capacity and maximum allowable working pressure of 15 psi.

The rupture and subsequent plant damage was caused by steam pressure that was generated by heat from a chemical reaction. A continuously increasing, highly exothermic reaction provided the heat source for the expanding supply of steam. The decomposition of this material resulted from overheating the vessel with steam to the coils during the cleaning operation.

The reconstruction of the new facility was completed one to two months ahead of schedule. Activities to mitigate the loss included the purchase of various raw materials from outside sources.

6/20/91
Dhaka, Bangladesh
$71,000,000
$76,700,000

The failure of a welded joint between a carbon dioxide stripper and the main cylindrical body resulted in the release of high pressure gas, which consisted of ammonia, carbon dioxide, and carbamate liquids. Subsequent to the release, an explosion resulted which caused significant damage to this fertilizer plant. The source of ignition for this explosion is unknown. This plant, which was constructed in 1970 and upgraded in 1988, has an annual production capacity of 340,000 tons.

5/1/91
Sterlington, Louisiana
United States
$105,000,000
$113,400,000

Workers were preparing to check a compressor in the nitroparaffin unit when they noticed a small fire and sounded the plant fire alarm. Approximately 30 seconds later, an explosion occurred which was followed by a series of smaller explosions. The effects of the initial explosion were reported as far away as eight miles from this 15-acre plant. Additionally, the initial explosion completely damaged an area of the plant approximately the size of a city block. Subsequent fires were reported to have burned for more than seven hours.

Although the incident did not damage the two ammonia units on-site, the entire plant was temporarily shut down for precautionary measures. The business interruption loss associated with this incident is estimated at $35,000,000.

3/12/91
Seadrift, Texas
United States
$80,000,000
$81,600,000

At 1:18 a.m., an explosion occurred in the ethylene oxide process unit at this plant. As a result of the explosion, the ethylene oxide refining column was completely destroyed, the glycol ether unit was substantially damaged, and the co-generation unit was partially damaged. A pipe rack near the storage area for liquid ethylene oxide was damaged when a large piece of shrapnel from the explosion hit the rack, rupturing lines which contained methane and other hydrocarbon products. The subsequent fire that resulted from the release products was the only significant fire to occur during this incident.

As as result of the explosion, all utilities at the plant were lost for approximately one week. Additionally, a significant number of the water spray systems were damaged by the explosion or inadvertently actuated due to a loss of plant air. These systems were shut off and placed back in service as appropriate. A manual fire fighting effort was used to extinguish the fire involving the pipe rack once the lines in the rack were isolated.

As a result of this incident, a business interruption loss of approximately $90,000,000 resulted mainly from the almost full year reduction in ethylene oxide production. The polyethylene production was restarted in early April 1991, utilizing externally sourced ethylene, while the olefins production was restarted in late April 1991.

3/11/91
Coatzacoalcos, Mexico
$91,300,000
$98,600,000

At approximately 8:30 a.m., a gas leak involving the pipe rack that runs from Cangrejera to the terminal in this petrochemical complex lead to an explosion. This explosion, which occurred near the complex chemical plant, caused additional damage to the pipe rack resulting in a major gas leak. A powerful second explosion occurred that reportedly could be felt more than 15 miles from the complex. This explosion and subsequent fire completely destroyed the chemical plant, caused significant damage to the pipe rack, and resulted in moderate damage to other complex buildings and adjacent third-party facilities. The fire was extinguished in approximately three hours.

Because of this incident the chemical plant at this complex was completely shut down for seven months, which was the time required to rebuild this plant and the pipe rack. During this period, the vinyl chloride production at this complex was lost, disrupting most of Mexico's total annual output of 200,000 tons.

11/6/90
Nagothane, India
$22,000,000
$24,400,000

A leak in a pipeline that transports ethane and propane to a gas cracker complex resulted in an explosion at an off-site gas treatment and compression facility. Since the explosion took place outside the complex, the cracker and downstream units were not damaged while the off-site facility experienced significant damage. The cracker was initially shut down due to feedstock supply problems but was later operating on a gas supply directly from the pipeline.

Prior to this incident, low density polyethylene (LDPE), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), and polypropylene (PP) units were to be brought on-line within a few months. The commissioning of these units was expected to be delayed between four and 12 months due to this incident.

7/5/90
Channelview, Texas
United States
$12,000,000
$13,300,000

An explosion and fire originating in a 900,000-gallon wastewater storage tank in the utilities area resulted in significant equipment damage throughout this plant. The explosion completely destroyed an area of the plant approximately the size of a city block. The explosion occurred during the reinstallation of a compressor on the side of this 40-foot storage tank. The compressor, which had been used to circulate vapors and remove hydrocarbons, had been out-of-service several days for maintenance.

This storage tank was designed to serve in the processing of wastewater from the propylene oxide-styrene monomer (PO/SM) unit prior to disposal of the treated wastewater in a deep disposal well on-site. An oxygen analyzer for this storage tank was used to regulate the nitrogen sweep rate for the tank. Prior to the explosion, the analyzer malfunctioned and allowed oxygen to accumulate in the storage tank as a result of a reduced nitrogen sweep rate. The flammable mixture in the tank vapor space is believed to have been ignited by the startup of the compressor.

292

Because of this incident, this plant was expected to be shut down for approximately six months for repairs. During this time, a business interruption loss in excess of $200,000,000 was expected to result from the loss of styrene monomer production capacity. The styrene monomer production capacity for this plant averages 1.4 billion pounds-per-year and represents approximately 15 percent of the total U.S.capacity.

