CHARACTERISTICS AND COMMON VULNERABILITIES INFRASTRUCTURE CATEGORY: PETROLEUM REFINERIES

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Preventing terrorism and reducing the nation's vulnerability to terrorist acts requires understanding the common vulnerabilities of critical infrastructures, identifying site-specific vulnerabilities, understanding the types of terrorist activities that likely would be successful in exploiting those vulnerabilities, and taking preemptive and protective actions to mitigate vulnerabilities so that terrorists are no longer able to exploit them. This report characterizes and discusses the common vulnerabilities of United States (U.S.) petroleum refineries, which produce and handle large quantities of inherently hazardous materials and manufacture final and intermediate products that are fundamental elements of other economic sectors.

REFINERY CHARACTERISTICS

Common Characteristics

A refinery comprises upstream components, process units, downstream components, and product storage. There are four basic processes used in refineries to produce products. Distillation is used to separate hydrocarbons of similar boiling range into intermediate and final products. Chemical processes are used to change the structure of the hydrocarbons to give them different properties—breaking them into smaller pieces or combining them into larger ones. Treating processes are used to remove impurities such as sulfur, and blending systems are used to combine intermediate products and additives into final products for sale.

Figure 1 Oil Refinery Showing Distillation Columns

Individual refineries differ by complexity and physical configuration. Figure 1 (on the previous page) is a photo of an actual petroleum refinery (http://www.howstuffworks.com/oil-refining3.htm). Figure 2 provides an example of the process flow of the more common refinery units (http://www.cheresources.com/refining.shtml).

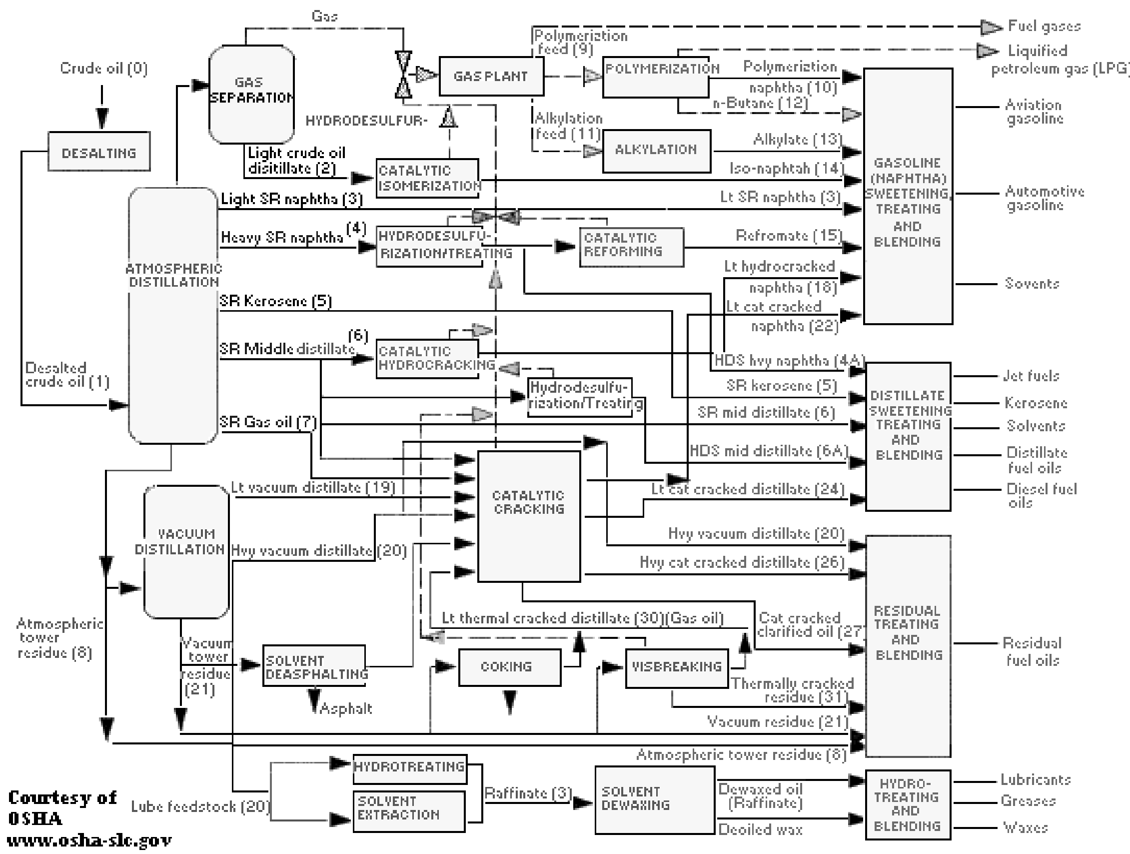

Figure 2 Schematic of Refinery Process Flow

Below is a list of components, equipment, and facilities typically found at refineries.

