Figure 4. LEWA diaphragm pump G4T: CCS at the Snøhvit gas field, Norway.

HYBRID theory

Anke Braun and Josef Jarosch, LEWA GmbH, Germany, and Rainer Dübi and Luzi Valär, Burckhardt Compression, Switzerland, discuss ways to improve efficiency of CO_2 and acid gas compression.

Estimations suggest that the burgeoning worldwide energy demand will be satiated by fossil fuels for some more decades, with clear and well documented environmental consequences. Capture and storage of CO_2 is the most promising process available to reduce greenhouse gas emissions.

Injection of CO_2 has taken place for many years as a consequence of pressing CO_2 into oilfields in order to enhance oil recovery (EOR). Faced with sour sources of natural gas, acid gas injection is employed by oil and gas producers in Canada to reduce emissions of H_2S into the atmosphere. Since CO_2 often represents the largest component in acid gas streams and it is costly to separate the two gases, large volumes of CO_2 are injected together with H_2S into geological formations.[1, 2] The methods and technologies that can be used for carbon capture and storage (CCS) are analogue to those developed for acid gas injection and EOR.

The overall acceptance of CCS will depend on a reduction of the cost and energy requirements for the whole process. Both capture and compression of CO_2 and H_2S are energy intensive undertakings. Since the compression of a liquid consumes less energy than compression of a gas, it could conceivably be reasonable to utilise new concepts with part compression followed by liquefaction and pumping.[3, 4] Significant power savings in the compression step can be achieved with this tandem approach.[5]

The hybrid approach

Figure 1 shows two ways of compressing 30 t /hr of CO_2 from 2 bara to 200 bara. One process, indicated by the red line, describes the conventional semi isothermal compression with multistage compression and inter stage cooling for reciprocating compressors. The compression ratio is in a range of 3 - 4. This compression path requires five compression stages and results in a power demand of 3 MW for this application.

The hybrid approach, indicated by the blue line, combines semi isothermal compression, cooling, liquefaction and increasing the pressure in a final single step to the pipeline condition by a pump. This combined path of compression reduces the power demand by 0.5 MW. The CO_2 is compressed to 70 bar by a reciprocating compressor with three stages, subcooled to 25 ˚C and boosted to the final pressure of 200 bar by a triplex diaphragm pump. However, there is no universally valid solution to CO_2 and acid gas compression duties. Specific storage site conditions such as location, ambient air temperatures, availability of cooling medium, etc. play a decisive role in determining the optimum configuration.

Increased efficiency

For this reason, only the shaft power is considered in the energy balance. The power consumption of the liquefaction depends on the ambient conditions. Figure 2 shows the condensation temperatures of acid gas at 65 bar and 70 bar. It can be seen that for pure CO_2, a temperature of approximately 20 ˚C is required for the cooling agent, which can be achieved with cooling water. Thus, if cooling water is available at the site of compression, the overall power saving can be up to 15% because the power consumption of the liquefaction is negligible. If active cooling is required, the power saving is still in the range of 5 - 8%. With an increasing amount of hydrogen sulfide in the acid gas, the condensation temperature rises and as a result the required temperature of the cooling liquid becomes less critical.

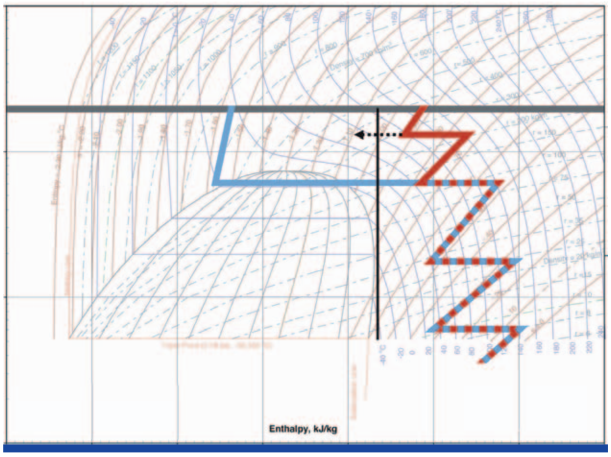

Figure 1. CO_2 pressure enthalpy diagram: compression schemes for CO_2 and minimum suction temperature (© Chemicalogic Corporation).

