THE ROLE OF COMPRESSION IN DOWNSTREAM DECARBONISATION

Megan Schaenzer, Michael Schulz and Dan Bissell, Siemens Energy, explain why compressors have such an integral part to play in decarbonising the oil and gas sector.

Downstream oil and gas facilities are under intense pressure to improve efficiency and decarbonise their operations. In the US, it is estimated that petroleum refining is responsible for 13% of industrial greenhouse gas (GHG) emissions, and approximately 3% of all emissions nationwide.[1]

In recent years, virtually all major operators have made formal pledges to achieve net zero by 2050, with many setting aggressive emissions reduction goals over the next decade.

Meeting established targets will require the adoption of new technologies and approaches surrounding electrification and digitalisation, as well as the production and utilisation of hydrogen.

Today, nearly all hydrogen used in refining processes, such as hydrocracking and desulfurisation, is considered grey. This means that it is produced via steam methane reforming (SMR) or autothermal reforming (ATR) of natural gas or the gasification of coal and oil. As these processes have a high carbon intensity, significant emissions reductions are possible by transitioning hydrogen production to blue (e.g. the addition of a carbon capture system) or green (e.g. renewable-powered electrolysis). Doing so also opens up opportunities for operators to meet the growing demand for carbon-neutral e-fuels from customers in the mobility and transportation sectors.

This article looks at the critical role that compression plays in these processes, and outlines considerations when selecting compressor technology for use in hydrogen applications. The article will also discuss how well-established technologies, such as heat pumps, can be applied to further drive decarbonisation, by removing the need for traditional gas or oil-fired heaters and boilers.

Compressing hydrogen

Relative to other industrial gases, such as natural gas or carbon dioxide (CO_2), hydrogen has a very high energy content per unit of weight (its caloric value = approximately 33 kWh/kg). While this makes it an ideal energy carrier, its low density at atmospheric conditions (90 g/m^3) presents unique challenges, and not only when it comes to compression.

These challenges were the focus of an article authored by Siemens Energy in the August 2021 issue of *Hydrocarbon Engineering*, entitled 'Under pressure: the challenges of hydrogen compression'.[2]

Currently, two primary methods are used for compressing hydrogen. The first is via positive displacement of the gas using reciprocating (i.e. piston) compressors. The second is with centrifugal-type turbocompressors, which use high-speed impeller rotation to impose high-velocity kinetic energy into the gas.

In the context of hydrogen, the most apparent differentiator between reciprocating and turbocompressors relates to hydrogen's low molecular weight. While reciprocating compressors can provide advantages when it comes to efficiency and leakage in certain applications, several additional factors must be considered during technology selection. These include, but are not limited to, the following:

Performance and footprint

The inherent design of the reciprocating compressor, whereby gas is drawn in and positively displaced by the action of a piston, means that compression efficiency is unaffected by gas molecular weight. Even at partial loads (down to 50% or more), efficiencies as high as 90% can be achieved.[3] This enables the reciprocating compressor to achieve high compression ratios in fewer stages than turbocompressors. Siemens Energy currently has more than 1500 reciprocating units (over 2 million hp) operating in hydrogen-rich service, including for tail gas, feed gas and make-up service. However, while turbocompressors may require more stages, their design enables multiple stages handling large volumes of gas to be accommodated in a unit that occupies a smaller footprint than several reciprocating compressors handling the same volumes of gas at similar pressure ratios.

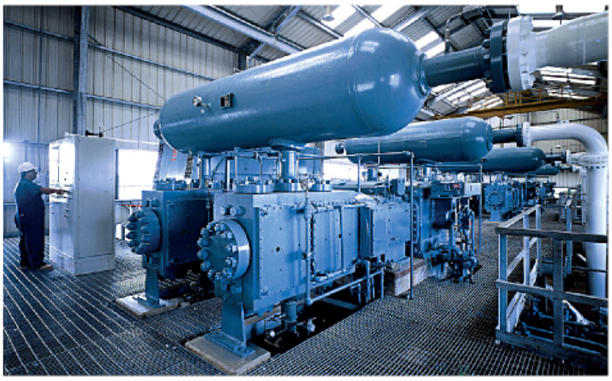

Figure 1. A Siemens Energy reciprocating compressor in operation.