Upstream Components

- Crude oil pipelines entering the site, often aboveground within the refinery fence line (may come from off site or from port/pier/dock/wharf)
- Crude oil pumps
- Crude heater
- Raw material pipelines (e.g., hydrogen)
- Port/pier/dock/wharf facilities

Process Units

- Desalter
- Atmospheric distillation unit
- Vacuum distillation unit
- Hydrocracking unit
- Fluidized-bed catalytic cracking unit (FCCU)
- Coker
- Continuous catalytic reformer (Platformer)
- Hydrotreater
- Alkylation unit
- Ultraformer
- Hydrogen production plant
- Gas separation unit

Support Components

- Operations control centers, including supervisory control and data acquisition (SCADA) systems and process monitoring equipment
- Sulfur recovery unit
- Cooling towers
- Mixing manifolds (i.e., a very large, complicated, and unique arrangement of pipes, valves, and interconnections from all over the refinery)
- Pumps
- Fire station/emergency response vehicles

Interdependencies

- Water supply pipeline
- Water pumps (off- and on-site)
- Water treatment plant (clarification)
- Underground wells
- Wastewater treatment plant
- Heat and steam plants (e.g., boiler house)
- Natural gas pipeline into the site (i.e., fuel for heat plants or cogeneration plants)
- Gas plant (fuel gas)
- Electric substations
- Electric cogeneration plants
- Telecommunications (i.e., radio, telephone, fiber optics)

Downstream Components

- Refined product pipelines leaving the site, often aboveground within the refinery fence line
- Port/pier/dock/wharf facilities for receipt of crude oil or delivery of refined product by marine transport (e.g., ship or barge)
- Rail off-loading facilities
- Truck off-loading facilities (rack) for hazardous materials and/or refined product

Storage

- Crude storage tanks
- Refined product storage tanks
- Ammonia storage vessels
- Hydrogen storage vessels
- Hydrofluoric (HF) acid storage vessels
- Butadiene/butane/propane/liquefied petroleum storage vessels (spheres)
- Chlorine tanks

Figure 3 shows hazardous materials spheres used for storage (www.petrostrategies.org/OilandGasbasics/).

Figure 3 Hazardous Materials Spheres

Standards

The petroleum refining industry is unique in that the environmental requirements aimed at it are of two basic types: (1) those mandating specific product qualities for reducing the environmental impacts associated with the downstream use of the product and (2) those directed at reducing the environmental impacts of the refineries themselves. Under the first category are environmental requirements for the production of reformulated gasoline products, which will reduce air pollution impacts. Under the second category, refineries must comply with all federal and state environmental regulations concerning the following:

- Air emissions from process units and risk management planning (Clean Air Act [CAA]);
- Toxic Release Inventory reporting and emergency planning in coordination with the Local Emergency Planning Commission (Emergency Planning and Community Right-to-Know Act of 1986 [EPCRA], expanded by the Pollution Prevention Act of 1990);
- Wastewater management, including wastewater discharges to water courses (Clean Water Act) and underground injection wells (Safe Drinking Water Act);
- Water withdrawal/treatment and the protection of sole-source aquifers (Safe Drinking Water Act); and
- Spill Prevention Control and Countermeasures planning (Oil Pollution Control Act).

Refineries have to comply with all employee safety and occupational health requirements, including personal protective equipment (PPE) and equipment control and maintenance (Occupational Safety and Health Act). In addition, refineries must comply with the regulations for the shipment of hazardous materials (49 U.S.C. 5101) and pipeline transport of hazardous materials (49 U.S.C. 60101).

CONSEQUENCE OF EVENT

The CAA requires facilities with more than a threshold quantity of a listed extremely hazardous substance to have a risk management program in place and to submit a Risk Management Plan (RMP) to the U.S. Environmental Protection Agency (EPA). The List of Regulated Substances includes 77 toxic substances and 63 flammable substances, which can be found in the *Code of Federal Regulations* (40 CFR 68). Information contained in an RMP for a facility of interest—which would include any refinery using, storing, manufacturing, or handling toxic or flammable chemicals—can be helpful in understanding both the specific facility assets that might be of interest to terrorist groups and the potential consequences of a successful attack.