10/23/89
Pasadena, Texas
United States
$675,000,000
$756,000,000

Shortly after 1:00 p.m., a large flow of ethylene, the reactant, and isobutane, a catalyst carrier, was released from one of the high density polyethylene (HDPE) units at this chemical complex. The vapor cloud drifted northward toward the center of the HDPE process area before ignition, which is believed to have occurred approximately one minute after the release. Seismograph data from recording stations in the area suggested the blast was equivalent to the detonation of 10 tons of TNT.

The explosion destroyed two high density polyethylene units, which included a total of eight particle form, loop reactor trains. The heat from the explosion caused BLEVEs of nearby pressure tanks. Other process units at this chemical complex sustained only minor damage and resumed normal production within a few weeks of the incident.

The initial release of ethylene and isobutane occurred through an 8-inch Demco ball valve on the No. 4 settling leg of a reactor in Plant V. The major function of this pnuematic valve is to isolate the settling leg and other downstream equipment from the reactor for maintenance. The company maintenance procedures for opening a settling leg included closing the Demco ball valve, inserting a lock-out device into this closed valve, closing the block valves to the air hoses for the valve operator, and disconnecting these air hoses. Company personnel confirmed that these maintenance procedures were performed on Saturday, October 21. Due to changes in maintenance priorities, the work on settling leg No. 4 was not started until Monday, October 23.

After the explosion, investigations indicated that the lock-out device had been removed from the Demco valve and the air hoses had been reconnected to the valve operator on settling leg No. 4. The Demco valve was found in the open position and the settling leg was open to atmosphere at the bottom of the leg where a swedge spool leading to the product take off valve should have been connected.

A business interruption loss in excess of $700,000,000 resulted from this incident since a period of approximately 24 months was required to restore the full HDPE production capacity at this chemical complex. This incident represents the largest single-owner property damage loss to occur in the petrochemical industry.

6/7/89
Morris, Illinois
United States
$32,500,000
$36,400,000

After a power outage for the amine system and butane column, plant operators worked to restore normal operating conditions in the ethylene production area. In the process of restoring operations, the vent valve for the depropanizer reflux drum was opened to reduce the pressure in this vessel. The vent line piping was arranged to route the excess product to the flare system or the gas compressor. Since the vent line to the compressor was out-of-service for maintenance, the excess propylene should have been routed to the flare system. However, the propylene was accidentally routed through the 2-inch vent line to the compressor, forming a vapor cloud in the ethylene production area.

While plant personnel attempted to dissipate the vapor cloud with fire water monitors and hose streams, the vapor cloud was ignited. The source of ignition is believed to have been a spark from an incandescent light fixture. The bulb was apparently broken by the cold water of a hose stream or vibrated loose. The vapor cloud explosion damaged approximately 40 acres of this plant, including the ethylene production area.

As a result of this incident, the plant was shut down for approximately three months. During this period, only the polypropylene production was continued, resulting in a business interruption loss of approximately $55,000,000.

3/7/89
Antwerp, Belgium
$77,000,000
$86,200,000

A hairline crack in a welded seam of piping to the level indicator system on the aldehyde column resulted in a minor ethylene oxide leak. As a result of this crack, which resulted from low cycle fatigue, ethylene oxide escaped near the level indicator and formed polyethylene glycols (PEG) in the mineral wool insulation. It is believed that both the leak and accumulation of PEG occurred over a period of time. During repairs to the level indicator, the metal sheathing of the insulation was removed and air contacted the insulation soaked with PEG. Auto-oxidation of the PEG resulted and the insulating material was ignited. The piping for the level indicator system was heated to such a degree that autodecomposition of the ethylene oxide within the piping occurred. This autodecomposition then propagated into the aldehyde column which subsequently exploded.

The force of the explosion destroyed the distillation section of this plant. The large resulting fire and impact of flying debris to other process sections resulted in extensive damage throughout the plant. Because of this incident, this plant was closed for at least 24 months and resulted in a business interruption loss of approximately $270,000,000.

11/14/87
Pampa, Texas
United States
$215,300,000
$256,200,000

Failure of a high pressure inlet receiver in the treating section of a large gas processing plant produced a vapor cloud which ignited. The explosion and ensuing fire caused equal blast and heat damage throughout the plant. It is reported that the receiver, which was located inside a building, became liquid-full and that hydrates had formed in the vessel affecting its relief ability. Attempts were being made to relieve the pressure when the failure occurred.

A business interruption loss of approximately $140,000,000 resulted from this incident.

6/15/86
Pascagoula, Mississippi
United States
$10,000,000
$12,300,000

A batch still used to separate aniline product from its reaction by-products was shut down on a Saturday due to a leak on the bonnet of a valve on the discharge side of a steam heated reboiler. The reboiler served the still and its feed drum. Since repairs were not to be made until Monday, the circulating feed pump was shut down and valves were closed to isolate the reboiler, the steam supply for the reboiler, and the leaking valve. Cooling water to the condenser and operation of the reflux pump continued for several hours to lower temperatures on the tower to a satisfactory level.

About 8-1/2 hours later operators observed a high level in the reflux drum and a high temperature at the bottom of the idle still. During the next hour operators attempted to reduce these levels and temperatures; however, for unknown reasons, pressures increased. A relief valve on top of the tower lifted, a vent at the reflux accumulator released liquids, and the tower bottom temperature rose to 550 degrees F. Shortly after the area was evacuated, several explosions occurred.

The explosions, the cause of which have not yet been determined, damaged structures and broke piping in an adjoining nitration unit. Flying fragments punctured two 2,000-barrel atmospheric tanks and a 15,000-gallon pressure tank which contributed fuel to a large ground fire. The still and its feed drum were destroyed, making the investigation into the cause of this incident most difficult.

