COMPRESSORS IN REFINERY SERVICE

Klaus Brun, Brian Pettinato, and Stephen Ross, Elliott Group, USA, examine typical refinery processes that require compressors.

Oil refineries are an essential part of the downstream petroleum industry. These large, industrial complexes transform and refine crude oil into many consumer and industrial hydrocarbon products including gasoline, diesel and jet fuels, fuel oils, kerosene, heating oil, asphalt, LPG, lubricants, ethylene, propylene, and petrochemical feedstocks to name a few. Deriving these products requires a variety of processing units, machinery, and auxiliary facilities, and each refinery is custom configured for the products it produces.

There are a large number of turbomachinery applications in refineries ranging from pumping and compression to mechanical drivers and power generation. In this article, the primary focus will be on typical refinery processes that require compressors.

Figure 1. Axial compressor for main air blower service.

Refinery functions

Raw or unprocessed crude oil must be refined into consumer and industrial products for transportation, heating, and chemical processing. Oil contains hydrocarbons of varying molecular masses, forms and lengths. The structural differences of the hydrocarbon molecules account for their varying physical and chemical properties, and this variety makes crude oil useful in a broad range of applications.

From a physical chemistry perspective, a refinery includes three types of transformation processes:

- Cracking – breaking of large hydrocarbon chains.
  - Thermal cracking – including steam, vis-breaking, coking.
  - Catalytic cracking – including fluid and hydrocracking.
- Alkylation – altering the molecular structure.
- Reforming (catalytic reforming) – combining molecular chains to form longer chains.

Although many products are derived in a refinery, a typical barrel of crude oil converts into approximately 40 – 45% gasoline, 2 – 6% propane, 15 – 25% heating oil and diesel, 1 – 3% asphalt, 10 – 15% jet fuels, and 15 – 25% others (lubrication oil, waxes, plastics, etc.) This is very much dependent on the type and the quality of the starting crude oil and the specific refinery processes.

Critical refinery processes

The crude oil distillation unit or column is the first processing unit and the most important in virtually all petroleum refineries. It distills the incoming crude oil into various fractions of different boiling ranges, each of which are then processed further in the other refinery processing units. Other critical refinery processes include:

- Hydrotreating – process for reducing sulfur, nitrogen and aromatics while enhancing the cetane/octane number, density and smoke point.
- Hydrocracking – the conversion of heavy hydrocarbons into lighter products under a wide range of high pressures and temperatures.
- Isomerisation – the process by which molecules are transformed into other related molecules (isomers) that are composed of the same atoms but with a different molecular arrangement.
- Reforming – the process used to convert heavier naphtha into high-octane liquid products called reformates.

Hydroprocessing

Hydroprocessing encompasses a variety of thermal conversion processes in which hydrogen, along with a catalyst, is used to convert petroleum fractions and products to meet the refiner's objectives. These conversion processes include hydrotreating and hydrocracking. In both processes, hydrogen recycle compressors circulate hydrogen rich gas through the conversion reactor and the rest of the plant. End products include gasoline, jet fuel, diesel fuel and kerosene. Because of the severe processing conditions and the high pressures required to convert petroleum fractions and products, these centrifugal compressors are nearly always vertically split designs for high-pressure, high-temperature applications.

A typical hydroprocessing centrifugal compressor train is a series configuration. Operating pressures range between 100 – 2300 psia suction to a wide range of discharge pressures depending on the process. Pressures as high as 4000 psia are possible.

Fluid catalytic cracking – power recovery

Energy represents the single largest operating expense within a refinery, and in some cases can account for nearly 50% of the total operating costs. Many refiners benefit from energy cost savings by using power recovery expanders. These units utilise the energy in high-temperature, low-pressure gas streams to drive generators and/or centrifugal or axial compressors in fluid catalytic cracking service. The high-flow capacity of axial compressors makes them suitable for larger, more efficient processes, and they can be used to supply air to the regenerator and other plant needs (Figure 1).

Catalytic reforming

Catalytic reforming converts low octane naphtha into a high octane reformate and/or aromatics such as benzene, toluene, and xylene for petrochemical plants. Reforming also produces high purity hydrogen for hydrotreating purposes.