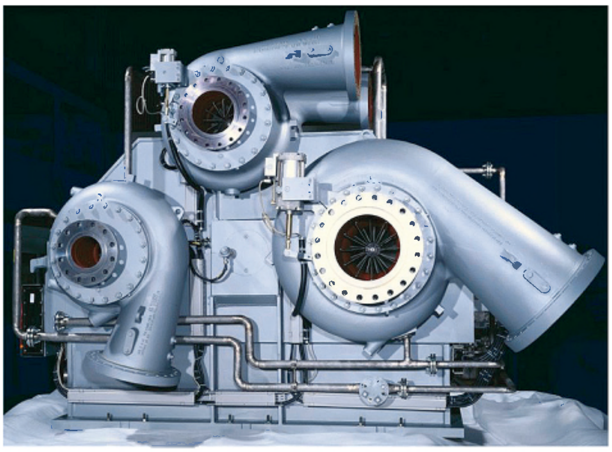

Figure 2. An integrally-geared compressor.

The efficiency of reciprocating compressors may also be reduced at high flow volumes, given the increased number of cylinders. As a result, turbocompressors are more often applied in moderate-to-high flow applications requiring lower pressure ratios, such as in hydrotreating units.

Reciprocating compressors, on the other hand, are typical in situations where lower volumes and higher pressures are required, or where part-load operation is expected. Prime examples would be for hydrogen make-up service or in a polymer electrolyte membrane (PEM) electrolyser unit, which uses electricity (preferably generated from renewables) to split water into pure hydrogen and oxygen. In the case of the latter, the hydrogen can potentially be combined with captured CO_2 to produce carbon-neutral e-fuels which can be directly burned or blended with conventional or biofuels to reduce the mixture's overall carbon intensity.

As an example of this, Siemens Energy recently partnered with Sweden-based Liquid Wind AB to develop a facility where green hydrogen produced via electrolysis will be combined with CO_2 captured from the flue gas of a nearby biomass plant to yield carbon-neutral e-methanol. The e-methanol will replace hydrocarbon-based fuels in shipping applications, removing approximately 100 000 tpy of CO_2 emissions. The long-term vision is to develop 500 of these standardised plants by 2050.[4]

CAPEX and OPEX

Another important consideration when specifying a compressor is total cost of ownership (TCO), dealing with both CAPEX as well as OPEX. Turbocompressors are typically capable of operating for much longer durations without requiring extensive service, resulting in improved uptime and reduced OPEX. In fact, it is not uncommon for centrifugal compressors to run for 8 – 10 years or more, uninterrupted. Furthermore, when the end user has a spare centrifugal compressor modular cartridge available, the time required to bring the facility or process back online if the compressor needs to be refurbished or replaced is reduced. To evaluate on CAPEX, both compressor products need to be aligned with the project-specific compression duty as requested. This is especially true for the case of small volume flows, whereby the reciprocating compressor might show improved economic viability.

Capacity control

Capacity control of the unit should also be considered as it impacts the efficiency of power consumption by enabling users to compress only as much hydrogen as is needed. With reciprocating compressors, this can be achieved using fixed volume clearance pockets within the compressor cylinder, suction valve unloaders to reduce compressor capacity, and reverse suction-flow or infinite-step capacity controls. For both reciprocating and turbocompressors, variable frequency drive

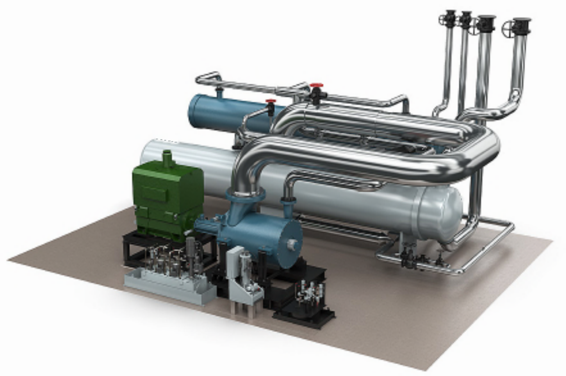

Figure 3. Illustration of an industrial heat pump.

(VFD) motors can be used to vary the rotating speed of the compressor to adjust to capacity demand.

Turbocompressors

Siemens Energy also has experience with turbocompressors for hydrogen service. The STC-SVm compressor was recently launched and merges all of the legacy experience accumulated from Siemens Energy and Dresser-Rand into one compressor platform.