5/19/85
Priola, Italy
$65,000,000
$81,300,000

Operations within this 600,000 metric tons-per-year ethylene plant were normal until a faulty temperature probe initiated an isolation of the hydrogenation equipment located within the cold section. While the operators were attempting to regain normal control, the pressure relief system came into operation. About the same time, fire was noted near grade level at the base of the de-ethanizer column. The source of fuel was believed to have been flange at the de-ethanizer column reboiler or in the relief system pipe work.

Leaking hydrocarbon, mostly propylene at 375 psig was possibly ignited by hot steam piping. The intense fire rapidly engulfed the adjoining ethylene and propylene distillation columns and spread 180 feet to the storage area. Eventually one tall vertical propane tank exploded, its top section skyrocketing 1,500 feet and missing a gas holder by 30 feet. Two other propylene tanks toppled; one on a pipe rack and the other against an ethylene tank. All were protected by deluge water spray systems which apparently were ineffective under the intense fire exposure. Five of the eight ethylene and propylene tanks collapsed or exploded. The fire also spread to the API separator and to three floating roof tanks. Pipe racks, motor control centers, pumps, etc., were severely damaged or destroyed.

Within a few minutes after the fire brigade responded, the ethylene column released its 9,300-gallon inventory, destroying one of the plant's two foam trucks. Assisted by outside fire fighting agencies, the plant fire brigade brought the fire under control in 40 hours and finally extinguished it four days after ignition.

Trended values in bold italic type

SHB-295

Petrochemical Plants

5/6/82
Duluth, Minnesota
United States
$14,000,000
$19,200,000

An explosion occurred in the drying and grinding area of a chemical plant where fumaric acid was being processed. The ensuing fire spread rapidly through the area, into an adjoining process area and to the 60-foot by 120-foot warehouse, which was totally destroyed. Apparently, a static spark from an electric motor ignited dust from the powdered acid and caused the explosion. The fire was extinguished in approximately three hours.

4/18/82
Edmonton, Alberta
Canada
$21,000,000
$28,800,000

The release of high pressure ethylene from a 1/8-inch stainless steel instrument tubing leading to a gage from a main line on the interstage piping system of a secondary compressor caused $20,000,000 damage to the low density polyethylene plant and an additional $1,000,000 damage to adjoining properties. The tubing failed as a result of transverse fatigue caused by vibrations from the reciprocating compressor. Ignition may have been by static electricity.

The unmanned compressor building was equipped with a combustible gas detection system; however, it failed to sound an alarm because of a faulty relay in the control room. Automatic fail-safe valves functioned properly, blocking in the flow of ethylene but not before 450 pounds to 11,000 pounds of gas had escaped.

3/9/82
Philadelphia,
Pennsylvania
United States
$25,000,000
$34,300,000

One of three phenol units was destroyed and the other two damaged by an explosion and fire. In the process, cumene is oxidized with air to produce cumene hydroperoxide which is cleaved to phenol and acetone by acid catalysis. The unit reportedly was shut down at the time 25,000 gallons of cumene hydroperoxide in an intermediate hold tank were being steam heated. Apparently, temperatures exceeded safe limits, leading to the venting of cumene from the system. This material ignited explosively and caused rupture of the 25,000-gallon tank. Eventually, two other process tanks, one containing fuel oil. became involved in fire.

The blast sheared off a 6-inch sprinkler riser; however, the plant's two 1,500 gpm steam and electric fire pumps, and two 2,500 gpm diesel fire pumps, augmented by 25 city fire department engine companies taking suction from city fire hydrants, were able to supply adequate fire water. The plant fire brigade, 160 city fire fighters, and mutual aid workers from nearby chemical companies and refineries participated in controlling the fire.

10/21/80
New Castle, Delaware
United States
$59,600,000
$97,100,000

Improper maintenance procedures during cleaning of a plugged recycle cooling line on a 10,000-gallon capacity polypropylene reactor released hydrocarbons and polymer. Instead of removing only the motor operator of a 4-inch plug valve, the valve itself was accidentally removed. The release of 12,000 to 16,000 pounds of monomer at 150 psi, produced a 250-foot by 450-foot vapor cloud which ignited after about two minutes.

The explosion broke flammable liquid lines throughout the three process trains and opened polymer lines in the finishing area. The blast also broke fire protection system risers, disrupting all fire water. Fires throughout the polymerization finishing and storage silo areas burned for over 10 hours. Two of the three process lines, the control building, and the finishing area were severely damaged. The compressor building, solvent recovery area, finished product warehouse, and cooling tower were moderately damaged. The fire fighting effort was accomplished with the use of 21 industrial fire brigades, volunteer and paid fire departments.

7/23/80
Seadrift, Texas
United States
$11,800,000
$19,200,000

A new ethylene oxide unit had been shut down due to a direct lightning strike during a thunderstorm. While being brought back on stream, there was a decrease in rpm on the recycle compressor due to instrumentation problems. An ignition within the first reactor produced a detonation in the bottom of the reactor and in the 36-inch feed lines. Heat transfer fluid released by the explosion ignited and involved the reactor structure and adjacent equipment. Damage was localized but severe.

5/17/80
Deer Park, Texas
United States
$18,700,000
$30,600,000

Vibration from a pump bearing failure in the cumene section of a phenol acetone unit caused the pump seal to fail. The released flammable liquids and vapors subsequently ignited. During the fire, several process pipes ruptured, adding fuel to the fire. Additionally, fin-fan coolers elevated above the pipe rack collapsed, as did one process column.

