Removing nitrogen

Doug MacKenzie, Ilie Cheta and Darryl Burns, Gas Liquids Engineering, Canada, present a comparative study of four nitrogen removal processes.

Nitrogen rejection applications can be divided into two categories based on the nitrogen source: naturally occurring nitrogen (NON) and enhanced oil recovery nitrogen (EOR nitrogen). The characteristics and processing requirements of the two application categories differ significantly.

Naturally occurring nitrogen

There are many gas reservoirs worldwide that contain high levels of 'naturally' occurring nitrogen. The nitrogen content in the produced gas of these reservoirs usually remains constant over the producing life of the reservoir. The design of the nitrogen rejection unit (NRU) can focus on an optimum design at a fixed feed composition. Usually, nitrogen is not injected into these reserves to enhance recovery, so the rejected nitrogen has little or no value as a product stream. For this reason, the product nitrogen pressure at the outlet of the process is not important. On the other hand, the hydrocarbon recovery from the vented nitrogen is very important: 'A typical value of hydrocarbon recovery is 98%. Lower recoveries impact the cost of the project, but recoveries below 95% usually result in significant hydrocarbon loss and could be an environmental problem with the nitrogen vent stream. Economic incentives for a specific project include only the values of the recovered liquids and residue (sales) gas that can be produced.' (GPSA)

Enhanced oil recovery nitrogen

During EOR programs involving the injection of nitrogen, it inevitably breaks through into the produced gas. Unlike naturally occurring nitrogen, the nitrogen content in the produced gas will increase with time for an EOR injection program. The values can range from 4 - 75% nitrogen in the produced gas over the lifetime of a project. The NRU process and its equipment must perform satisfactorily over a broad range of feed compositions and flexibility is a key design requirement. The recycling of rejected nitrogen is generally less expensive than the independent production of nitrogen from air. As a result, the available pressure of the rejected nitrogen stream is important in minimising the cost of recompression. Project economics must include the value of the nitrogen at an elevated pressure as an additional product stream.

Separation between nitrogen and methane

Since nitrogen removal is performed where nitrogen and methane are the predominant components, the possibility of separation between nitrogen and methane by fractionation can be examined using the T-x-y curves of these two components (Figure 1). Here, the separation between nitrogen and methane is easy, requiring low reflux ratios and a small number of stages. The difficulty associated with this separation is the low temperature refrigeration required. There are many processes proposed in past research[1-9] to perform the separation of nitrogen from gas. Each one has limited possibilities in achieving a desired separation economically. These limited possibilities can be examined with respect to the nitrogen content in the inlet gas.

Study

A comparison of four basic nitrogen removal processes was performed examining the compression power required with a varying inlet nitrogen gas content, over a range of 6 - 75% nitrogen. The following assumptions were considered: the inlet gas comes from a turboexpander plant at 450 psia and -57 ˚F; the rejected nitrogen stream discharges at 500 psia; the natural gas stream discharges at 265 psia; the nitrogen content in the residue gas is 3%; the desired methane recovery is 98% minimum.

Nitrogen removal processes

Single column process (1COL process)

This nitrogen removal process utilises a single distillation column sustained by a heat pump system. The 1COL

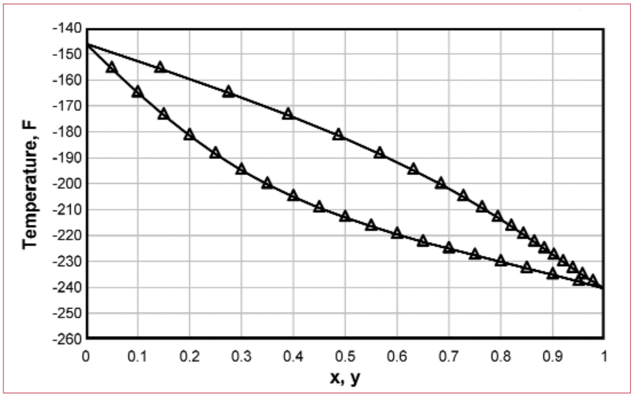

Figure 1. T-x-y curve for N_2-CH_4 at P=400 psia.