Unfortunately, until 1999, the executive summaries were available publicly and could have been acquired by terrorist organizations. Currently, RMP executive summaries can no longer be accessed from the EPA website directly. Complete RMPs, including the offsite consequence analysis (OCA), which describes the demographics within a certain radius of the facility as well as environmental receptors within that radius, are kept by the EPA. Other governmental agencies may have access to this information upon special request to the EPA. In addition, complete RMPs (including OCA information) are available (with certain restrictions) for viewing in paper form at EPA and the Department of Justice reading rooms located throughout the U.S. Such access is required by Public Law 106-40 (the Chemical Safety Information, Site Security, and Fuels Regulatory Relief Act, see Ref. 4). Furthermore, RMP information can be obtained for most covered facilities from the Right-to-Know Network (http://d1.rtk.net/rmp/wgrmp.php). This website could be an important source of information for terrorists to use in selecting targets and estimating the consequences of their attack scenarios.

The executive summaries available on the Internet vary in level of detail but often provide in-depth information that could be useful to terrorists planning an attack. These summaries must, by regulation, include a description of (1) the accidental release prevention and emergency response policies at the facility; (2) the facility and the regulated substances handled; (3) the worst-case release scenario(s), defined below, and the alternative release scenario(s), including administrative controls and mitigation measures to limit the distances for each reported scenario; (4) the general accidental release prevention program and chemical-specific prevention steps; (5) the five-year accident history; (6) the emergency response program; and (7) planned changes to improve safety. Some executive summaries also contain detailed OCA information.

An estimated 15,000 facilities nationwide handle, manufacture, use, or store toxic and flammable substances in quantities above the EPA-regulated thresholds. The worst-case release scenario included in the RMP considers a hypothetical release of toxic or flammable substances that has the greatest exposure distance in any direction. Many facilities exist in populated areas where a chemical release could threaten thousands.

Not all refineries store or use the same chemicals, have exactly the same processes, or operate in the same fashion. In addition they do not have similar off-site circumstances. Therefore, consequences of an event will vary for each individual refinery. An example of a common worst-case scenario, as defined by the EPA, associated with toxic substances in RMP-covered processes at a refinery with HF acid might be a failure of the HF acid storage tank in the HF alkylation unit. If such a failure released the maximum inventory of the tank (thousands of pounds), the HF acid would vaporize, resulting in a toxic exposure hazard in the downwind area that would extend outside of the boundary of the refinery. As specified by the EPA, this analysis assumes that all of the HF acid is released into the air. An example of a worst-case scenario associated with a refinery that does not use HF might be a catastrophic failure in the hydrocracker, resulting in a release of about 60,000 lb of anhydrous ammonia over a 10-minute period.

A common example of a worst-case scenario associated with a release of flammable substances in RMP-covered processes at a refinery might be a vapor cloud explosion, involving the full inventory of the largest storage tank containing butane. The analysis assumes that the maximum possible inventory of millions of pounds is released, completely vaporizes, and ignites, resulting in a vapor-cloud explosion. If there are public receptor locations just outside the refinery property, this event could affect members of the public at those closest locations. The worst circumstances for such an event would probably involve the periodic refinery “turnaround,” when the refinery is subject to maintenance and retooling, which may involve many (up to 1,000 to 2,000) employees and contractors on site at one time.

Loss of the output of product from a large refinery, or one that produces certain specialty reformulated fuels, can create fuel shortages or price spikes locally or even nationally.

COMMON VULNERABILITIES

Critical infrastructures and key assets vary in many characteristics and practices relevant to specifying vulnerabilities. There is no universal list of vulnerabilities that applies to all assets of a particular type within an infrastructure category. Instead, a list of common vulnerabilities has been prepared, based on experience and observation. These vulnerabilities should be interpreted as possible vulnerabilities and not as applying to each and every individual facility or asset.

The following is a list of common vulnerabilities found at refineries.