12/11/79
Ponce, Puerto Rico
$15,000,000
$26,600,000

The petrochemical complex which produced dicyclopentadiene, isoprene, and paraxylene had been shut down for 24 hours when a massive failure of a 13-foot diameter dimerizer vessel occurred. The 15 ton 1-1/8 inch thick steel head traveled 1,900 feet to an adjoining paraxylene plant, landing on a propane refrigeration system and setting fire to one of its three units. The blast released 25,000 gallons of hydrocarbon liquids from the dimerizer as well as 80,000 gallons from a nearby solvent tank. Ignition was immediate, and fire damage extended over a 170-foot by 170-foot area while the blast damage covered a considerably larger area of approximately 240-feet by 400-feet in size.

As a result of this incident, approximately $5,000,000 of damage occurred in the isoprene plant and $10,000,000 of damage in the adjoining paraxylene plant.

12/8/77
Brindisi, Italy
$28,300,000
$58,000,000

A major gas release in the cold section of a 230,000 metric tons-per-year ethylene unit became ignited and caused severe blast and fire damage. Two nearby ethylene units were also damaged. The control building had brick panel walls within a reinforced concrete frame. Blast overpressures blew out the wall panels and destroyed the controls. Fire water streams from 40 fire trucks could not be carried off by the plant sewers, resulting in an 18-inch backup of floating burning liquid and heavy hydrocarbons throughout the process area. The fires were controlled in eight hours and extinguished three days later.

Petrochemical Plants

5/24/76 **Geismar, Louisiana** **United States** $9,000,000 ***$19,500,000***	The explosion involved a large polyglycol ether reactor with the release of unreacted ethylene oxide, propylene oxide, glycol, and glycerin. Cause of the failure is believed to be the loss of agitation, and/or failure of a temperature transmitter, and/or the introduction of insufficient catalyst to the reactor. The explosion threw the reactor head 1,400 feet. Fragments ruptured a 320,000-gallon polyglycol ether tank and broke the sprinkler system riser. The ensuing fires in the reactor and tank farm areas were extinguished by the plant fire brigade within one and one-half hours.
11/7/75 **Beek, Netherlands** $22,900,000 ***$53,300,000***	Cold brittle fracture of a 1.57-inch connection of a feed drum to its safety valve in an olefins unit naphtha cracker undergoing start-up caused the escape of a mist of an estimated three to five tons of hydrocarbons, mostly propylene. The subsequent explosion involved nearby storage tanks, buildings, and other parts of the plant as well as off-premises damage.
11/29/74 **Beaumont, Texas** **United States** $16,000,000 ***$40,900,000***	Vapor cloud explosion and ensuing fires resulted from a spill of 16,800 gallons of in-process hydrocarbon liquid, and gases discharging through a broken expansion joint in the suction line of a pump. The explosion created blast waves that broke many process lines, resulting in multiple fires in the isoprene synthesis plant and adjoining tank farm. It also ruptured fire mains and disabled the fire pumps. A major explosion occurred when a 20,000-gallon isoprene storage tank ruptured approximately 15 minutes after the first explosion. About one and one-half hours later, a 12-foot diameter by 200-foot high distillation column collapsed into the isoprene structure causing a flare-up and further involvement of thousands of gallons of hydrocarbons.
6/1/74 **Flixborough,** **United Kingdom** $66,200,000 ***$169,600,000***	Massive failure of a 20-inch diameter bypass assembly around a cyclohexane oxidation reactor caused the release of cyclohexane. The huge vapor cloud expanded into other areas of the plant that produced caprolactam and was ignited. The pressure waves from the explosion and the ensuing fire, involving an estimated 433,000 gallons of flammable liquids, destroyed much of the plant. Off-premises damage extended eight miles and included over 2,400 homes, shops, and factories.
7/8/73 **Tokuyama, Japan** $14,800,000 ***$42,300,000***	Inadvertent interruption of instrument air in an ethylene plant caused an accumulation of hydrogen in an acetylene hydrogenation column. An exothermic reaction occurred because ethylene hydrogenated to ethane, consequently decomposing ethane to methane, carbon, and hydrogen. Leakage resulted in fire and explosion.

Trended values in bold italic type

11/7/71
Morris, Illinois
United States
$5,600,000
$18,400,000

An instrument failure in a utility plant boiler feed control at a petrochemical plant allowed the steam drum to overfill. Water carryover to the steam mains caused a drop in the super-heat temperature of steam to the ethylene plant turbine. The operator then cut off steam to the turbine. This reduction in steam demand caused further upsets in the utility plant, resulting in surging of a recycle gas compressor in the ethylene oxide-ethylene glycol plant. The steam low-flow trip on the recycle compressor had not been reset after having been set down because of previous steam shortages.

At the time of the upset condition, the decision was reached to operate the oxide-glycol plant on one reactor train. Additionally, the No. 2 train oxygen analyzer was bypassed, causing the No. 1 reactor train to trip out on high oxygen level. This oxygen imbalance in the feed to the reactor led to a violent detonation in the No. 2 reactor train gas-to-gas exchanger. This detonation ruptured both reactor trains and ignited the oil in the heat transfer system for the unit. The recycle and reclaim compressors and the No. 2 reactors were severely damaged. There was blast overpressure and shrapnel damage throughout much of the plant.

The fire was brought under control within an hour by the plant fire brigade assisted by six public fire departments.

