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Improve gas compression systems with all-welded shell-and-plate heat exchangers

They offer benefits compared to shell-and-tube and welded-plate designs

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Multistage gas compression is one of the most common processes in any industrial plant. Applications vary from one industry to another and include natural gas processing, petroleum refining, and manufacturing of chemicals and end-product gases. Pressurizing the gas enables it to be stored and transported more easily. The use of shell-and-plate heat exchangers in place of conventional welded-plate heat exchangers and shell-and-tube units provides a lot of benefits. With the shell-and-plate design you avoid the corner welds that are critical for the traditional "four-corner grid" welded-plate design and you also save space and weight compared to the shell-and-tube units. The shell-and-plate design also offers full maintainability with an option for a removable plate-pack core via a bolted cover on one end of the shell that enables the unit to be mechanically cleaned. The potential for improved process reliability and efficiency that this offer is ever more widely appreciated.

Interstage cooler design. In the design of the interstage coolers in a gas compression process, it is necessary to have a good understanding of the physical laws governing fluid flow and heat transfer in corrugated channels. In the interstate coolers, partial condensation will occur when the gas is cooled between two stages. Since the pressure loss due to fluid friction contributes to decreased compressor efficiency, and thereby increased energy input to the compressor, it is essential that the designer is well aware of the aspects influencing the pressure loss. Several correlations exist on how to calculate two-phase pressure drop but the sources in the literature cannot agree upon a common complete adequate theory to predict the two-phase flow behavior. Because of this the engineering contractors need to rely more on the applications expertise of the manufacturers who usually use in-house programs based on empirical or semiempirical correlations to choose a correct size of heat exchanger. Hence, an experienced designer can help the process engineers save energy consumption by proper cooler design. The shell-and-plate design makes it possible to meet the heat transfer requirements with a relatively low pressure drop that contributes to increased process performance.

The gas compression process. Fig. 1 presents a typical flow diagram for the gas compression process. The gas is typically compressed in several stages working with equal pressure ratios and mechanical work input. Since the compressor efficiency is a function of the compression ratio single-stage compression is inefficient. The gas enters the first compressor and is compressed to the first pressure level. When the pressure of the gas is increased the temperature will also increase by the definition of the ideal gas law. The hydrocarbon gas is then cooled in the interstage cooler and condensed liquids are separated from the gas stream in the free water knock-out drum. The separated gas enters a new compression stage and the process starts all over again. It is important to monitor the suction temperature at each stage since it must be kept away from the saturated liquid line to avoid liquid droplets in the compressor.

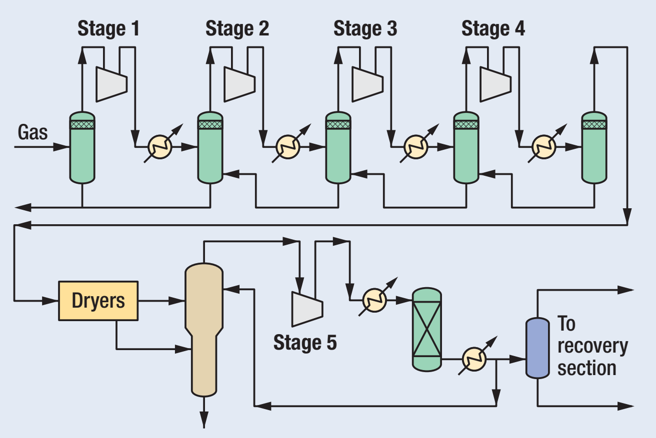

FIG. 1 Typical gas compression process.

Liquid is constantly removed from the gas prior to each compression stage. Depending on the gas dryness requirements further dehydration might be necessary before final storage or transportation. After the compression all the liquid has usually gone into solution with the vapor phase. If any subsequent corrosion cannot be tolerated the gas must be dehydrated—preferably with an absorption unit such as a TEG glycol process. In the glycol contactor the wet gas flows counter current with lean glycol, which absorbs the water vapor from the hydrocarbon gas by chemical affinity. The rich glycol is collected in the bottom of the contactor and flows to the regeneration skid where rich glycol is regenerated to lean glycol by boiling off the water vapor. The dry gas then flows from the contactor to the last compression stage. The gas is compressed to the appropriate discharge pressure and then cooled in a last cooler before being exported to storage or transportation.