Exhibit 1 Economic and Institutional Vulnerabilities	
Economic and institutional vulnerabilities are those that would have extensive national, regional, or industry-wide consequences if exploited by a terrorist attack.	
1	The number of petroleum refineries in the U.S. continues to decrease. No major refineries have been built in 20 years. A disruption at a petroleum refinery has the potential to have local, regional, and national impacts.
2	The petroleum industry is a critical U.S. infrastructure. Loss of petroleum products, as demonstrated in the late 1970s and early 1980s, impacts other industries, infrastructures, and the national economy and security. Refineries are a critical link in this infrastructure by processing crude oil into finished products (e.g., gasoline, heating oil, jet fuel) that are used by consumers.
3	A loss of critical components (e.g., catalytic cracker, coker) has the potential to shut down a refinery for an extended period of time. Spare parts that are large and/or expensive may be in short supply. Economic considerations may have reduced spare part inventories. Some parts may have long lead times to obtain or may be available only from overseas vendors.

Exhibit 2 Site-Related Vulnerabilities

Site-related vulnerabilities are conditions or situations existing at a particular site or facility that could be exploited by a terrorist or terrorist group to do economic, physical, or bodily harm or to disable or disrupt facility operations or other critical infrastructures.

Access and Access Control

1	Public roads may be in close proximity to critical assets (e.g., storage tanks) or refinery entrance points.
2	Critical assets may be set close to the perimeter fence.
3	Public roads or rail lines may pass over some refineries.
4	Rail lines adjacent to or through refineries may make it difficult to define and protect refinery perimeter.
5	Rail lines or spurs may pass through or may be adjacent to refineries.
6	Railcar storage may be located within or may be adjacent to refineries.
7	The contents of railcars may not be provided to facility owners.
8	Hazardous materials are loaded/unloaded at refineries.
	Facilities may not have rigorous procedures to inspect railcars before entering the facility.
9	Facilities may not have rigorous procedures to inspect trucks before entering the facility.
10	Heavy truck traffic comes through a refinery. Inspect ions to verify cargo, driver identification, bill of laden, and weight may not be rigorously conducted.
11	Facilities may not provide on-site escorts for all hazardous shipments routinely entering the site.
12	Railcar or truck spills could be caused intentionally and spread throughout a refinery, requiring facilities to implement its hazardous material spill prevention, response, and mitigation plan.
13	Access control at ports/piers, via either the water or a beach, may be difficult to enforce.
14	Gates and critical assets near the perimeter fence line may not be protected by appropriate barriers or other hardening equipment.
15	Many refineries use contract guard services. Guard staff may not be adequately trained and may not be armed. Company security departments may be understaffed.
16	Critical facilities or assets may not be completely or adequately enclosed.
17	Refineries may not have signs posted to deter vehicles, boats, or pedestrians from entering the facility premises.
	Continued on next page.