2/26/71
Longview, Texas
United States
$5,700,000
$18,700,000

A drain fitting on piping between the booster and 40,000 psi high pressure compressors broke allowing a release of ethylene. Automatic equipment promptly detected the hazardous vapor and operated the automatic high-density water-spray system designed to wash ethylene from the atmosphere. Apparently, the leak was too large for the spray system to handle. Ethylene entered the exhaust system of an engine which was driving one of the compressors, causing the muffler to detonate, and thus igniting the rest of the vapors.

The explosions, which were felt six miles away, destroyed 12 buildings and caused lesser damage throughout the polyethylene plant and to the surrounding properties.

10/23/69
Texas City, Texas
United States
$8,000,000
$32,600,000

The 100-foot high refining column in the butadiene unit of a new billion pounds-per-year olefins complex disintegrated with explosive ignition of 540 gallons of liquid hold-up. The unit was operating normally when the stripper make-up compressor was found to be running hot. Crude feed was reduced in preparation for repairing a bad compressor valve. The refining section was put on total reflux for eight hours while compressor repairs were made. It is believed that the explosion was a heat-triggered decomposition of vinyl and ethylacetylenes which had accumulated at the tower bottom until an explosive concentration was reached.

The initiator is believed to have been a thermal polymerization assisted by sodium nitrate. This created a deflagration wave that lifted the bottom trays and moved upward in the column. The temperature, pressure, and concentration of vinyl acetylene were high enough at the fourteenth tray to cause the detonation. Sections of metal plate were spread uniformly over a radius of 1,500 feet. One section weighing about 800 pounds traveled 3,000 feet. All five towers in the butadiene section were either felled or heavily damaged.

8/25/65
Louisville, Kentucky
United States
$10,000,000
$51,200,000

The manufacturing process involves the three-step conversion of acetylene gas to mono vinyl acetylene (MVA), then to chlorobutadiene (CD), and by polymerization to neoprene. Mechanical failure in a compressor circulating gaseous MVA in the reactor system caused localized heating in metal moving parts to such an extent that the extremely high temperature initiated decomposition. Several subsequent explosions were caused by fragments from the first explosion, flame impingement, and flame transmission through pipelines.

Gas Processing Plants

8/15/87
Ras Tanura,
Saudi Arabia
$60,000,000
$71,400,000

A series of electric power interruptions caused several shutdowns of one or both of the identical 165,000 barrels-per-day gas fractionation process trains. The parallel trains were separated from one another by about 100 feet. At the time of the loss, propane feed to Plant I was about 100 percent of design capacity and feed to Plant II was about 25 percent of capacity.

It is believed that there was a release of about 1,900 barrels of propane in Plant I over a half-hour period. Ignition of the large vapor cloud is believed to have been by a security vehicle which had stalled and was being restarted. The probable source of propane was a flange in a 4-inch relief valve line.

9/30/84
Basile, Louisiana
United States
$30,000,000
$37,800,000

Failure of a threaded one and one-half inch drain connection on a rich oil line at the base of an absorber tower in a large (135 MMscfd) gas producing plant allowed the release of rich oil and gas at 850 psi at -40 degrees. The resulting vapor cloud probably ignited from the ignition system of engine driven recompressors. The 75-foot high by 10-foot diameter absorber tower eventually collapsed across the pipe rack and on two exchanger trains. Broken pipelines added more fuel to fire. Severe flame impingement on an 11,000 horsepower gas turbine driven compressor-waste heat recovery and super-heater train resulted in its near total destruction.

4/14/83
Bontang, Indonesia
$50,000,000
$65,500,000

The main cryogenic heat exchanger serving one of two identical 265 MMscfd processing trains of a liquified natural gas plant ruptured violently. The investigation revealed that a valve on the 24-inch blowdown line which collected the discharge from various relief valves protecting both shell and internal coils of the main heat exchanger was closed. This effectively prevented the safety relief valves from performing their function. It also prevented a pressure controller at the top of the shell from operating, since it also discharged into the same header. It appears that this valve was omitted from the valve check list for start-up operations. Both trains were being started up following a shutdown to allow tie-ins from two additional newly constructed LNG trains.

The 141-foot by 14-foot diameter exchanger was designed for 60 psig and an operating pressure of 25.5 psig on the shell side. Derime gas from a source in excess of 500 psig caused massive failure of the exchanger. Fragments and coil sections of the all-aluminum 170-ton column were thrown as far as 160 feet. The ensuing fire was limited and extinguished in less than one-half hour.

4/15/78
Abqaiq, Saudi Arabia
$53,700,000
$102,600,000

A 22-inch gas transmission pipeline operating at 500 psig developed a leak due to internal corrosion. The leak expanded and the line parted releasing a vapor cloud near a gas processing plant with an area 405 feet by 435 feet. After about seven minutes, ignition occurred from a flare located 1,500 feet downwind. The jet/whipping action of escaping gas threw a 22-foot section of pipe 400 feet where it struck the vapor space of a 10,000-barrel spheroid. A second vapor cloud formed and was ignited, developing detonation overpressures of 7.8 psi.

5/11/77
Abqaiq, Saudi Arabia
$54,500,000
$111,700,000

Failure of a 30-inch crude oil pipeline, buried eight feet and operating under 925 psi, resulted in a fire which destroyed three 40,000-barrel spheroids, pumping units, and other equipment. Over 300 valves had to be closed to shut in the gas field and eliminate the fuel supply to the fire. Ignition was by a motor vehicle.

