ON-PURPOSE PROPYLENE PRODUCTION

Stephen Ross, Shane Harvey, and Christopher Braman, Elliott Group, USA,
highlight the use of centrifugal compressors for propane dehydrogenation.

Until recently, the chemical building block propylene was mostly a byproduct of steam crackers in ethylene plants and fluid catalytic cracking (FCC) units in refineries, with on-purpose propylene production accounting for less than 3% of the total amount produced. However, current demand for propylene is exceeding the supply, and on-purpose propylene production is expected to increase to 30% of the total by 2030.[1] Most of the existing and planned commercial propylene plants use propane dehydrogenation (PDH) technology. Centrifugal compressors are integral to several different processes in these PDH plants. This article will briefly describe some of these large, robust centrifugal compressors, including their features and challenges, and how they are used with PDH technology.

Commercial PDH processes

Two of the leading process licensors for PDH technology are Honeywell UOP Oleflex® and Lummus CATOFIN®.[2] In both processes, heat exchangers and charge heaters raise fresh and recycled propane feed to reaction temperature. The charge then passes through a series of reactors with catalyst beds where the dehydrogenation reaction occurs. Reactor design and catalysts are different for the two processes, but the next step for both is to raise the pressure of the gas using large centrifugal compressors before sending it to the recovery and purification section. Currently, Elliott Group is contracted to supply centrifugal compressors to existing and planned PDH plants that use both the Honeywell UOP and Lummus processes.

Reactor effluent compressors

Gas leaving the Honeywell UOP Oleflex reactor (effluent) passes through several coolers before entering the reactor effluent compressor string at a temperature of approximately 43˚C (109˚F). Pressure varies from near atmospheric to sub-atmospheric, and is as low as 0.8 bar absolute (11.4 psia). The gas has a molecular weight of 23 – 24 and is composed of

45 – 47% hydrogen, 32 – 35% propane, 14 – 16% propylene, and 5 – 7% other constituents (mostly heavier hydrocarbons). These conditions, along with the high flow rates of a modern PDH facility producing 450 – 750 000 tpy of propylene, result in very high inlet volume flow rates, up to 527 000 m^3/hr (310 000 inlet cubic feet per minute [ICFM]).

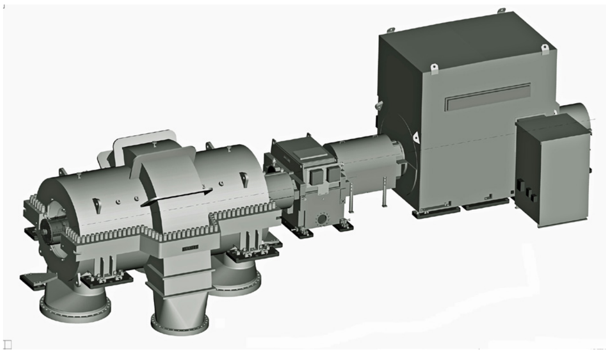

Figure 1. Reactor effluent stage 1 compressor and gearbox.

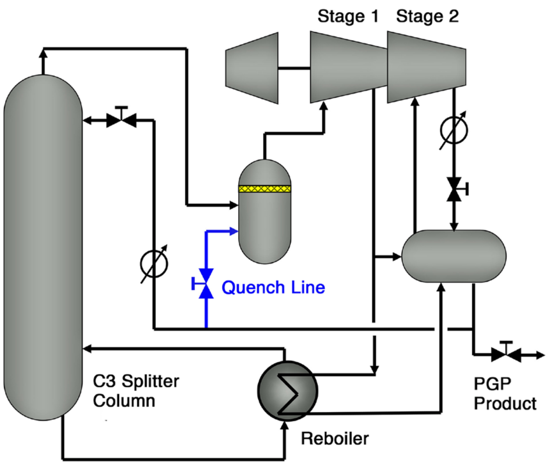

Figure 2. Heat pump compressor process schematic.

Figure 3. Heat pump compressor rotor.

The reactor effluent compressor string is typically arranged as two large-frame, horizontally split casings or bodies. Process pipe connections are in the lower half of the casing so the upper half can be easily removed for maintenance. The first compressor body is often a double-flow arrangement, with two inlet connections and three or four impellers in series on each end of the rotor, exiting through a common discharge connection at the centre. Pressure ratios for the first body range between 2.3 – 4.6, with a discharge temperature of 93 – 146˚C (200 – 294˚F). The gas then passes through an intercooler before entering the second compressor body. The casing may include spray nozzles between the impellers for injection of wash oil for online cleaning of the internal flow passages.

The second compressor body is usually one frame size smaller than the first due to the reduced gas volume. This body will have five to eight impellers in a series arrangement, typically without intercooling, giving pressure ratios between 3.8 – 5.6 and a discharge temperature of 111 – 151˚C (232 – 304˚F).

Reactor effluent compressors have a variety of driver arrangements. Many use a single steam turbine coupled to both the first and second bodies. These turbines have a power range of 35 500 – 53 400 kW (47 600 – 71 650 HP). Other strings drive each compressor individually by a synchronous or induction motor, with or without variable frequency drives, and with or without speed increasing gearboxes. Figure 1 shows a motor-driven first-stage compressor.