18	Camera surveillance may not cover all critical assets.
19	Lighting may be inadequate in certain parts of the refinery (e.g., too little, poorly spaced, or improperly directed). At ports, lighting may be limited due to regulations (e.g., fish breeding, neighbor complaints).
20	Entrances to critical assets within the facility (e.g., control rooms) may not have controlled access. Once someone has gained access to the site, that person may have access to multiple areas within the refinery.
21	During turnaround periods, 1,000 to 3,000 additional contractors may be onsite, which may cause additional security issues associated with access and vehicle checks.
22	Employee and visitor parking may be located next to critical buildings.
Operational Security	
23	Risk Management Plan information may be publicly available. Worst-case scenario for toxic and flammable release may be available.
24	Background checks conducted on employees and contractor personnel may be limited. Some states or even union contracts may limit the use of background investigations.
25	There may be gaps in coordination with local, state, and federal agencies on roles/responsibilities.
26	Websites may provide detailed information on refinery locations, critical assets, maps, and other operational data.
27	Hacking may provide adversaries with additional information.
28	Lists of refinery locations may be available through public sources.
SCADA & Process Control	
29	Security may be lacking around servers and control rooms.
30	There is a potential for an intruder to hack into SCADA/process control through the company enterprise network.
31	There is a potential for a controller to cause an undesirable event.
32	Wireless PLCs, which are being implemented in refinery SCADA/process control systems, may add information technology vulnerabilities.
33	Standardized systems (e.g., Windows) and protocols may be used for SCADA and process control systems such that a vulnerability exploited at one refinery may be relevant at multiple refineries.
34	The facility may not have a backup control center.
Emergency Planning and Preparedness	
35	Contingency plans may not be exercised on a routine basis.
36	Emergency operation center backup facilities may not be in place.
37	Spare parts that are large and/or expensive may be in short supply. Economic considerations may have reduced spare part inventories. Some parts may have long lead times to obtain and/or may be available only from overseas vendors.
38	Onsite aboveground pipelines may be vulnerability to attack causing fire or explosions.
39	Nontraditional fires/explosions may be created at refineries that may cause additional challenges to first responders.
40	Additional coordination of emergency plans may be needed with industry neighbors and with local, state, and federal governmental authorities.
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Hazardous and Toxic Materials	
41	Worst case scenarios may be included in publicly available RMP filings, including identification of HF acid and butane spheres.
42	Large HF tanks or LPG storage vessels (a.k.a “bullets”) may be identifiable from offsite.
43	Light-end products such as butane and propane are highly flammable.
44	Certain chemicals at a refinery may pose large loss-of-life scenarios if released in sufficient quantities.
45	Because of the volatile nature of the products being produced, the destruction of a pipe or storage vessel may result in a significant fire hazard.
Other System Operation Considerations	
46	Critical pipelines (e.g., crude delivery, onsite pipelines from docks/piers, and refined product transportation), manifolds, and valves may be aboveground within the refinery premises.
47	The Strategic Petroleum Reserve (SPR) is on a two-week release cycle, while most refineries have a one-week supply on site.
48	Refineries may be limited as to the types of crude oil they can process.
49	Oil tanker vessels may be vulnerable to an attack, causing loss of product to the refinery, environmental damage, and health/safety concerns.
50	Piers may be accessible, particularly at night, via swimming, foot, boat, or vehicle.
51	With a single train process configuration (all or none running), the loss of one asset could halt, rather than just reduce, production.

Exhibit 3 Interdependent Vulnerabilities	
Interdependency is the relationship between two or more infrastructures by which the condition or functionality of each infrastructure is affected by the condition or functionality of the other(s). Interdependencies can be physical, geographic, logical, or information-based.	
General	
1	Loss of feedstock (e.g., nitrogen, hydrogen) may reduce refinery operations and even shut down a refinery.
2	Ports/docks/piers may be shared by multiple refineries, such that loss of one asset may impact more than one refinery.
3	If a large marine vessel cannot unload at the initial port of call, it may not be able to unload at the next available port, because, with the full load of cargo, it may not meet the draft limits at that next port.
Natural Gas	
4	Loss of natural gas may reduce or shut down refinery operations.
5	Although most natural gas pipelines are underground, valves and other aboveground equipment may be visible and detectable.
6	Natural gas rights-of-way are identified by signs.
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Water	
7	Loss of water supply may shut down refinery operations (e.g., steam or other process or fire-fighting resources).
8	Spare water pumps may or may not be available. Long lead times may be needed to procure new pumps.
9	Contamination of the water supply could impact refinery operations.
10	Quantities of chlorine may be stored on-site for water purification and chemical processing.
Electric Power	
11	Off-site electric substations are generally unmanned and remote.
12	Off-site electric substations are easily identified by entry and exit of large, high-voltage wires.
13	Although usually enclosed by a fence, critical equipment at on-site electric substations may be identified from off site.
14	Off-site electric substations are usually surrounded by the property of third parties, over which the owner electric utility may have little or no control or with which it may have little or no cooperation.
15	At off-site electric substations, a long lead time may be needed for replacement transformers because of the wide diversity in transformers installed at substations throughout a utility's service territory. Depending on the date of installation and the function at the substation, some may be actually unique to the rest of the utility's transformer inventory.
16	Utilities may not maintain an inventory of large spare transformers required for critical high-voltage electric substations.
19	Off-site electric utility transmission lines and support towers may be identifiable and vulnerable because of their remote and easily accessed locations.
Telecommunication	
20	Handheld radios may be critical to refinery operations. Disruption of communications could reduce refinery throughput or even shut down a refinery.
21	Refineries may have 1,000 or more handheld radios, so it may be difficult to prevent theft.
22	Refinery radio communications may not be encrypted and frequencies may be able to be scanned by adversaries to determine operating conditions, location of employees, on-going activities, etc.
23	Communication with first responders is crucial to react in a timely manner to incidents. Jamming or other methods may be used to disrupt communication channels.
24	Telecommunications may rely on a public switch network. Telephone congestion may occur during emergencies.

