HOW OIL REFINERIES WORK

In order to model oil refineries for model railroads some research was conducted into how they operate and what products a refinery produces. Presented below is a basic survey on the inner workings of a typical oil refinery.

The typical oil/petroleum refinery is an industrial process plant with many different structures designed to receive crude oil , processes and refine it into petroleum products, such as gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas. Raw or unprocessed crude oil is not generally useful since the lighter elements form explosive vapors in fuel tanks and are therefore hazardous. Instead, the different hydrocarbon molecules that make up crude oil are separated by the refinery into components which can be used as fuels, lubricants, and as 'feedstock' for other downstream structures in the petrochemical processes that manufacture such products as plastics, detergents, solvents, elastomers and fibers such as nylon and polyesters.

Oil refineries are typically very large complexes with extensive piping running throughout, connecting the various chemical processing units. There is usually an oil depot (tank farm) at or near an oil refinery for storage of bulk liquid products. One will also see hemispherical high pressure tanks that are primarily used to house petroleum / chemical products stored under pressure such as Benzene, Ammonia, Liquid Propane, Liquid Oxygen or Nitrogen.

Oil can be used in a variety of ways - different types of petroleum fossil fuels are burned in various internal combustion engines to provide power for ships, automobiles, aircraft engines, lawn mowers, chainsaws, and etc. precisely because it contains hydrocarbons of varying molecular masses, forms and lengths. The differences in the structure of these molecules account for their varying physical and chemical properties one of which is the boiling point.

Different boiling points allow the hydrocarbons to be separated by distillation so a refinery typically contains a large number of distillation columns. Since the lighter liquid products are in great demand for use in internal combustion engines, a modern refinery will convert heavy hydrocarbons and lighter gaseous elements into these higher value products.

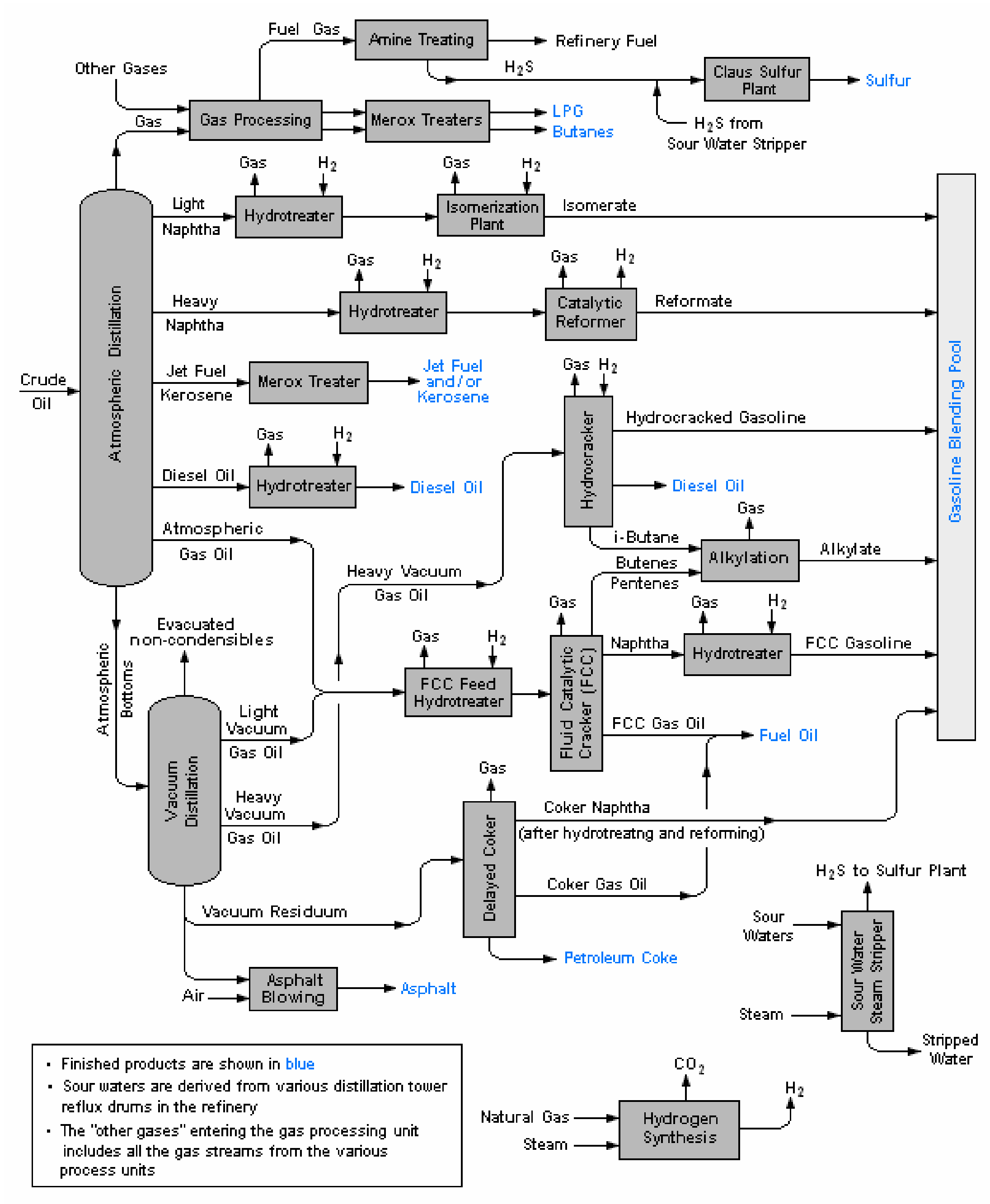
The octane grade of gasoline can also be improved by catalytic reforming, which involves removing hydrogen from hydrocarbons producing compounds with higher octane ratings such as aromatics. Intermediate products such as gas-oils can even be reprocessed to break a heavy, long-chained oil into a lighter short-chained one, by various forms of cracking such as fluid catalytic cracking, thermal cracking, and hydro-cracking The final step in gasoline production is the blending of fuels with different octane ratings, vapor pressures, and other properties to meet product specifications.