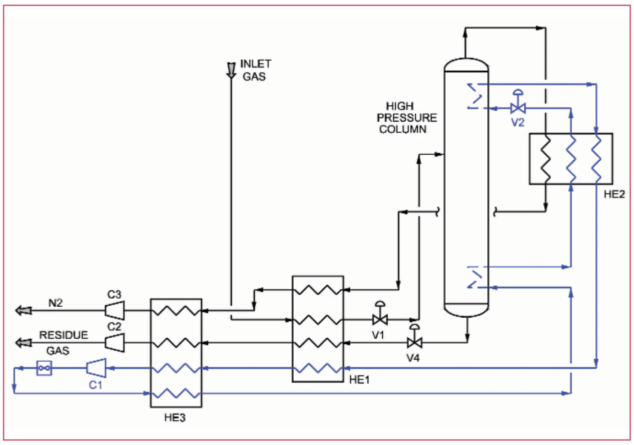

Figure 2. Single column process (1COL process).

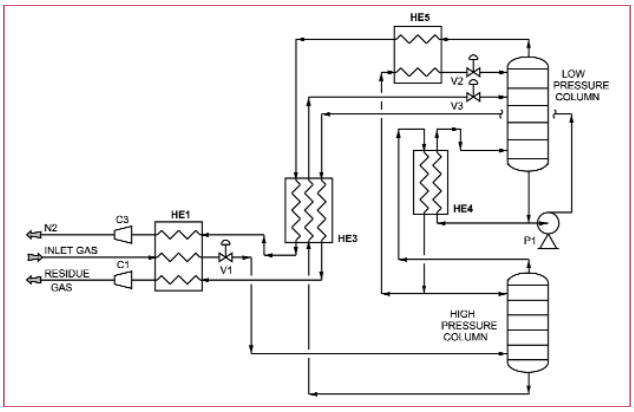

Figure 3. Double column process (DBLC process).

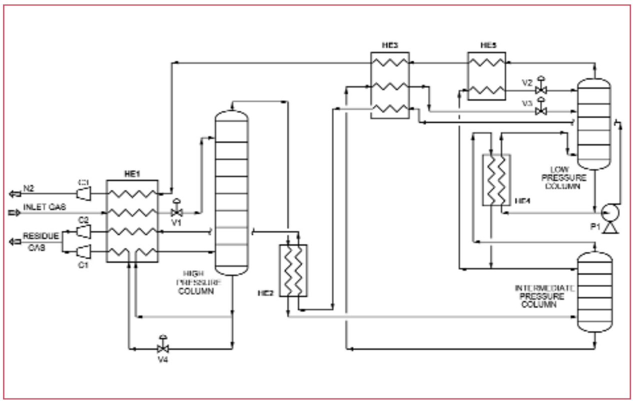

Figure 4. Three column process (3COL process).

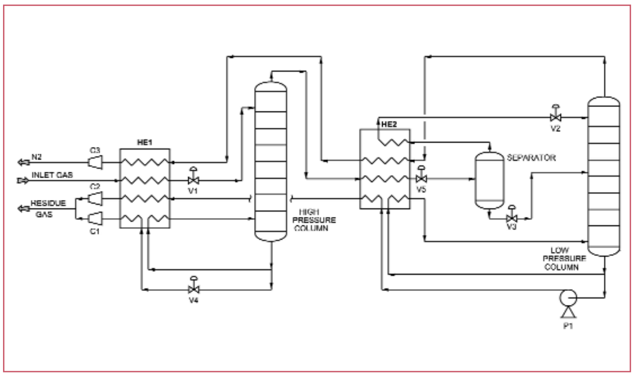

Figure 5. Two column process (2COL process).

process flow sheet is illustrated in Figure 2. The feed stream is cooled, throttled and fed to an intermediate stage of the column operating at pressures anywhere from 200 - 400 psig. A reboiler provides the heat necessary to make the residue product at required specifications, while a condenser is used to provide reflux and purify the overhead nitrogen product. The bottom liquid is the methane-rich residue product, which is throttled and reheated against the incoming feed stream. The pressure to which this stream is throttled depends on the nitrogen content in the inlet gas. In general, this pressure decreases as the inlet nitrogen content increases. The reboiler and condenser duties are provided by a heat pump system in which methane (the heat pump fluid) condenses at high pressure in the reboiler and is throttled and vaporised at low pressure in the condenser. A sub cooler minimises the flash of the methane as it is throttled into the condenser. An external compressor restores the methane pressure.