The compressor is designed to facilitate high rotational speeds, which allows for a smaller footprint and stage count by leveraging the Euler equation of turbocompressors. This makes it particularly advantageous for high-flow hydrogen applications. Additional advancements to the STC-SVm platform, which will enable its footprint to be reduced even further, are expected in the near-term, thus contributing to increased economic viability.

The enhanced modular cartridge of the STC-SVm can easily be swapped out with a spare cartridge for time-optimised services. This feature also supports revamp opportunities within a continuously growing hydrogen business. To follow the path of decarbonisation, the dry gas seal system as applied is optimised for minimised leakage and lower emissions, and offers high levels of interchangeability, which reduces requirement for spares. Other core features include duct resonator arrays which reduce compressor noise and instrumentation failures brought about by acoustic vibrations. Digital capabilities are inherent to the design, including state-of-the-art cybersecurity and remote monitoring capabilities.

Heat pumps

Oil refineries are among the largest static industrial consumers of thermal energy in the world. In the US alone, refineries are estimated to use more than 80 GW of thermal energy every year.[5] Among the most significant consumers of heat are processes for atmospheric and vacuum crude distillation, fluid catalytic cracking (FCC), catalytic hydrotreating (i.e. desulfurisation), catalytic reforming, and alkylation.

Currently, most of the heat for these processes is produced by natural gas-fired boilers or resistive heaters, or extracted from hot exhaust streams of gas or steam turbines. While some of these options can reach up to 100% efficiency, heat pumps can deliver multiple times more heat energy than the amount of electric energy input to the system. The ratio of heat energy output to electricity input is referred to as the Coefficient of Performance (COP) and is regularly as high as four for heat pump systems. A COP of four means that a process requiring 10 MW of thermal energy could be serviced by a heat pump running on 2.5 MW of electrical energy. Due to these clear benefits, heat pumps are rapidly becoming a go-to technology for industrial customers targeting reduced energy consumption, reduced emissions and decarbonised heat energy

At the core of the heat pump is a specially designed compressor capable of compressing high mole weight refrigerant gases in a standard vapour-compression cycle. Centrifugal compressors, both integrally geared and in-line machines, are typically the best suited compressor type for industrial heat pumps.

Large versions can deliver up to 70 MWh in a single casing and are engineered to achieve very high coefficients of performance within the overall heat pump system. Advanced sealing technology enables these compressors to meet strict leakage rate limits of less than 1% refrigerant gas leakage per year. The low leakage rate also means that the refrigerant very rarely needs to be recharged.

Due to the orders of magnitude higher performance when compared to traditional boilers, resistive heaters and even combined cycle plants, heat pumps can significantly reduce the amount of energy required to fulfil thermal demands at a refinery, thus eliminating emissions that would otherwise be generated by burning fossil fuels.

Conclusion

Compression is a key component in the hydrogen value chain and plays a critical role in a variety of systems and technologies that will be needed to drive decarbonisation of downstream facilities, as well as the broader oil and gas industry.

When specifying a compressor for a project, it is important for operators to engage as early as possible with the original equipment manufacturer (OEM) so that a compressor design can be implemented that is optimised given the operational constraints of the facility and/or process. While this is true in any end use application, it is particularly the case with hydrogen, as there are unique challenges that may have to be addressed. Although not discussed within this article, this is also the case when compressing CO_2.

With a portfolio of both turbo and reciprocating compression solutions, along with a global manufacturing network, Siemens Energy can help operators meet compression needs across the entire operating range. Additionally, the company's existing portfolio of industrial heat pump products includes proven solutions for buildings, as well as industrial process applications, with heat supply temperatures that can reach up to 270°C. Future Siemens Energy heat pumps are targeting temperatures in excess of 450°C.

References

1. 'Technological Pathways for Decarbonizing Petroleum Refining', World Resources Institute, (October 2021).
2. 'Under pressure: the challenges of hydrogen compression', *Hydrocarbon Engineering*, (August 2021).
3. 'H_2 Compression: An Integral Part of the H_2 Value Chain', Siemens Energy, (2021).
4. 'Siemens Energy partners with Liquid Wind to produce green fuel', Pro MFG Media, https://www.promfgmedia.com/siemens-energy-partners-with-liquid-wind-to-produce-green-fuel.php?article_id=317
5. 'Refinery Capacity Report', US Energy Information Administration, (2021).