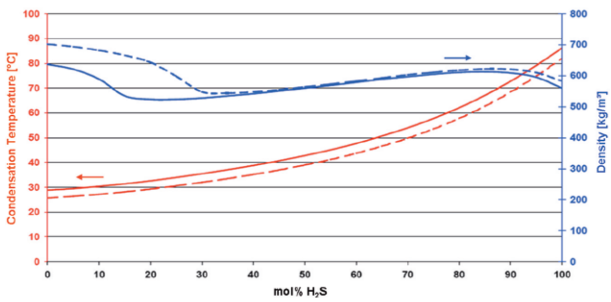

Figure 2. Condensation temperature and density of acid gas at 65 bar (dotted line) and 70 bar (straight line).

Given that reciprocating compressors and pumps work on a volumetric base, the density and compressibility of the fluid determines the size of the machine. To be in an economic range for the capital costs of diaphragm pumps, the density of the pumped fluid should at least be 500 kg/m^3. As can be seen from the Figure, this minimum density can be attained if the acid gas is liquefied at a pressure of approximately 70 bar.

Corrosion protection

Beside the efficiency improvement, the hybrid compression path also mitigates an important corrosion issue with acid gas. At higher pressure, the suction temperature is close to the two phase region. At these conditions, there is a risk of corrosion if the acid gas decompresses in the packing and sealing elements and liquefies. This is illustrated in the pressure enthalpy diagram in Figure 1, which shows the limit in suction temperature for pure CO_2.

To avoid this corrosion problem it is necessary to increase the suction temperature for the upper stages, which, as a result, increases the number of stages. For the case study presented here, this concerns the suction temperature of stage four and five. For acid gas with a high content of H_2S, this issue already arises at lower stages. As a consequence, the combination of reciprocating compressors and pumps for acid gas compression also reduces corrosion issues for processes with discharge pressures above 100 bar for pure CO_2 and even lower discharge pressures for acid gas.

Advantageous flexibility

Additionally, reciprocating machines offer advantages where process flexibility is an important criterion. Reciprocating compressors can be adapted to varying mass flows by speed control in combination with valve unloading, and diaphragm pumps by speed control. In this way, a turndown ratio of 1:4 is achieved for the compressor and 1:4 or 1:5 for the pump, dependent on the pump size. By using speed control, reciprocating machines can deliver variable flow rates at a constant high efficiency.

Also varying gas compositions, occurring in enhanced oil recovery and acid gas injection, can be handled easily by reciprocating compressors and pumps. Varying compositions bring about changes in density and compressibility, which result in changing volumetric flow rates. Again, this can be accomplished by speed control without loss in mechanical efficiency.

Finally, for all compression and storage operations it is a quite conceivable scenario that the discharge pressure will vary over time due to changes in the reservoir pressure. With the hybrid compression path, this case would not require any adaption of the installation since the fluid is boosted to the final pressure by the pump in one single step.

Pushing the limits

Figure 3 shows the plant layout for the example of compressing 30 t /hr of CO_2 in a three stage reciprocating compressor and a diaphragm pump, including the interstage coolers and pulsation dampers for each stage. The first compressor stage requires two pistons, the second and third stage one piston each. After the compressor, the CO_2 is liquefied in the subcooler before it is boosted by the triplex diaphragm pump to the reservoir pressure.

The limit for piston compressors and diaphragm pumps lies at approximately 150 t /hr of acid gas. In terms of carbon capture and storage, the CO_2 emissions of many CO_2 generating processes and fossil fuelled power plants of 200 - 300 MW can be handled with one set of machines. Power plants of 200 - 400 MW would need two or three sets of reciprocating machines operated in parallel. The range above (up to 1200 MW) would be the field of turbocompressors and turbopumps, though with significantly lower efficiency, especially at part load. For high capacity power plants where concurrently high flexibility is required, it is conceivable to use turbo machines to cover the base load and reciprocating machines to accomplish the peak load at high efficiency.