The number of trays and position of the feed tray in the column have a great influence on the compression horsepower of the process. As the nitrogen content of the inlet gas increases, the top temperature decreases, the condenser duty increases and pressure to which the methane is throttled in the refrigeration cycle decreases. This throttling causes a corresponding increase in the compression hp. Due to critical pressures of nitrogen-methane mixtures, the upper pressure limit for the distillation is 400 psig. Also the minimum temperature of methane, after the JT expansion, is one corresponding to the expansion to close to atmospheric pressure. Due to these two limits, the top product of the column is more difficult to condense with methane, as the nitrogen content in the product increases. Even if the process, in principle, could be supplied with unlimited refrigeration, it is not able to achieve a methane recovery of 98% for a nitrogen content of the inlet gas higher than 30%.

Double column process (DBLC process)

The DBLC process flowsheet is illustrated in Figure 3. Inlet gas is cooled, throttled and fed into the bottom of the high pressure column. A condenser provides both the reflux for the high pressure column and a high purity liquid nitrogen product stream, which is used as reflux for the low pressure column. The bottoms from the high pressure column, having some of the nitrogen removed, forms the feed stream to the low pressure column. Both product streams from the high pressure column are sub cooled prior to throttling into the low pressure column to minimise the flash off across the valve

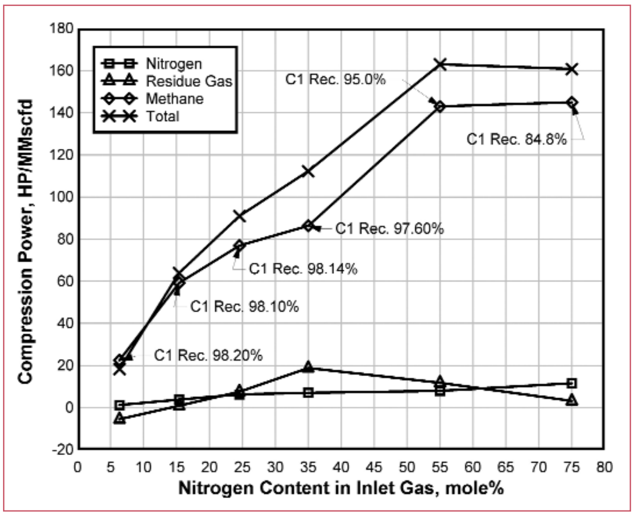

Figure 6. Total and component compression power for single column process.

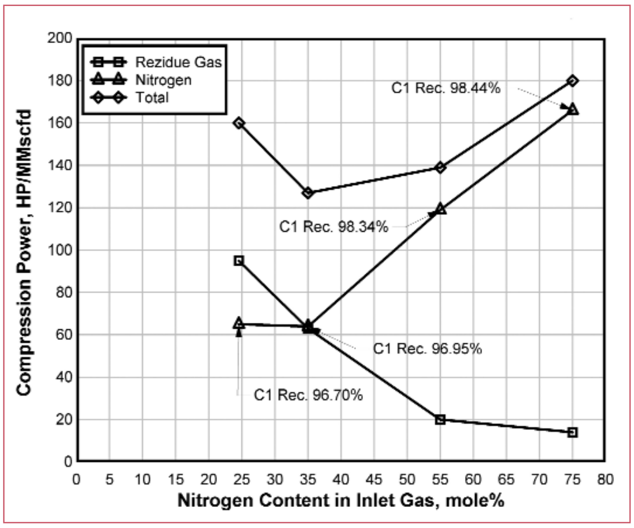

Figure 7. Total and component compression power for double column process.

and the resultant methane losses into the nitrogen product stream. The low pressure column performs the final separation between the nitrogen and methane. The nitrogen gas stream of the top of the low pressure column is reheated against the incoming feed stream. The reboiler at the bottom of the low pressure column provides a methane-rich liquid, which is pumped to a higher pressure, vaporised and reheated against the incoming feed. The pressure to which this stream can be pumped depends on the nitrogen content in the inlet gas. The reboiler duty, necessary in the low pressure column to provide a residue product with low nitrogen content, is provided by condensing the nitrogen at the top of the high pressure column.

The DBLC process can be attractive from a compression power point of view to perform any desired separation between nitrogen and methane when the nitrogen content in the inlet gas is above 50%. The refrigeration requirements of the process can be satisfied in two ways. The first way is the Joule-Thomson expansion applied to various streams within the process. The second way to satisfy the refrigeration requirements for the process is to change the discharge pressure of the methane-rich liquid cryogenic pump at the bottom of the low pressure column. Roughly speaking, by decreasing the discharge pressure of this pump, no additional refrigeration is generated, but more refrigeration is generated at a lower temperature at the expense of losing an equivalent amount of refrigeration at higher temperatures. The operating pressure of the low pressure column has a strong impact on the required compression power. The operating pressure of the low pressure column depends on the methane recovery and the nitrogen content in the inlet gas. The operating pressure is close to atmospheric pressure for high methane recovery and high nitrogen content in the inlet gas. The operating pressure of the high pressure column is set up so that the overhead vapour of the high pressure column condenses in the reboiler of the low pressure column. Compared with other processes, more compression power is required to achieve a 98% methane recovery when the nitrogen content in the inlet gas decreases below 45%.