Applications include net gas and hydrogen recycle services. Hydrogen recycle compressors usually require an alternate nitrogen operating case for start-up or catalyst regeneration and must be carefully evaluated for safe operating range and temperature limits. There are several service applications ranging from mid-pressure (< 1000 psia) to high pressure (> 4000 psia).

Delayed coking

Delayed coking is a thermal cracking process that upgrades and converts petroleum bottoms into liquid and gas product streams and petroleum coke. Coker applications are challenging due to the wide range of operating conditions required and the fouling properties of the compressed gases. Wet gas compressors for coker service are subject to foulant on the aerodynamic surfaces of the compressor. Foulant build-up can increase rotor vibration, constrict process gas passageways, decrease efficiency and reduce output. Anti-fouling coatings minimise foulant build-up (Figure 2).

Alkylation

In the alkylation process, olefin yield, commonly from a fluid catalytic cracker (FCC), is used as a feedstock and reacted with

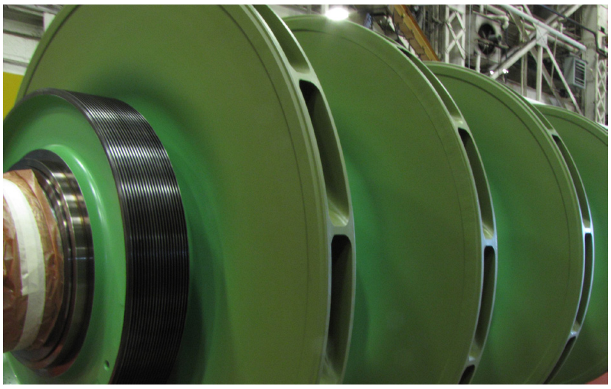

Figure 2. Compressor rotor with anti-fouling coating.

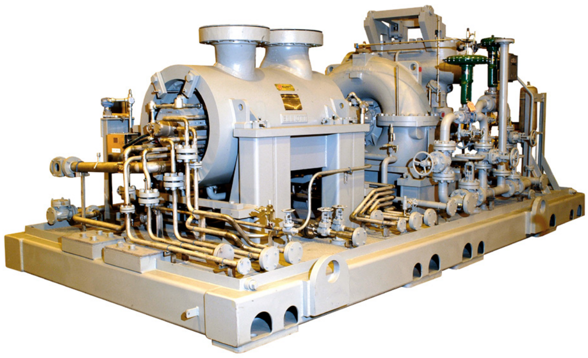

Figure 3. Hydrogen recycle compressor with steam turbine driver.

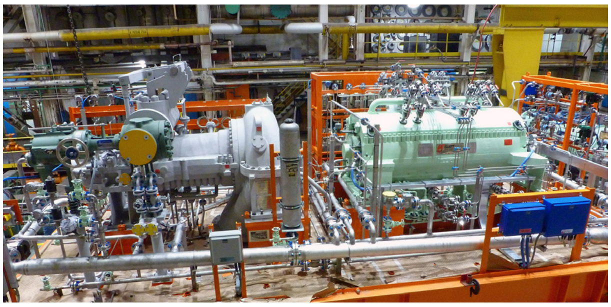

Figure 4. Wet gas compressor driven by a steam turbine.

isobutane in the presence of an acid catalyst. Centrifugal compressors recirculate the isobutane. The resulting alkylate is available for market as high octane fuel, or blended with lower grade gasoline to raise the octane level. The high-octane value makes alkylate an excellent blendstock for premium grades of gasolines. Since alkylate contains no olefins, aromatics or sulfur, it is also an excellent blendstock for reformulated gasolines.

Compressors in the refinery

Throughout the refinery, centrifugal compressors move gas from low-pressure areas to higher-pressure areas within the various plants. Compressor selection is based on the requirements for flow, range, pressure ratio, and specification. The specification used for refineries is API 617, 'Axial and Centrifugal Compressor and Expander-Compressors' for main chemical processes. End users may also have their own specifications in addition to those of API.

Centrifugal compressor applications are numerous and include, but are not limited to:

- Hydrogen recycle.
- Wet gas.
- Fluid Catalytic Cracker Unit (FCCU) main air blower.
- Alkylation refrigeration compressor.