Two-phase pressure drop. The two-phase pressure loss is a very important factor for overall compressor efficiency (based on energy input vs. enthalpy increase) due to the partial condensation occurring when the gas is cooled. The two-phase pressure drop is a function of vapor quality and, since the quality varies with progression downstream, it is necessary to integrate any correlation that depends on quality over the heat exchanger length to compare with actual measurements conducted in experimental facilities. The most commonly used model for predicting the pressure loss in two-phase flows is the classical Chisholm and Lockhart–Martinelli correlations. In this model the pressure drop of the two-phase flow may be related to the pressure drop of the single-phase flow (as calculated by standard correlations) by a two-phase multiplier defined as:

$$\phi_l^2 = \frac{(\Delta p / \Delta L)_{tp}}{(\Delta p / \Delta L)_l} = 1 + \frac{C}{X_{LM}} + \frac{1}{X_{LM}{}^2} \tag{1}$$

where X_{LM} is the Lockhart–Martinelli parameter and C is the Chisholm parameter. The Lockhart–Martinelli parameter is defined as the ratio of liquid to vapor pressure gradients, with the assumption that each phase flows alone in the channel. The parameter takes different forms depending on the assumed or measured flow regime of each phase. The most commonly used assumption is that both phases are turbulent. There are insufficient experimental data for general conclusions to be made for the value of C. However, C seems to vary with hydraulic diameter and several suggestions exist for the C value. It should be noted that the prediction accuracy of any of the existing models is quite low. Since the correlations in the literature are only suitable for certain geometries at different mass fluxes, heat fluxes, and vapor qualities and flow orientations, the uncertainty is within the range of ± 20% and even more in special geometries. Hence, reliable manufacturing data in conjunction with a critical eye of the engineering contractor are essential in predicting the pressure loss.

Optimizing the gas compression process. The work input to the compressor is highly dependent on the pressure ratio between the compressor inlet and outlet and the inlet temperature on the suction side of the compressor. Optimizing a compressed-gas system is hence not the easiest task. While each compressor may very well be 70–80% efficient this high efficiency cannot be achieved if one compares the energy input to the increased enthalpy across the total compressor because friction in piping and heat exchangers tend to consume this. The efficiency that can usually be achieved by taking into account all the extra frictional loss may be 65% for a single-stage unit with a 6% drop for every added stage. With five stages one could expect an efficiency to be around 35% (based on energy input vs. enthalpy increase). Since the frictional loss is such an important factor for the overall compression efficiency, the pressure drop across the interstage coolers should be kept as low as possible. Hence, reliable manufacturing data cannot be neglected and as described, it is not always an easy task to predict the two-phase pressure drop.

Why shell-and-plates? The benefits of using plate heat exchangers are well known. They are more efficient, occupy less space, are less heavy, and do not need to be cleaned as often as shell-and-tube heat exchangers. When the material is exotic (high cost) the price will also be less than for traditional shell-and-tube heat exchangers due to less required heat transfer area. Therefore, it will save costs where corrosive fluids are present. However, traditional welded plate heat exchangers with rectangular plates (four corner grid design) exhibit poor performance because of low resistance to thermal and pressure fatigue and are not ideal for the application. The corner welds very often result in crack propagation that results in unexpected shut down and maintenance. Therefore, this antiquated design should be replaced by more reliable shell-and-plate heat exchangers to improve reliability and availability in the hydrocarbon industry.

The shell-and-plate heat exchangers introduced in recent years, have presented solutions to some of the traditional shell-and-tube/four corners grid limitations. They provide the thermal efficiency and the compactness of a plate-and-frame heat exchanger while handling pressures and temperatures otherwise requiring shell-and-tube units. Their excellent resistance to thermal and pressure fatigue makes them superior to other welded technologies. The shell-and-plate design has also proven to withstand challenging process conditions with liquids, gases, steam and two-phase mixtures. The compact design enables very close temperature approaches and the small hold-up volume provides fast startups and close following of process changes. From a thermal point of view the shell-and-plate design is very well suited for vapor/liquid mixtures. The short flow path and the large cross section makes it particularly suited for two-phase flows with a high LMTD between the hot and cold sides of the heat exchanger.

Summary of advantages of shell-and-plate compared to other types of heat exchangers:

- Less than half the size of a shell-and-tube unit for comparable duties as a result of higher heat transfer coefficient created by the corrugated patterns of their plates
- Turbulent flow even at low velocities keeping the plates free from scaling and fouling longer than does the laminar flow seen in shell-and-tube units.
- Easy to maintain due to the option for removable plate-pack core via a bolted cover on one end of the shell in combination with a traditional CIP unit.
- Superior to any other type of welded heat exchanger due to the lack of corner welds which are critical in other "four-corner grid" designs.

Conclusion. Plate technology has been used for more than a decade in main hydrocarbon processes. Gas compression operations are now beginning to enjoy the advantages of all-welded shell-and-plate heat exchangers. The shell-and-plate concept is superior to a four-corner grid design since the resistance to thermal and pressure fatigue is very much improved, especially for dynamic processes where close following of process changes is needed. Circular shell-and-plate designs eliminate the corner welds that are most susceptible to problems. **HP**

Stefan Gavelin is the area sales manager (Europe) for Tranter's oil & gas market segment. He holds an M.Sc. degree in mechanical engineering from the Royal Institute of Technology, Sweden and has specialized in thermodynamics and heat transfer. At Tranter he has the task of researching and finding new application areas, as well as developing sales concepts and initiating product development according to the new applications. Mr. Gavelin also has experience from the refrigeration industry especially in the design of evaporators and condensers. As a member of the HTFS organization, Tranter is constantly aware of the latest developments in two-phase flow theory.