Three column process (3COL process)

This process is made up of the double column from the above process and a prefractionator. The process is illustrated in Figure 4. Inlet gas is cooled, throttled and fed into the top stage of the prefractionator. From the bottom of the prefractionator, methane rich liquid is throttled and reheated against the incoming feed stream. The overhead vapour, having some of the hydrocarbons removed, forms the feed stream to the double column system.

The prefractionator allows some of the hydrocarbons to be separated and recovered at higher operating temperatures than the double column system. This reduces the compression power required and also increases the tolerance to carbon dioxide in the feed gas. As the nitrogen content in the inlet gas increases, the advantages of the first column diminish as a result of a decrease in the methane rich liquid generated at the bottom of the prefractionator. The 3COL process can be attractive from the point of view of compression power for any desired separation between nitrogen and methane when the nitrogen content in the inlet gas is below 50%.

Two column process (2COL process)

This process is illustrated in Figure 5. The process comprises a high pressure prefractionator, an intermediate pressure liquid-vapour separator and a low pressure column. To a certain extent, this process is similar to the 3COL process. There, a system of two thermal coupled columns is used, while in the 2COL process, the two columns system is replaced by a liquid-vapour separator and a distillation column. The cold inlet gas is throttled and fed to the top stage of the prefractionator. The bottom methane rich liquid is throttled and reheated against the incoming feed stream, similar to the 3COL process. The overhead vapour, having had some of the hydrocarbons removed, is further cooled, throttled and fed into the liquid-vapour separator. The liquid product stream from the separator is again throttled and fed to an intermediate stage of the low pressure column. The vapour from the separator is sub cooled prior to throttling into the low pressure column to minimise the flash off and the resultant methane losses into the nitrogen product stream. The low pressure column performs the final separation between nitrogen and methane. The overhead nitrogen stream is reheated against the incoming feed stream. A reboiler in the bottom of the low pressure column provides a methane rich liquid, which is pumped to a higher pressure, vaporised and reheated against the incoming feed stream. The operating pressure of the methane rich liquid pump is dependent on the nitrogen content of the inlet gas. The operating pressure of the low pressure column has a strong impact on the process cost. The operating pressure of the low pressure column depends on the methane recovery and the nitrogen content in the inlet gas. The operating pressure is close to atmospheric pressure for high methane recovery and high nitrogen content in the inlet gas. For a given methane recovery, the operating

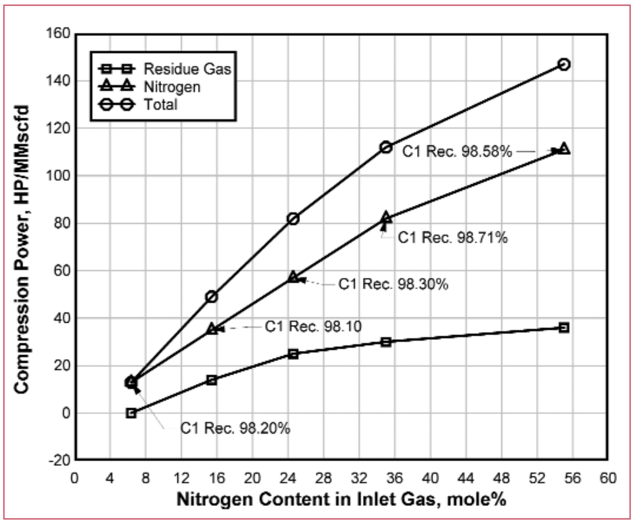

Figure 8. Total and component compression power for three column process.