Hydrogen recycle compressors

Hydrogen recycle compressors are used in a variety of refinery processes including hydrocracker, hydrotreater, platformer, and isomerisation units. Their main purpose is to move feedstock through a reactor, then separators, then recycle the gas, which is mostly hydrogen plus any remaining hydrocarbon vapours (usually heavy, high molecular weight vapours) through the compressor and back to the process loop. The hydrogen consumed in the process is replaced by a make-up gas or reciprocating compressor.

Since the gas is mostly hydrogen, the molecular weight will be low, typically in the range of 4 – 8. Low molecular weights are difficult to compress and have little pressure rise or volume reduction per stage. For this reason, hydrogen recycle compressors may have many stages, up to 12, or they may run at high speeds, or both. Required flow rates are typically low, so the frame sizes range from small to medium.

Wet gas compressors

Major refinery conversion units (catalytic cracker, delayed coker, and flexicoker) employ a fractionator (combination tower) that separates out gases and various liquids. The gas, which is taken from the top of the fractionator, contains condensable hydrocarbons and is therefore referred to as 'wet gas'. The gas stream is passed to a vapour recovery unit where it is compressed by the wet gas compressor then routed to a gas plant for treatment to remove condensable liquids and sulfur components. Compression is performed in either one or two stages (sections) of compression. Most configurations involve two stages.

Most wet gas compressors combine two stages of compression into a single compressor body with an intercooler/separator between the stages. The two stages can be arranged in either a compound or a back-to-back configuration. Combining the two stages of compression into a single body has advantages and disadvantages when compared to using two separate bodies. Among the advantages, the footprint and capital cost is reduced. The disadvantages are few and primarily relate to managing the design through good engineering (i.e. nozzle placement, bearing design, seal leakage management). One particular disadvantage of a single-body two-section compressor is that the overall settle out pressure will equalise in the two sections due to internal leakage. Overall, the advantages reside with the end user and the disadvantages reside with the manufacturer.

Main air blower

The main air blower (MAB) in an FCCU provides air (containing oxygen) necessary for combustion to burn coke away from catalyst in the regenerator. The rate of supplied air must match the rate that coke is created. The blower can be a large centrifugal compressor or an axial compressor for increased efficiency. This is one of the more critical compressors in terms of lost production if the machine experiences unscheduled outages. While a centrifugal compressor is more robust, axial compressors are also well suited to constant head and variable flow applications such as the MAB. The blower may be driven by a motor, a steam turbine, a power recovery turbine, or a combination of the three.

Alkylation refrigeration compressors

In the alkylation process, an olefin feed is reacted with isobutane in the presence of an acid catalyst. The resulting high-octane alkylate is used for gasoline blending to improve quality. The sulfuric acid (H_2SO_4) alkylation process requires a refrigeration section whereas the hydrogen fluoride (HF) alkylation process does not. One commonly used process is the STRATCO® effluent refrigeration alkylation process. The refrigeration section is typically comprised of a centrifugal compressor and a depropaniser. Since any propane that is delivered with the feed tends to concentrate in the refrigeration section, the depropaniser is required to manage the propane concentration.

Overall, the refrigerant compressor serves two purposes: to provide suction in order to maintain the desired reaction temperature, and to compress and cycle the isobutane that is flashed as refrigerant in order to cool the feed hydrocarbons to the desired reaction temperature.

Summary

Modern refineries use a wide range of turbomachinery that must operate in harsh environments. In refinery service, fluids pose unique aerodynamic, material, and structural design challenges, including wet gas service, high gas path temperatures, and corrosive, flammable, and sometimes toxic service. These conditions make the design, packaging, controls, application, and operation of turbomachinery in refineries highly complex and challenging.

Most refineries operate in a quasi-steady state, so process optimisation and control is critical, and equipment reliability, availability, and ease of maintenance and repairs is paramount. Because many processes require significant start-up time and complex sequences, refining operations are often planned as campaigns that can last from several months to over a year, usually with month-long planned outages for maintenance, repairs, clean up, and prepping for the next campaign.

Refinery equipment must be highly reliable and rugged so as not to cause a system or process upset that could lead to a lengthy shutdown. For this reason, equipment selection is usually based on reliability, availability, ease of repairs and maintenance, and ruggedness, rather than highest efficiency or cost requirements. Most refineries work closely with the machinery original equipment manufacturers (OEMs) to select the best equipment based on process specifications, and to coordinate repairs, overhauls, and maintenance to reduce risk and to achieve highest equipment reliability.

Note

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