Some of the more common process units found in a refinery are:

- Desalter unit washes out salt from the crude oil before it enters the atmospheric distillation unit.
- Furnaces/Re-boilers to per-heat oil prior to delivery to distillation towers.
- Atmospheric distillation unit distills crude oil into fractions.

- Vacuum distillation unit further distills residual bottoms after atmospheric distillation.
- Naphtha hydro-treater unit uses hydrogen to desulfurize naphtha from atmospheric distillation. Must hydro-treat the naphtha before sending to a Catalytic Reformer unit.
- Catalytic reformer unit is used to convert the naphtha-boiling range molecules into higher octane reformate (reformer product). An important byproduct of a reformer is hydrogen released during the catalyst reaction. The hydrogen is used either in the hydro-treaters or the hydro-cracker
- Distillate hydro-treater unit desulfurizes distillates (such as diesel) after atmospheric distillation.
- Fluid catalytic cracker (FCC) unit upgrades heavier fractions into lighter, more valuable products.
- Hydro-cracker unit uses hydrogen to upgrade heavier fractions into lighter, more valuable products.
- Vis-breaking unit upgrades heavy residual oils by thermally cracking them into lighter, more valuable reduced viscosity products.
- Merox unit treats LPG, kerosene or jet fuel by oxidizing mercaptans to organic disulfides.
- Coking units (delayed coking, fluid coker, and flexicoker) process very heavy residual oils into gasoline and diesel fuel, leaving petroleum coke as a residual product.
- Alkylation unit produces high-octane component for gasoline blending.
- Dimerization unit converts olefins into higher-octane gasoline blending components. For example, butenes can be dimerized into isooctene which may subsequently be hydrogenated to form isooctane. There are also other uses for dimerization.
- Isomerization unit converts linear molecules to higher-octane branched molecules for blending into gasoline or feed to alkylation units.
- Steam reforming unit produces hydrogen for the hydro-treaters or hydro-cracker
- Liquefied gas storage units store propane and similar gaseous fuels at pressure sufficient to maintain them in liquid form. These are usually spherical vessels or bullets (horizontal vessels with rounded ends.
- Storage tanks store crude oil and finished products, usually cylindrical, with some sort of vapor emission control and surrounded by an earthen berm to contain spills.

A typical oil refinery configuration is shown below:



Desalter Unit

A desalter is a process unit on an oil refinery that removes salt from the crude oil. The salt is dissolved in the water in the crude oil, not in the crude oil itself. The desalting is usually the first process in crude oil refining. The salt content after the desalter is usually measured in PTB - pounds of salt per thousand barrels of crude oil.