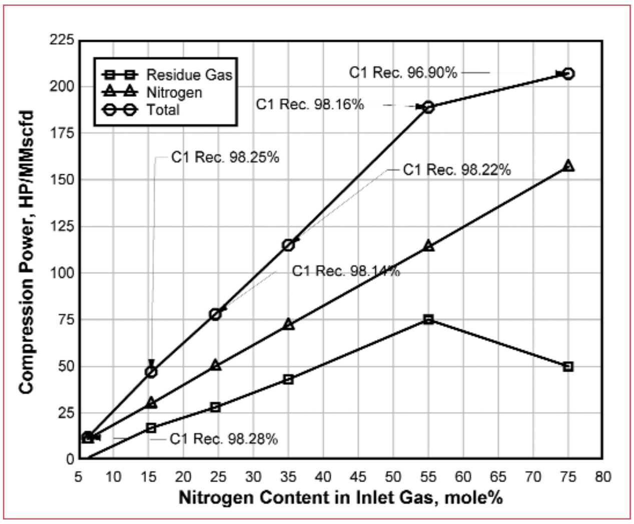

Figure 9. Total and component compression power for two column process.

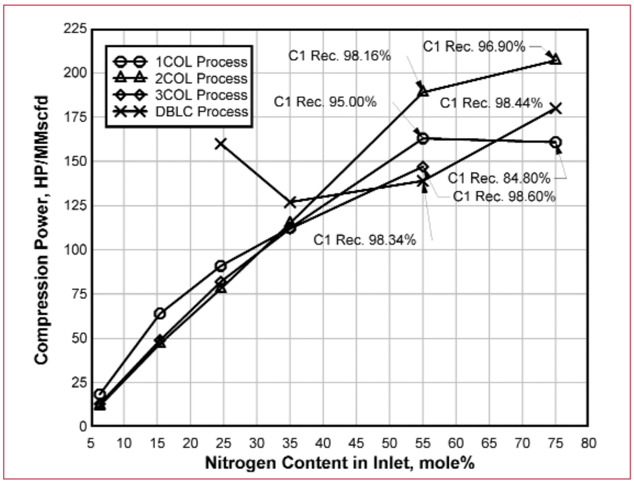

Figure 10. Total compression power for four NR processes.

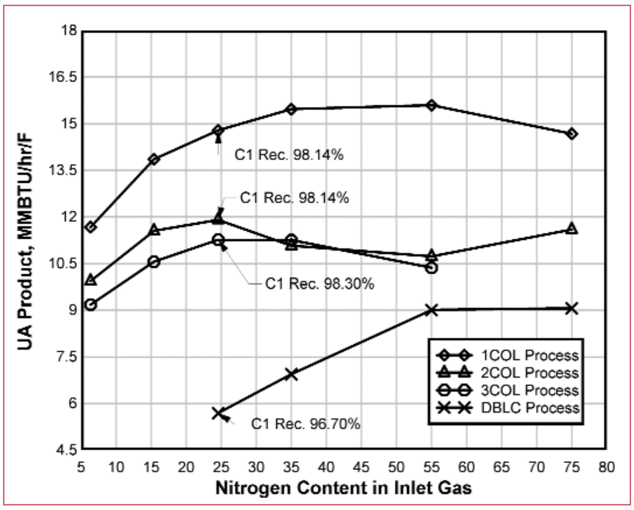

Figure 11. UA product for four nitrogen removal processes.

pressure can be increased as nitrogen content in the inlet gas decreases. The 2COL process scheme is simpler than the 3COL Process. Also, in comparison to the 3COL process, the 2COL process has a greater potential to increase the operating pressure of the low pressure column as the nitrogen content in the inlet gas decreases. The drawback to the 2COL process is that it cannot achieve a 98% methane recovery when the inlet gas goes above 60% nitrogen.

Results of the simulation study

Single column process (1COL process)

Compression power required by this process is illustrated in Figure 6. Total compression power, hp/MMSCFD inlet gas, is made up of three components: compression power for hydrocarbons, for nitrogen and for methane. The compression power for methane is the predominant component. According to Figure 6, the total compression power increases as the nitrogen content in the gas increases. The 1COL process is not able to perform a methane recovery of 98% when the nitrogen content is higher than 30%. For a nitrogen content in the inlet gas of 35%, the methane recovery drops to 97.6%. As the nitrogen content in the inlet gas increases past 35% to 55%, the methane recovery slowly drops off to 95%, while the compression power significantly increases from 112 - 163 hp/MMSCFD. For a nitrogen content greater than 55%, the methane recovery rate dramatically decreases, while the compression power remains practically constant.