4/3/77
Umm Said, Qatar
$76,400,000
$156,500,000

A 260,000-barrel tank containing about 236,000 barrels of refrigerated propane at -45 degrees F failed massively. The wave of liquid propane swept over the dikes and inundated the 51,000 barrels-per-day process area before igniting. An adjoining tank containing 125,000 barrels of refrigerated butane also was destroyed as was most of the process area. The fire burned out of control for two days and was extinguished after eight days.

Reportedly, the tank weld which failed had been repaired following a weld failure incident one year earlier in which 14,000 barrels of propane were released. The April 3 weld failure was attributed to three possibilities including microbiological sulfate reducing bacteria from hydrotesting the tank with seawater. In the first incident, a massive vapor cloud traveled 500 feet but did not ignite.

7/9/65
Carthage, Texas
United States
$3,000,000
$15,400,000

Failure of pump packing or a brass valve in a one and one-half inch steel line carrying lean oil at 175 psi and 150 to 175 degrees F resulted in a release of oil. The oil was ignited by exposed parts of a 600-pound steam regulator in an absorption gasoline plant. Employees discovered the fire almost immediately and used two 150-pound dry chemical extinguishers to try to control it. They seemed to be making progress when they noticed that the heat had caused the head of an oil-to-oil heat exchanger to start leaking around the seals, adding additional fuel to the fire. The employees then tried to put a mechanical foam line in operation, but the rapidly intensifying heat forced them to leave the area.

Shortly thereafter, the unprotected steel supports on a 600-barrel rich oil surge tank collapsed. When the tank fell, the pipelines from the tank to a 70-foot high reabsorber tower pulled the tower over. The tower fell across the ends of a 600-barrel distillate surge tank and the rich oil surge tank, apparently squeezing the end of the distillate surge tank open and causing it to rocket about 150 feet. This released additional fuel and led to more pipeline and equipment failures.

Because of the intensity of the fire and rupturing of equipment, fire fighters did not enter the plant. The fire burned for several days, until all the fuel was consumed.

SHB 302

Terminals

8/21/91
Melbourne, Australia
$11,200,000
$12,100,000

An explosion occurred at approximately 2:15 p.m. in a 72,700-gallon acrylonitrile storage tank at this petrochemical bulk storage facility. The subsequent fire spread resulting in additional explosions, with rocketing tank lids and collapsing tanks. The final explosion and fire occurred from a leaking methyl ethyl ketone (MEK) tank on August 22. A total of 32 storage tanks were destroyed or damaged from this incident.

A toxic cloud of phenol and acrylonitrile was released by the initial explosion, forcing the evacuation of thousands of residents within a four square mile area of the facility.

The fire water main and fixed foam protection systems for the acrylonitrile storage tank were damaged by the initial explosion, hampering the manual fire fighting effort for this tank. At least 155 fire fighters worked to control the fire and protect nearby storage tanks. The fire was finally extinguished at this facility on August 23. In excess of 100,000 gallons of AFFF foam concentrate were used during the fire fighting effort.

Due to the extensive repairs needed at this facility, a business interruption loss of approximately $40,000,000 was expected to result from this incident.

11/25/90
Denver, Colorado
United States
$32,000,000
$35,500,000

A fire occurred at this 16-acre flammable liquids tank farm which supplies jet fuel to an adjacent international airport. The fire burned for more than 55 hours, damaging seven storage tanks and consuming more than 1.6 million gallons of jet fuel. This tank farm contained a valve pit, south impounding area, north impounding area, and 12 storage tanks.

At approximately 9:20 a.m., the fuel supply company received a "no flow" indication in the pipeline to the tank farm. Shortly after that time, the airport control tower noticed a column of black smoke from the tank farm. An initial fuel leak originating at an operating fuel pump in the valve pit was ignited by the electric motor for the pump, resulting in the fire. A cracked supply pipe in the valve pit formed two "V" shaped streams extending 25 to 30 feet into the air, providing additional fuel to the pool fire. As the fire continued, coupling gaskets in the piping deteriorated and more fuel flowed out of the storage tanks, substantially spreading the fire. Additionally, the valve controlling fuel flow in the supply line to the airport sporadically released fuel into the valve pit. Fire fighters were unable to prevent the back flow of fuel from this line since the nearest manual shutoff valve was two miles from the tank farm.

At the initial fire alarm, the airport fire department dispatched four aircraft rescue and fire fighting (ARFF) trucks and one rapid intervention vehicle. The second and third fire alarms provided an additional five pumpers, three fire trucks, and one rescue unit from the Denver Fire Department. Besides the foam concentrate on hand, foam concentrate was received from fire departments in Seattle, Chicago, Houston, and other cities. After repeated unsuccessful attempts to extinguish the fire by the Denver Fire Department, additional foam concentrate arrived from a foam manufacturer, and a private contracting company specializing in petroleum fire fighting assisted the Denver Fire Department in extinguishing the fires throughout this tank farm.

Although the operations at the international airport were not affected by this incident, a significant property damage loss resulted at the tank farm.

12/21/85
Naples, Italy
$42,000,000
$52,500,000

Twenty-four of the 32 storage tanks at a large government owned marine petroleum products terminal were destroyed by fire which began with a tank overfill. Twenty-seven thousand tons (715,000 barrels) of gasoline and fuel oil were being off-loaded into tanks which reportedly were equipped with high liquid level gages.

A large spill developed followed by a vapor cloud which was ignited by an unknown source. Almost immediately, 20 of the tanks were involved in a massive fire covering 3.7 acres. The devastating explosion caused complete destruction of the terminal buildings and extensive damage to nearby industrial and residential structures. Tank piping failed, contributing more fuel to the fire. The main fire fighting control center as well as electric and engine driven fire pumps and foam lines were disabled. Efforts to extinguish the fire were handicapped by intense heat radiation and by debris from the explosion.