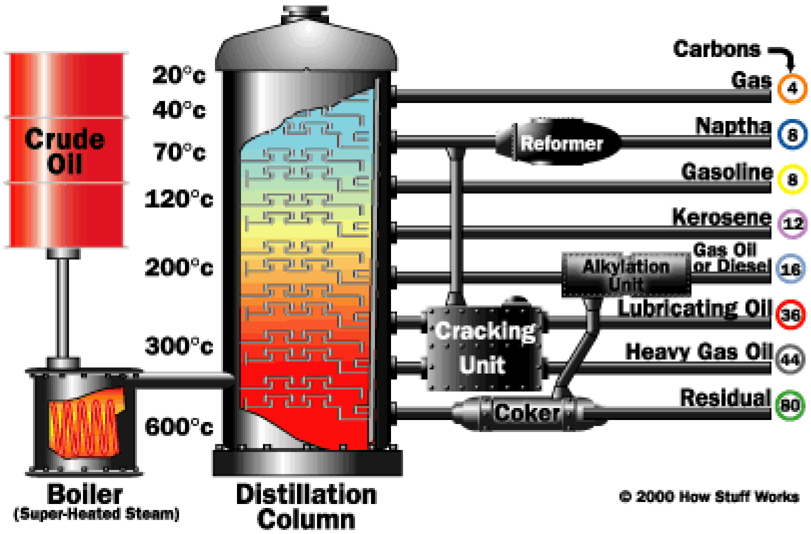
Distillation

The various components of crude oil have different sizes, weights and boiling temperatures; so, the first step is to separate these components. Because they have different boiling temperatures, they can be separated easily by a process called fractional distillation.

Distillation Tower Designs

Fractional distillation consists of:

1. Heating the mixture of two or more substances (liquids) with different boiling points to a high temperature. Heating is usually done with high pressure steam to temperatures of about 1112 degrees Fahrenheit / 600 degrees Celsius.
2. The mixture boils forming vapor (gases).
3. The vapor enters the bottom of a long column (fractional distillation column) that is filled with trays or plates. The trays have holes or bubble caps in them to allow the vapor to pass through. These trays increase the contact time between the vapor and the liquids in the column. The trays help to collect liquids that form at various heights in the column.
4. Because there is a temperature difference across the column (hot at the bottom, cool at the top) the vapor rises in the column. As the vapor rises through the trays in the column, it cools.
5. When the particular substance in the vapor reaches a height where the temperature of the column is equal to that substance's boiling point, it will condense to form a liquid. (The substance with the lowest boiling point will condense at the highest point in the column; substances with higher boiling points will condense lower in the column.).
6. The trays collect the various liquid fractions. The collected liquid fractions may either pass to condensers, which cool them further, and then go to storage tanks or go to other areas for further chemical processing.



Dimensions for a distillation column vary considerably measuring from 3 to 48 feet in diameter. (O scale 1 – 12 inches) and 18 to 180 feet in height (O scale 4 – 40 inches). One rule of thumb is that the length to diameter < 30 so a 180 foot height necessitates a 6 foot diameter (O scale 40/1.5 inches).

Fractional distillation is useful for separating a mixture of substances with narrow differences in boiling points, and is the most important step in the refining process. The fractions at the top of the fractionating column having lower boiling points than the fractions at the bottom are lighter. The remaining heavy bottom fractions are not very useful for the market so must be chemically processed to make other lighter more useful fractions. As an example roughly 40% of distilled crude oil is gasoline; however, gasoline is one of the major products made by oil companies. Rather than continually distilling large quantities of crude oil, oil companies chemically process some other fractions from the distillation column to make gasoline; this processing increases the yield of gasoline from each barrel of crude oil.