OTHER INFORMATION

General Description of the Refining Process[1]

Petroleum refining is the physical, thermal, and chemical separation of crude oil into its major distillation fractions, which are then further processed through a series of separation and conversion steps into finished petroleum products. The primary products of the industry fall into three major categories: fuels (motor gasoline, diesel and distillate fuel oil, liquefied petroleum gas, jet fuel, residual fuel oil, kerosene, and coke); finished nonfuel products (solvents, lubricating oils, greases, petroleum wax, petroleum jelly, asphalt, and coke); and chemical industry feedstocks (naphtha, ethane, propane, butane, ethylene, propylene, butylenes, butadiene, benzene, toluene, and xylene).

A relatively small number of people are employed by the petroleum refining industry in relation to its economic importance. The U.S. Bureau of the Census estimates that 75,000 people were directly employed by the industry in 1992. However, the industry also indirectly employs a significant number of outside contractors for many refinery operations, both routine and nonroutine.

For reasons of efficiency in transporting crude oil feedstocks and finished products, petroleum refineries typically were sited near crude oil sources (onshore petroleum terminals, oil and gas extraction areas) or consumers (heavily industrialized areas). Consequently, the distribution of facilities is more concentrated along the Gulf Coast and near the heavily industrialized areas of both the East and West Coasts.

Crude oil is a mixture of many different hydrocarbons and small amounts of impurities. The composition of crude oil can vary significantly depending on its source. Petroleum refineries are a complex system of multiple operations, and the operations used at a given refinery depend on the properties of the crude oil to be refined and the desired products. For these reasons, no two refineries are alike. Portions of the outputs from some processes are re-fed back into the same process, fed to new processes, fed back to a previous process, or blended with other outputs to form finished products. The typical major unit operations at petroleum refineries are described briefly below. In addition, there are many special-purpose processes that cannot be described here.

Refining crude oil into useful petroleum products can be separated into two phases and a number of supporting operations. The first phase is desalting of crude oil and the subsequent distillation into its various components or “fractions.” The second phase is made up of three different types of “downstream” processes: combining, breaking, and reshaping. Downstream processes convert some of the distillation fractions into petroleum products (residual fuel oil, gasoline, kerosene, etc.) through any combination of different cracking, coking, reforming, and alkylation processes. Supporting operations may include wastewater treatment, sulfur recovery, additive production, heat exchanger cleaning, blowdown systems, blending of products, and storage of products.

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[1] Environmental Protection Agency Sector Notebook Profile of the Petroleum Refining Industry, September 1995 (http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/petrefsnpt1.pdf).

Distillation involves the heating, vaporization, fractionation, condensation, and cooling of feedstocks. In atmospheric distillation, desalted crude oil is heated in a heat exchanger and furnace to about 750 °F and fed to a vertical distillation column. Fractions obtained from atmospheric distillation include naphtha, gasoline, kerosene, light fuel oil, diesel oils, gas oil, lube distillate, and heavy bottoms. Heavier fractions from the atmospheric distillation unit that cannot be distilled without cracking under its pressure and temperature conditions are vacuum distilled. Vacuum distillation is simply the distillation of petroleum fractions at a very low pressure (0.2 to 0.7 psia) to increase volatilization and separation. In most systems, the vacuum inside the fractionator is maintained with steam ejectors and vacuum pumps, barometric condensers, or surface condensers.

Certain fractions from the distillation of crude oil are further refined in thermal cracking (visbreaking), coking, catalytic cracking, catalytic hydrocracking, hydrotreating, alkylation, isomerization, polymerization, catalytic reforming, solvent extraction, Merox, dewaxing, propane deasphalting, and other operations. These downstream processes change the molecular structure of hydrocarbon molecules by either breaking them into smaller molecules, joining them to form larger molecules, or reshaping them into higher-quality molecules. For each of these operations, a number of different techniques are used in the industry. While the major techniques used for each process are described, it was not possible to discuss all of the different processes currently in use.

Thermal cracking, or visbreaking, uses heat (2,000°F) and pressure (140 psig) to break large hydrocarbon molecules into smaller, lighter molecules. The process has been largely replaced by catalytic cracking; some refineries no longer employ thermal cracking. Coking is a cracking process used primarily to reduce refinery production of low-value residual fuel oils to transportation fuels, such as gasoline and diesel. A number of different processes are used to produce coke; “delayed coking” is the most widely used today, but “fluid coking” is expected to be an important process in the future. In delayed coking operations, the same basic process as thermal cracking is used, except feed streams are allowed to react longer without being cooled.