About 800 fire fighters with 166 pieces of mobile equipment responded from throughout south central Italy. This included airport crash trucks and even air tanker planes which dropped foam on the fire. Four-hundred sixty tons (132,000 gallons) of foam were used in the fire fighting effort. The fire was extinguished three and one-half days after it started.

11/5/85
Mont Belvieu, Texas
United States
$43,000,000
$53,700,000

A contractor accidentally cut into a 10-inch propane line operating at 900 psi at a natural gas liquids terminal. The large vapor cloud estimated to cover an area 44 acres in size was ignited about four to five minutes later by an unknown source. Liquid products from five of 26 salt dome caverns fed the fire with an estimated 18,000 to 30,000 gallons of LPGs for almost six hours before being blocked in and the fires extinguished. Both engine driven fire pumps failed; one because intense radiated heat damaged its ignition wires and the other because the explosion broke a sight glass fuel gage, which spilled diesel fuel that ignited and destroyed the fire pump engine.

Intense heat melted the large glass windows of the control center on the second floor of the office building, resulting in total loss of electronic equipment.

In addition to a large loss of NGL inventory and widespread structural damage throughout the terminal, there was about $8,000,000 damage to electronic and computer equipment by radiated heat.

Trended values in bold italic type

SHB-304

11/19/84
Mexico City, Mexico
$19,900,000
$25,100,000

This explosion and fire, occurring at a government owned and operated LPG terminal, is perhaps the most devastating such incident ever. Three refineries supplied the facility with up to 1,300,000 gallons of LPG daily. This was stored in six spheres and 48 bullets with a combined capacity of 4,242,000 gallons. Tanks were about 90 percent full at the time of the loss.

Product for storage was being received at 341 psig via a 12-inch pipeline from a refinery 250 miles distant. The two largest spheres, each with a capacity of 630,000-gallons, and the 48 cylindrical tanks had been filled. The four remaining spheres, each with capacity for 420,000 gallons, were receiving product and were about one-half full when an 8-inch line to one of the spheres ruptured. The pressure drop was immediately sensed by the refinery operators. Attempts to contact the terminal by telephone were unsuccessful and since the flow could only be stopped at the terminal it continued. About 10 minutes later the large vapor cloud which had formed was ignited by a grade level burn pit-flare. Within five minutes of ignition the first of a series of massive BLEVEs occurred, producing a fire ball estimated to be 1,200 feet in diameter. The radiated heat from the rupturing tanks and the missile damage allowed the release of more fuel from other tanks. Eventually, the four smaller spheres and 44 of the bullets BLEVEd or were ruptured by missiles. Some tanks weighing 20 tons skyrocketed and landed 3,900 feet away.

The terminal's fire water system was disabled in the initial blast. Water transported to the scene by 100 tank cars was used by fire fighters in keeping the two large spheres sufficiently cool to prevent their failure. These spheres developed leaks in their vapor spaces which allowed them to depressure and burn under controlled conditions.

1/7/83
Newark, New Jersey
United States
$35,000,000
$45,900,000

Pipeline gasoline was being received into a 42,000-barrel internal floating roof tank at a products terminal when an overfill occurred, spilling about 1,300 barrels into the tank dike. A slight wind (1 to 5 mph) carried the developing vapor cloud about 1,000 feet to a drum reconditioning plant where an incinerator provided the ignition source. The resulting explosion caused $10,000,000 damage to the terminal and up to $25,000,000 in over 2,000 claims to rail rolling stock and adjacent properties. Although dikes contained the burning spill to the tank which was overfilled, two adjoining internal floating roof tanks and a smaller transmix tank ignited and eventually were destroyed along with 120,000 barrels of product. Since the burning tanks presented little exposure to other facilities, the decision was made to let the fire burn itself out.

1/8/79
Bantry Bay, Ireland
$20,600,000
$36,400,000

An 11-year-old 121,000 DWT tanker had completed unloading its first parcel of Arabian heavy crude at a deep-water port. No transfer operations between the ship and the jetty were in process when a small fire was noticed on deck. About 10 minutes later, fire spread aft along the length of the ship and was observed on the sea at both sides of the ship. After a half hour, a massive explosion occurred. It is theorized that the initiating event of the disaster was the buckling of the ship's structure at or about deck level. This was immediately followed by explosions in the ballast tanks and the breaking of the ship's back. These events were produced by the conjunction of two separate factors: a seriously weakened hull due to inadequate maintenance, and an excessive stress due to incorrect ballasting at the time of the disaster.

A fragment of the ship weighing 1,000 pounds was found at the base of a "Jumbo" crude oil tank, a distance of 1,800 feet from the ship. In addition to total loss of the ship, 1,130 feet of the concrete and steel jetty were damaged or destroyed.

Miscellaneous

7/19/90
Cincinnati, Ohio
United States
$23,000,000
$25,500,000

This manufacturing plant produces various types of resins which are used as industrial coatings. At this plant, a batch of acrylic resin had been processed and removed from the reactor. Prior to processing the next batch of resin, plant operators were to clean the reactor.

During the cleaning process, cleaning solvent was pumped into the bottom of the reactor. Due to the residual heat of the reactor, some of the cleaning solvent vaporized and overpressurized the reactor, causing the actuation of the rupture disc for this vessel.

The hot solvent and vapors were released through this rupture disc and subsequently formed a vapor cloud in the reactor building. The vapor cloud then contacted an ignition source, resulting in an explosion which completely damaged the reactor building and related equipment. Several adjacent buildings and some storage equipment, including raw material and products, were also damaged at this plant.