Double column process (DBLC process)

Compression power required by this process is illustrated in Figure 7. The total compression power is made up of two components, compression for the methane rich gas and compression for the nitrogen gas. The DBLC process is able to perform any separation between nitrogen and hydrocarbons when the nitrogen content of the inlet gas is greater than 50%. The DBLC process is not able to perform methane recovery of 98% when the nitrogen content in the inlet gas is below 50%. This is seen in Figure 7 where methane recoveries are below 98% for 35 and 24.56 mole% of nitrogen in the inlet gas. Also shown in Figure 7, the compression power for the nitrogen increases as the nitrogen content in the inlet gas increases above 35%. This is because the compression power is determined by the flow rate of nitrogen product, which increases as the nitrogen content in the inlet gas increases. For nitrogen contents less than 35% in the inlet gas, the shape of the nitrogen compression power curve depends on more competitive factors such as nitrogen content in the inlet gas, the hydrocarbon loss in the nitrogen stream, and the operating pressure of the low pressure column. The compression power required by the residue gas increases as the nitrogen content in the inlet gas decreases because of two associated factors, the hydrocarbon flow rate increases while the discharge pressure of the cryogenic pump decreases. The total compression power curve has a minimum somewhere between 35 - 55% nitrogen in the inlet gas.

Three column process (3COL process)

The compression power required by this process is illustrated in Figure 8. The total compression power is made up of two components, compression power for the residue gas and compression power for nitrogen. Since the advantage provided by the first column diminishes as the nitrogen content in the inlet gas increases, this process was examined over the range of 6 - 55% nitrogen in the inlet gas stream. In all cases hydrocarbon recovery is above 98%. According to Figure 8, the compression power for nitrogen increases as the nitrogen content in the inlet gas increases. This is a result of the nitrogen flow rate increasing directly with respect to increasing nitrogen content in the inlet gas. The compression power for the residue gas also increases as the nitrogen content in the inlet gas increases. The compression power curve for the residue gas is the result of three contradictory factors, decreasing flow rate, decreasing discharge pressure of the cryogenic pump and decreasing throttle pressure of the methane rich residue product. The compression power for the nitrogen stream becomes the predominant when the nitrogen content of the inlet gas is higher than 30%. The total compression power curve monotonically increases as the nitrogen content in the inlet gas increases.

Two column process (2COL process)

Compression power required by this process is illustrated in Figure 9. Again the total compression power is made up from the power required to compress the residue gas and the power to compress the nitrogen. The total and the component compression power curves (Figure 9) have the same shapes as in the 3COL process case. This resemblance is not surprising since the two processes are similar. For the 2COL process the compression hp increases significantly when the nitrogen content in the inlet gas is higher than 35%. As the nitrogen content in the inlet gas increases, the stream that feeds the liquid-vapour separator has to be cooled to a lower temperature in order to have the desired hydrocarbon recovery. To achieve this, the hydrocarbon stream from the bottom product of the first column has to be throttled to a lower pressure and also the discharge pressure of the cryogenic pump has to be decreased as the nitrogen content in the inlet gas increases. When the nitrogen content of the inlet gas is above 60%, the desired methane recovery of 98% cannot be achieved, even with the hydrocarbon stream resulting as bottom product from the first column being throttled close to atmospheric pressure. For this reason, C1 recovery is below 98% when the nitrogen content of the inlet gas is above 75%.

Heat exchanger area

A rough comparison of heat exchange areas required by the four processes examined in this study may be based on the total UA product required by each process. Figure 11 illustrates the total UA product by each process as a function of nitrogen content in the inlet gas. One can see that the 1COL process requires the greatest value of UA product for any nitrogen content in inlet gas in the range of 6 - 75%. The UA values of the 2COL and the 3COL processes are not significantly different for nitrogen content in inlet gas from 6 - 55%. Also, the UA values of the 2COL process and the DBLC process are not significantly different for nitrogen contents in inlet gas from 55 - 75%. The DBLC process requires the smallest UA values. However it should be noted that this process requires the highest values of compression power and it performs limited hydrocarbon recoveries when the nitrogen content in the inlet gas is below 35%.

Conclusion

By examining the total compression power curves for the four processes considered in this study, as illustrated in Figure 10, the following conclusions can be drawn. There is no significant difference between compression power required by the 2COL process and the 3COL process when nitrogen content in the inlet gas is below 35%. The 1COL process requires more compression power than the 2COL process or the 3COL process when nitrogen content of the inlet gas is less than 30%. This difference in the required compression power is significant for higher inlet gas flow rates. The 3COL process requires the lowest compression power to perform methane recovery at 98% when the nitrogen content in the inlet gas varies from 6 - 55%. The DBLC process requires the lowest compression power to perform methane recovery to at least 98% when the nitrogen content in the inlet gas is higher than 40%.

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