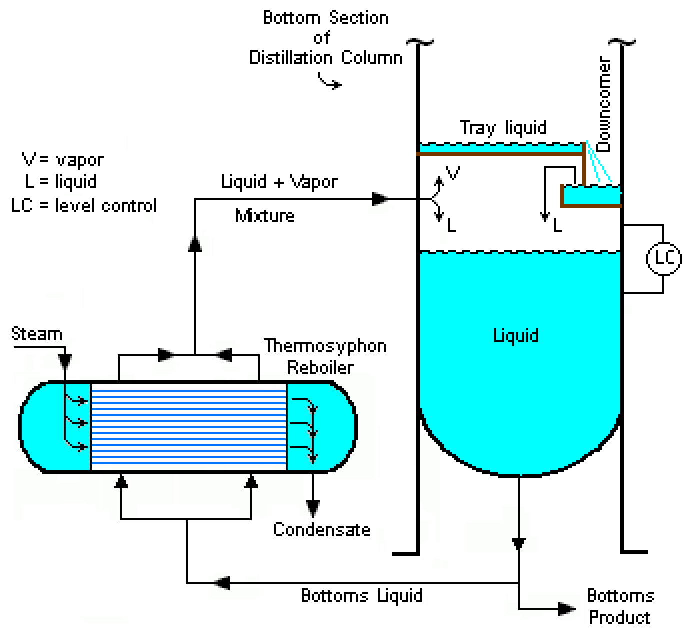
Reboiler

Reboilers are heat exchangers typically used to provide heat to the bottom of industrial distillation columns. They boil the liquid from the bottom of a distillation column to generate vapors which are returned to the column to drive the distillation separation.

Proper reboiler operation is vital to effective distillation. In a typical classical distillation column, all the vapor driving the separation comes from the reboiler. The reboiler receives a liquid stream from the column bottom and may partially or completely vaporize that stream. Steam usually provides the heat required for the vaporization.

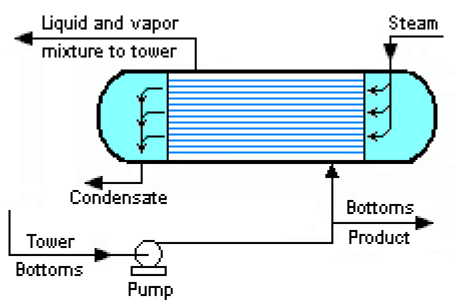
Thermosyphon reboilers. These do not require pumping of the column bottoms liquid into the reboiler. Natural circulation is obtained by using the density difference between the reboiler inlet column bottoms liquid and the reboiler outlet liquid-vapor mixture to provide sufficient liquid head to deliver the tower bottoms into the reboiler. Thermosyphon reboilers (also known as calandrias) are more complex than kettle reboilers and require more attention from the plant operators.

There are many types of thermosyphon reboilers. They may be vertical or horizontal and they may also be once-through or recirculating. Some fluids being reboiled may be temperature-sensitive and, for example, subject to polymerization by contact with high temperature heat transfer tube walls. In such cases, it is best to have a high liquid recirculation rate to avoid having high tube wall temperatures which would cause polymerization and, hence, fouling of the tubes. The thermosyphon reboiler depicted in Image 2 is a typical steam-heated recirculating thermosyphon reboiler.



Forced circulation reboilers. This type of reboiler uses a pump to circulate the column bottoms liquid through the reboilers. Image 4 depicts a typical steam-heated forced circulation reboiler.

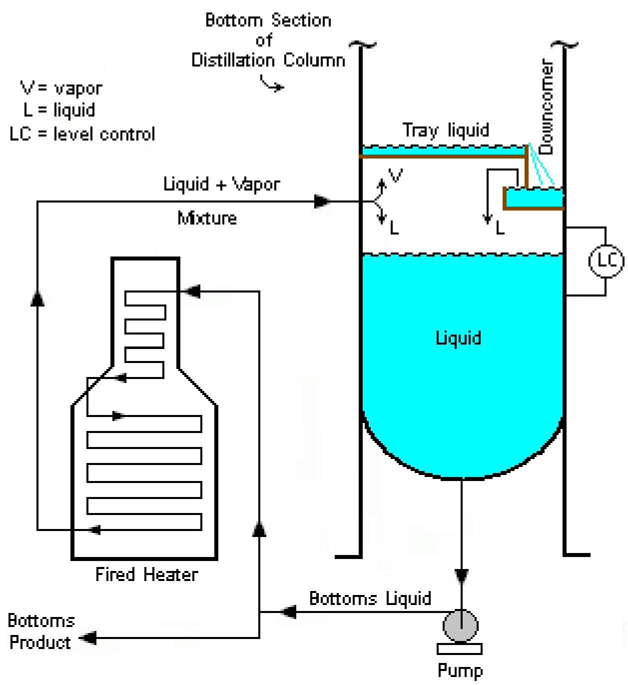
It should be noted steam is not the only heat source that can be used. Any fluid stream at a high enough temperature could be used for any of the many shell and tube heat exchanger reboiler types.