2/14/89
Urdingen, Germany
$40,000,000
$44,800,000

During the initial production stage at this paint manufacturing plant, various chemicals are mixed in an agitator vessel and then brought to reaction. The temperature of this reaction is to be maintained at 355 degrees F (180 degrees C) by means of steam heating and water cooling. Prior to the incident, the temperature rose to 410 degrees F (210 degrees C) and could not be reduced with the available means of cooling. As a result, the agitator vessel exploded and released a cloud of gas which was subsequently ignited, setting several plant buildings on fire. The exact cause of the temperature rise and explosion are unknown at this time.

The business interruption loss associated with this incident was estimated at $85,000,000. The length of time required to restore plant operations was unknown. It should be noted that the demolition work was expected to be complicated and lengthy since the debris was considered toxically contaminated.

01/30/89
Secunda, South Africa
$13,000,000
$14,600,000
New this edition

At approximately 9:10 a.m., a fire occurred near a quench tower in the reactor area of this synthetic fuels plant. The main process equipment, such as the quench tower and associated heat exchangers, was not seriously damaged by the fire; however, the piping, instrumentation, and electrical equipment in the process area experienced substantial damage. The tower skirts and pipe rack supports were protected by three to four hour rated fireproofing, which prevented the failure of these structures and limited the amount of property damage.

The fire resulted when a 6-inch carbon steel pipe, which is the return line of the recycle system for the quench tower that cools and separates the Synthol reactor product stream, failed as a result of corrosion/erosion. Iron particles in the oil stream, subjected to a zone of turbulence, were a contributing factor in the pipe failure. The failure of the pipe caused a release of hydrocarbon product that spontaneously ignited under the high pressure and high temperature operating conditions.

Trended values in bold italic type

SHB-307

The water spray systems and fire water monitors provided for the Synthol unit were immediately activated by plant personnel. The plant fire brigade responded within minutes to protect nearby equipment and contain the fire. The fire was brought under control by 11:00 a.m. and completely extinguished by 1:00 p.m.

Because of this incident, the entire plant was shut down for 11 days and operated at 50 percent capacity for another 13 days. The damaged Synthol reactor train was returned to service after 12 weeks of downtime, with all stainless steel piping for the quench tower recycle system. A business interruption loss of $49,000,000 resulted from this incident.

5/26/83
Prudhoe Bay, Alaska
United States
$31,6000,000
$41,400,000

A low-pressure NGL feed surge drum ruptured violently in this crude oil flow station, resulting in direct damage and subsequent fire damage to one-third of the enclosing module as well as moderate fire exposure damage to the exterior of surrounding structures within 100 feet. It is believed that high pressure from downstream vessels backed up past valves into the feed surge drum filling it with liquid product until it structurally failed. The equipment involved was not critical to oil production so operations were suspended for only a short time.

2/26/80
Brooks, Alberta
Canada
$40,000,000
$65,200,000

Rupture of a short section of buried 36-inch mainline between the flange and the valve body of a gate valve assembly was the source of an explosion and fire which destroyed much of a large natural gas transmission compressor station. At the time of the loss, throughput was 3.2 billion cubic feet per day, or 80 percent of capacity.

The initial blast produced a small crater, thus exposing a 34-inch turbine discharge line which tied into the 36-inch mainline. Force of the escaping 950 psi gas twisted the 36-inch mainline upward and wrapped it around the 34-inch pipe which also ruptured. Ignition was prompt, and the gas jet was directed toward compressor buildings 250 feet distant where two out of three 20,000-horsepower turbine-driven compressors were destroyed and the third seriously damaged. The control building and meter house 600 feet from the fire source were destroyed. A building housing five reciprocating compressors was destroyed, as was the auxiliary shop. Automatic control facilities operated immediately after the first explosion to close all valves. Backflow of gas between the line break and the next downstream valve 15 miles away burned off after about three hours.

7/8/77
Fairbanks, Alaska
United States
$36,500,000
$74,700,000

Accidental starting of a pipeline pump while a strainer cover plate on the 26-inch pump suction line was being removed allowed crude oil at 250 psi to be released. Ignition probably was from hot main turbines. The fire was mostly confined to the pump house and extinguished in about three hours.

SHB 308

M&M Protection Consultants—consultants to management in hazard control, dedicated to the protection of lives, the conservation of property, and the continuity of business.

M&MPC Headquarters
1166 Avenue of the Americas
New York, New York 10036
(212) 345-6020

With North American offices in:

Appleton
Atlanta
Boston
Buffalo
Calgary
Casper
Cedar Knolls
Charlotte
Chicago
Cincinnati
Cleveland
Columbus
Dallas
Detroit
Edmonton
Grand Rapids
Greenville
Hartford
Houston
Indianapolis
Jacksonville
Kansas City
Los Angeles
Milwaukee
Minneapolis
Montreal
New York
Philadelphia
Phoenix
Pittsburgh
Portland
Richmond
Rochester
San Francisco
Seattle
St. Louis
Stamford
Toronto
Vancouver
Washington, D C.
Winnipeg

And members of the M&MPC Global Network in:

Argentina
Australia
Belgium
Bolivia
Brazil
Chile
Colombia
France
Germany
Hungary
Ireland
Italy
Japan
Mexico
Netherlands
New Zealand
Nigeria
Peru
Portugal
South Africa
Spain
Sweden
Trinidad
United Kingdom
Venezuela

MARSH &
MCLENNAN
M&M Protection Consultar

Printed in U.S.A.

LPCA 1-95-5.0