Heat pump compressors

The propylene-propane splitter column in the recovery and purification section of the Oleflex process lends itself to the use of a heat pump compressor, which is typically a two-stage, large-frame compressor in a tandem arrangement. The first stage takes gaseous flow from the column overhead, nearly pure propylene, and compresses it with one or two impellers. The heat of compression raises the temperature. This warm flow exits the casing and most of it is sent to the reboiler at the column bottom. Once cooled in the reboiler and condensed, this flow becomes liquid propylene product.

A small amount of the first-stage flow, 14 – 18% on a mass flow basis, is returned to the second stage and is further compressed by two or more impellers. Because this flow is significantly reduced, these second-stage impellers are typically smaller in frame size and have low flow coefficients. This mismatch of internal components becomes a challenge for the designer. A water-fed aftercooler condenses the second-stage discharge, which is added to the liquid propylene product. Having the second stage allows some operational flexibility in the event of process upsets.

A steam turbine or motor and speed increasing gearbox can drive the heat pump compressor. Despite the energy required to drive the compressor, it is still economical as it replaces the utility heat that would be required for the reboiler, and also allows the column to operate at a lower pressure. Figure 2 is a schematic of the heat pump compressor process. Figure 3 shows a heat pump compressor rotor.

Product gas compressors

In the Lummus CATOFIN process, product gas compressors serve a similar purpose as the reactor effluent compressors in the Honeywell UOP Oleflex process. Gas leaving the CATOFIN reactor section passes through several coolers before entering the product gas compressor string at a temperature of approximately 38˚C (100˚F). The pressure is sub-atmospheric, as low as 0.24 bar absolute (3.5 psia). The gas has a molecular weight near 29, and is composed of 27 – 29% hydrogen, 35 – 38% propane, 23 – 25% propylene, and 11 – 12% other constituents – mostly heavier hydrocarbons. These conditions, along with the high flow rates of a modern PDH facility producing 550 – 900 000 tpy of propylene (or a combination of propylene and isobutylene), also result in very high inlet volume flow rates, up to 721 900 m^3/hr (424 900 ICFM).

The product gas compressor string is typically arranged for three stages of compression. The first stage may be a large-frame, horizontally split, double-flow arrangement. Alternatively, the higher flow first stages may consist of two separate, very large frame compressors operating in parallel. Pressure ratios for the first body can range between 3.3 – 4.3 with a discharge temperature of 121˚C (250˚F) or less. The gas then passes through an intercooler before entering the second and third stages.

The second and third stages typically consist of three or four impellers each on a single rotor in a large frame casing. An intercooler is located between the second and third stages. The overall pressure ratio for this casing or body is approximately 14, and the discharge temperature for each stage is 121˚C (250˚F) or lower. All casings typically include spray nozzles between the impellers for injection of wash oil for online cleaning of the internal flow passages. Spray nozzles may be included to inject water for evaporative cooling.

Product gas compressors use a variety of driver arrangements. These include a single steam turbine coupled to one, two, or three bodies with a rated power up to 44 657 kW (60 000 HP). Other options include a synchronous motor with a speed increasing gearbox.

Refrigeration compressors

The CATOFIN process requires both propylene and ethylene refrigeration loops to remove the light hydrocarbons from the product gas. These compressors are similar to the refrigeration compressors used in ethylene production. Each has multiple stages operating at different levels of cooling. The inlet (lowest) temperature for propylene service is -36˚C (-32˚F), and for ethylene service it is -101˚C (-150˚F). Figure 4 shows a typical propylene refrigeration compressor.

Figure 4. Propylene refrigeration compressor.

Select compressor features and benefits

Centrifugal compressors offer some specific features that make them attractive when using PDH technology. Reactor effluent and product gas compressors have low inlet pressure, which means they are a favourable solution for the double-flow first-stage compressors. Used extensively in the first stages of ethylene cracked gas compressors, the double-flow compressor allows for a significant volume reduction during the first stage, while leading to a second stage that has very similar compressor performance and excellent speed matching, enabling the use of common drivers. A double-flow compressor splits the first-stage flow into two balanced inlets at each compressor end and compresses the flow to a common discharge at the centre. The benefit is that a smaller, faster, and more efficient compressor can handle twice the volume flow. As both sides of the compressor are symmetric, the compressor experiences little or no thrust, has no balance piston, and has inherently equalised seals.

Honeywell UOP heat pump compressors are rather unique in that the mass flows between the first and second sections are drastically different. Because the vast majority of the flow is recirculated in the C3 splitter, the first section ideally has a compressor multiple frame sizes larger than the compressor for the second section. The application of modern, high-flow coefficient staging allows for an improved matching of the impeller and casing diameters in the first and second sections, leading to lower capital cost, while maintaining the expected process performance.[3]

The first PDH compressors in the early 1990s used wet seals. However, all units from the early 2000s onwards have used dry gas seals. Careful engineering of the seal buffer system is required, which must take into account the buffer source pressure and primary vent pressure, and ensure that a positive pressure differential is maintained across both the primary and secondary seal faces at all times.

Most compressors in PDH service have six to eight impellers. The large diameter process pipe connections and high efficiency staging require a substantial axial length. All of these factors combine to produce long bearing spans for the rotors. A large main shaft diameter, careful attention to rotor dynamic analyses, optimised tilting pad journal bearings, and at-speed balanced rotors allow for operation with minimal vibration.

As a result of the features and benefits they offer, centrifugal compressors of various types and configurations have an essential role to play in the growth of propylene manufacturing and PDH plants.

References

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