Fired heaters (furnaces) may be used as a distillation column reboiler. A pump is required to circulate the column bottoms through the heat transfer tubes in the furnace's convection and radiant sections.

Image 3 depicts a fired heater being used in a configuration that provides recirculation of the column bottoms liquid. However, with some relatively minor changes inside the bottom section of the distillation column, a fired heater can also be used in once-through configuration.

The heat source for the fired heater reboiler may be either fuel gas or fuel oil. Coal would rarely, if ever, be used as the fuel for a fired heater reboiler.



Catalytic Cracking

Chemical processing usually takes place with the following processes:

1. A Fluid catalytic cracker (FCC) unit breaks heavier fractions into lighter, more valuable products.

Fluid catalytic cracking (FCC) is the most important conversion process used in petroleum refineries. It is widely used to convert the high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils to more valuable gasoline, olefinic gases and other products. Cracking of petroleum hydrocarbons was originally done by thermal cracking which has been almost completely replaced by catalytic cracking because it produces more gasoline with a higher octane rating. It also produces byproduct gases that are more olefinic, and hence more valuable, than those produced by thermal cracking.

The feedstock to an FCC is usually that portion of the crude oil that has an initial boiling point of 340 °C or higher at atmospheric pressure and an average molecular weight ranging from about 200 to 600 or higher. This portion of crude oil is often referred to as heavy gas oil. The FCC process vaporizes and breaks the long-chain molecules of the high-boiling hydrocarbon liquids into much shorter molecules by contacting the feedstock, at high temperature and moderate pressure, with a fluidized powdered catalyst.
The modern FCC units are all continuous processes which operate 24 hours a day for as much as 2 to 3 years between shutdowns for routine maintenance.

There are a number of different proprietary designs that have been developed for modern FCC units. Each design is available under a license that must be purchased from the design developer by any petroleum refining company desiring to construct and operate an FCC of a given design.

Basically, there are two different configurations for an FCC unit: the "stacked" type where the reactor and the catalyst regenerators are contained in a single vessel with the reactor above the catalyst regenerator and the "side-by-side" type where the reactor and catalyst regenerator are in two separate vessels.

In effect, refineries use fluid catalytic cracking to correct the imbalance between the market demand for gasoline and the excess of heavy, high boiling range products resulting from the distillation of crude oil.

Fluid Catalytic Cracking

2. A Hydro-cracker unit uses hydrogen to upgrade heavier fractions into lighter, more valuable products.

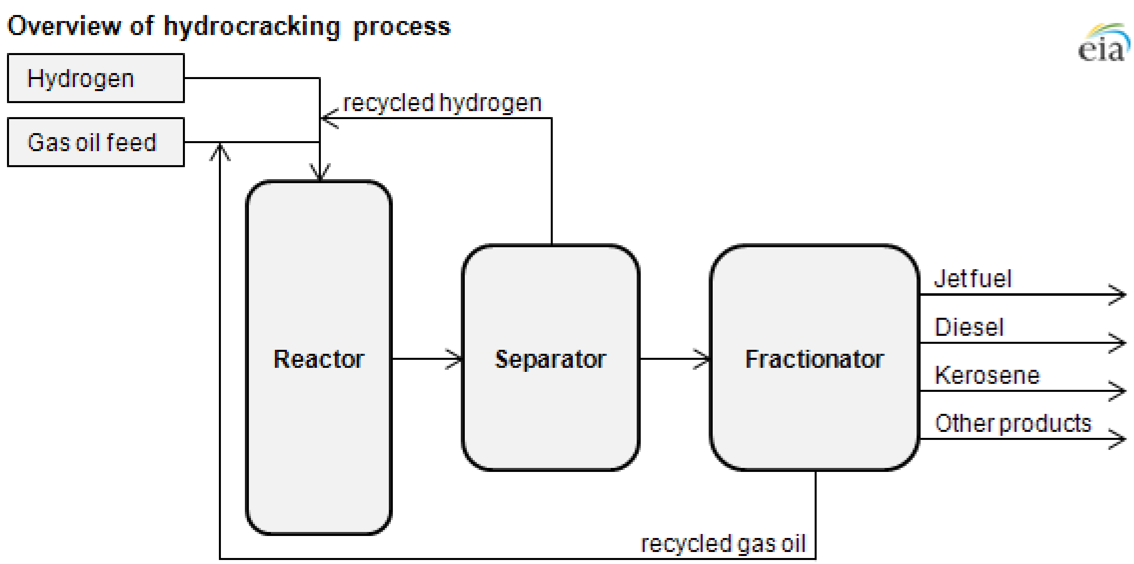
Two stage hydro-cracker: This configuration uses two reactors and the residual hydrocarbon oil from the bottom of reaction product fractionation tower is recycled back into the second reactor for further cracking. Since the first stage reactor accomplishes both hydro-treating and hydro-cracking, the second stage reactor feed is virtually free of ammonia and hydrogen sulfide. This permits the use of high performance noble metal (palladium, platinum) catalysts which are susceptible to poisoning by sulfur or nitrogen compounds.