Catalytic cracking uses heat, pressure, and a catalyst to break larger hydrocarbon molecules into smaller, lighter molecules. Catalytic cracking has largely replaced thermal cracking because it is able to produce more gasoline with a higher octane and less heavy fuel oils and light gases. A number of different catalytic cracking designs are currently in use in the U.S., including fixed-bed reactors, moving-bed reactors, fluidized-bed reactors, and once-through units. The fluidized-bed and moving-bed reactors are by far the most prevalent, and the fluidized-bed catalytic cracking units are the most common. In recent years, moving-bed reactors have largely been replaced by fluidized-bed reactors. In the fluidized-bed process, oil and oil vapor pre-heated to 500 to 800°F are contacted with a hot catalyst at about 1,300°F either in the reactor itself or in the feed line (riser) to the reactor. The cracked products then flow to a fractionating tower where the various compounds are separated and collected. Catalytic hydrocracking normally utilizes a fixed-bed catalytic cracking reactor, with cracking occurring under substantial pressure (1,200 to 2,000 psig) in the presence of hydrogen.

Hydrotreating and hydroprocessing are similar processes used to remove impurities. They use catalysts in the presence of substantial amounts of hydrogen under high pressure and temperature to react the feedstocks and impurities with hydrogen. Alkylation is used to produce a high-octane gasoline blending stock from the isobutane formed primarily during catalytic cracking and coking operations and also from catalytic reforming, crude distillation, and natural gas processing. The products are alkylates, including propane and butane liquids. Hydrofluoric acid alkylation units require a special engineering design, operator training, and safety equipment precautions to protect operators from accidental contact with HF acid, which is an extremely hazardous substance. In the sulfuric acid process, the sulfuric acid removed must be regenerated in a sulfuric acid plant, which is generally not a part of the alkylation unit and may be located off site.

Isomerization is used to alter the arrangement of a molecule without adding or removing anything from it. Isomerization reactions take place at temperatures in a range of 200 to 400°F in the presence of a catalyst that usually consists of platinum on a base material. Polymerization is occasionally used to convert propene and butene to high-octane gasoline blending components. The process is similar to alkylation in its feed and products, and it is often used as a less-expensive alternative to alkylation. The reactions typically take place under high pressure in the presence of a phosphoric acid catalyst.

Solvent extraction uses solvents to dissolve and remove aromatics from lube oil feedstocks, improving their viscosity, oxidation resistance, color, and gum formation. A number of different solvents are used, with the two most common being furfural and phenol. Typically, feed lube stocks are contacted with the solvent in a packed tower or rotating disc contactor.

In petroleum refining, chemical treating is used to remove or change the undesirable properties and may include “Merox” extraction. Propane deasphalting produces lubricating oil base stocks by extracting asphaltenes and resins from the residuals of the vacuum distillation unit. Propane is usually used to remove asphaltenes because of its unique solvent properties.

Relatively large volumes of water are used by the petroleum refining industry. A large portion of water used in petroleum refining is used for cooling. Wastewaters from a refinery must be treated in a wastewater treatment plant before being legally discharged.

Heat exchangers are used throughout petroleum refineries to heat or cool petroleum process streams. The heat exchangers consist of bundles of pipes, tubes, plate coils, or steam coils enclosing heating or cooling water, steam, or oil to transfer heat indirectly to or from the oil process stream. Most refinery process units and equipment are manifolded into a collection unit, called the blowdown system.

Storage tanks are used throughout the refining process to store crude oil and intermediate process feeds for cooling and further processing. Finished petroleum products are also kept in storage tanks before transport off site.

USEFUL REFERENCE MATERIAL

1. Environmental Protection Agency Sector Notebook, *Profile of the Petroleum Refining Industry,* September 1995 (http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/petrefsnpt1.pdf).

2. How Stuff Works Website (http://science.howstuffworks.com/oil-refining3.htm).

3. American Petroleum Institute (http://api-ec.api.org/newsplashpage/index.cfm).

4. U.S. Environmental Protection Agency, Chemical Emergency Preparedness and Prevention Office, *EPA Federal Reading Rooms* (http://yosemite.epa.gov/oswer/ceppoweb.nsf/content/readingroom.htm).