The limit in discharge pressure for this hybrid solution is approximately 500 bar, depending on the actual flow rate, while the suction pressure needs to be at least atmospheric. In low pressure applications (up to approximately 150 bar), the compression can be performed by multistage reciprocating compressors only.

Varied applications

Ring sealed reciprocating compressors are employed for a very wide range of applications. Burckhardt Compression's portfolio of ring sealed reciprocating compressors with crosshead (API 618) ranges

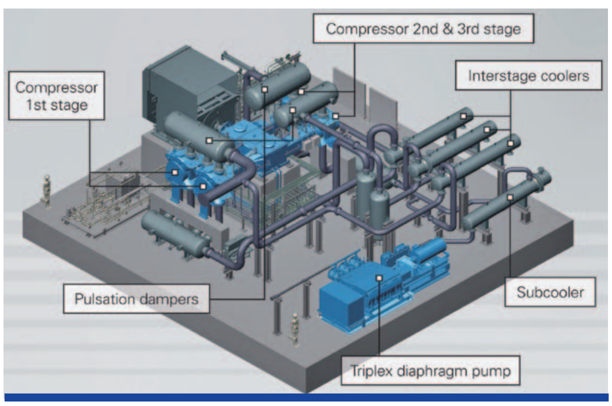

Figure 3. Plant layout for compressing 30t /hr CO_2.

from 200 - 31 000 kW, and discharge pressures of up to 1000 bar can be reached. There are in excess of 370 Burckhardt compressors installed for CO_2 and approximately 30 for H_2S services worldwide.

Diaphragm pumps are primarily used for low to medium flow rates at medium to high pressures. They are predominantly known for low flow, high head applications and for fluids that have to be metered without leaks and with high accuracy. However, in the last 25 years LEWA process diaphragm pumps were developed to hydraulic powers of several hundred kW. Today, the allowable physical values such as pressure, flow rate and viscosity cover several orders of magnitude.

The aforementioned process conditions are typical applications for plastic diaphragms. They are usually employed for pressures up to 400 bar at temperatures of -50 ˚C - 150 ˚C. Special designs are used in processes up to 800 bar.

Diaphragm pumps are absolutely leak free because the hydraulically actuated diaphragm completely separates all susceptible parts of the pump from the process fluid. This is why they have found a wide field of applications in all industries that handle fluids with the potential to be hazardous, dangerous or toxic. Therefore, the diaphragm pump technology is not only suitable to convey CO_2 for carbon capture and storage, but also acid gas, containing highly toxic H_2S, for sequestration or enhanced oil recovery.

Leakages in case of damage are avoided through the multilayered diaphragms with a diaphragm rupture indication technology. The fluid remains contained in the pump even if one diaphragm is damaged. For fluids that tend to diffuse through the diaphragm (especially CO_2), there is a special diaphragm rupture indication that differentiates between tiny leakages caused by diffusion and real damages of the diaphragm. Other safety features are implemented in the hydraulic part of the pump to render it inherently safe against upset conditions such as overload or cavitation.

In addition to their leak free qualities, diaphragm pumps have all the advantages of reciprocating displacement pumps, such as high accuracy, as well as high volumetric and mechanical efficiency. Additionally, the pressure firm characteristics of the pumps mean that the capacity is nearly unaffected by the backpressure. Linear capacity control is possible through speed adjustment; for some pump types it can also be achieved by stroke adjustment.

Technology in action

CO_2 is the most frequently pumped fluid by LEWA pumps. Many of these pumps are employed in low flow, high pressure applications. However, the biggest diaphragm pump ever built by LEWA also conveys CO_2. It is placed at an LNG production facility in Norway where CO_2, which is originally contained in the natural gas, is compressed for sequestration in a deep sub sea formation beneath the gas field for final storage. The four headed diaphragm pump boosts 110 m^3/hr CO_2 from 60 - 215 bar. In this case, the hybrid compression consumes more than 1000 kW less than the conventional compressor process.[6]

LEWA pumps are also employed for acid gas injection in Canada where absolutely leak free pumps are required due to the high toxicity of H_2S.

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