The high-boiling, high molecular weight hydrocarbons used as feed-stocks for catalytic hydro-crackers include what are commonly referred to as atmospheric gas oil from atmospheric crude oil distillation units, vacuum gas oil from vacuum distillation units, delayed coking gas oil from delayed coking units and cycle oil from fluid catalytic cracking units. For describing the hydro-cracking process depicted in the typical flow diagram below, the feedstock will be referred to as simply gas oil.

The gas oil from the feed-stock pump is mixed with a stream of high-pressure hydrogen and then flows through a heat exchanger where it is heated by the hot effluent reaction products from the hydro-cracker's first stage reactor. The feed-stock is then heated further in a fuel-fired heater before it enters the top of first stage reactor and flows downward through three beds of catalyst. The temperature and pressure conditions in the first stage reactor depend upon the specific licensed hydro-cracker design, the feed-stock properties, the desired products, the catalyst being used and other variables. As a broad generality, the pressure in the first stage reactor may range from 35 to 200 bar and the temperature may range from 260 to 480 °C.

After the effluent reaction product stream from the reactor bottom is cooled by the incoming gas oil feed-stock, it is injected with wash water, partially condensed in a water-cooled condenser and routed into a high-pressure vapor-liquid separator for separation into three phases: hydrogen-rich gas, hydrocarbon liquid and water. Sulfur and nitrogen compounds in the gas oil feed-stock are converted into gaseous hydrogen sulfide and ammonia by the hydrogenation that takes place in the first stage reactor. The purpose of the wash water is to dissolve some of the hydrogen sulfide and ammonia gases present in the first stage reaction product stream. The resulting aqueous solution of ammonium hydro sulfide (NH4HS) is referred to as sour water and is typically routed to a sour water stripper elsewhere in the petroleum refinery. The sour water stripper removes hydrogen sulfide from the sour water and that hydrogen sulfide is subsequently converted to end product elemental sulfur in a Claus process unit.

Fluid catalytic cracking (FCC) is the most important conversion process used in petroleum refineries. It is widely used to convert the high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils to more valuable gasoline, olefinic gases and other products. Basically, there are two different configurations for an FCC unit: the "stacked" type where the reactor and the catalyst re-generator are contained in a single vessel with the reactor above the catalyst re-generator and the "side-by-side" type where the reactor and catalyst re-generator are in two separate vessels. The FCC designed by Model Structures for Model RR's is a 2-stage Hydro-cracker that uses two reactors. Input (feed-stock) for the first reactor is high boiling point atmospheric gas oil from atmospheric crude oil distillation units or vacuum gas oil from vacuum distillation units simply referred to as gas oil. The gas oil is pumped from an upstream Distillation Tower and is mixed with hydrogen catalyst from the catalyst re-generator and pumped into the reactor where the cracking process takes place. Cracked hydrocarbons are released from the top of the tank and sent to a down-line Distillation tower where gasoline and other gas oils are created. Spent catalyst is sent back to the catalyst re-generator from the bottom of the reactor. Waste product and gas are sent from the top of the catalyst re-generator to a Flare Tower for disposal. The Model Structures design contains a 3-inch diameter reactor and a 2 ½ inch diameter catalyst re-generator. Piping for catalyst recovery is supplied at the bottom of the tanks. Output piping from the top of the reactor to a downstream distillation tower along with piping from the top of the catalyst re-generator for waste removal is included. Input piping from an upstream distillation tower and between the catalyst re-generator and reactor are also supplied. The catalyst re-generator and waste removal piping are painted red oxide. The Hydro-cracking Unit superstructure along with the reactor and associated piping are painted dark gray. Overall footprint for the structure is xxxxxxxxxxxxxxxxxxxxxx



Hydro Cracking

3. Thermal cracking uses heat. This process has been mostly replaced by the other methods of cracking.

Coking Units

Still more processing can be accomplished with the heaviest residue from the distillation process. Coking units such as Delayed Coking, Fluid Coker, and Flexicoker are used to convert the heavy residuum and asphalt from the distillation unit into fuel gas, gasoline, diesel, gas oil and petroleum coke. But it takes time and heat for the chemical reaction, called "cracking," to happen. A large drum is filled with the heated distillation residuum. In this drum some of the residuum is "cracked" into products like gasoline and diesel fuel. The product left over in the drum is petroleum coke, and it looks like a cross between a chunk of coal and a sponge. When a drum is filled with coke high pressure water is used to "cut" the coke into small chunks that can fall out of the drum. Usually two drums are used so one can be kept full of oil while the other is cutting the coke.

Delayed Coking Unit

Alkylation Unit

Another method to squeeze even more out of crude oil is the use of Alkylation (Alky) Units to combine olefins (propylene and butylene) from the FCC with isobutane and a sulfuric acid catalyst. It's mixed vigorously before the sulfuric acid is again removed. What's left is pumped to distillation towers, where it's separated into liquefied petroleum gas (LPG), mixed butanes and alkylate. Alkylate is a high-octane blending component used in lead-free premium gasolines.

Alkylation Unit with Distillation Towers

Vis-breaking Units

A vis-breaker is a processing unit in oil refinery whose purpose is to reduce the quantity of residual oil produced in the distillation of crude oil and to increase the yield of more valuable middle distillates (heating oil and diesel) by the refinery. A vis-breaker thermally cracks large hydrocarbon molecules in the oil by heating in a furnace to reduce its viscosity and to produce small quantities of light hydrocarbons (LPG and gasoline). The process name of "vis-breaker" refers to the fact that the process reduces (i.e., breaks) the viscosity of the residual oil.

Vis-breaker Unit

Flare Towers

A gas flare, alternatively known as a flare stack or tower is used to eliminate waste gas which is otherwise not feasible to use or transport. They also act as safety systems for non-waste gas and is released via pressure relief valve when needed to ease the strain on equipment and protect gas processing equipments from being over-pressured. In the picture above air fans are attached to the tower. Its primary purpose is to act as a safety device to protect vessels or pipes from over-pressuring due to unplanned upsets. Whenever plant equipment items are over-pressured, the pressure relief valves on the equipment automatically release gases (and sometimes liquids as well) which are routed through large piping runs called flare headers to the flare stacks. The released gases and/or liquids are burned as they exit the flare stacks. The size and brightness of the resulting flame depends upon how much flammable material was released.

Typical heights are usually 30 to 100 feet (O scale – 8 to 25 inches)

Model Structures refinery model presently consists of:

Tank Farm with Pump Shed used as storage tanks for crude oil
Twin Vertical tanks to store product.
Desalter unit
Bulk Furnace to heat crude
Various Distillation Tower designs
Reboilers for reheating residuum (connected to distillation towers)
Hydro-cracking Unit
Alkylation Unit design (new twin horizontal tank structure)
Elevated Storage tanks for product or mixing ingredients for processing equipment
Small Industrial storage tanks for mixing ingredients
Maintenance sheds plus smaller pump and electrical shed designs
Flare Tower for gas burn-off
Pipe Transfer Line to direct product to different destinations
Pipe Support columns for above ground piping
High Pressure Spherical tanks to hold liquidized gas products
Propane / CO2 tanks
Floating Top Storage Tanks
Fuel loading platforms to load product into rail cars or tractor trailer
Pipe Distribution Network to load product into tank cars (sits over track)

Standard product is designed for underground piping. For additional cost Model Structures will design the necessary above ground piping using our pipe stands to connect all purchased product.