THERMODYNAMICALLY EFFICIENT DISTILLATION:
NGL FRACTIONATION

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Abstract

The problem of separating the liquid components which have been recovered from natural gas is discussed. Opportunities for improved efficiency using distributed distillation, recycle coupling, heat pumping, and partial effect distillation are presented. Emphasis is placed upon energy efficiency with potential savings in capital costs as applied to heat driven processes.

1. Introduction

Significant savings in utilities may be achieved by using heat integrated distillation in innovative configurations. On a percentage basis, capital savings are somewhat smaller than utility savings; but they are not negligible. The improvements are at the expense of increased complexity, and incur the risk of new technology. However, conventional equipment may be used, and only the configurations changed.

The innovative configurations may be generated by observing thermodynamic inefficiencies in conventional process designs. These are typically apparent in relationships between the primary process variables such as temperature, pressure, and composition. The relationships may be observed through conventional analysis such as McCabe - Thiele diagrams, composite heating and cooling curves, and temperature - composition plots.

Because of the multiple products produced by the fractionation of natural gas liquids and because of the large amount of energy required, NGL fractionation provides several opportunities for economical process improvements through improved thermodynamic efficiency.

2. Conventional NGL Fractionation

Table 1 shows the feeds and products normally encountered in the NGL fractionation process. The feed is a “raw mix” which is gathered from several upstream demethanizing gas plants and is transported via pipeline as a liquid under pressure. Some minor components, such as neopentane, sulphur compounds, and water, have been omitted; and the gasoline fraction characterization has been simplified to include only pentanes, normal hexane, and normal heptane. The battery limits conditions reflect pipeline or deep well storage requirements.

A conventional process ( for fractionating the feed is shown in figure 1. The deethanizer (DER) operates at about 450 psia and separates ethane from the propane and heavier components. Because the critical temperature of ethane is about 90°F, the condenser of the deethanizer must be refrigerated. The depropanizer (DPR) operates at about 250 psia and separates propane from the butanes and heavier components. The debutanizer (DBR) operates at about 70 psia and separates the butanes from the gasoline. The deisobutanizer (DIBR) operates at about 85 psia and separates isobutane from normal butane. This separation is positioned at the end of the process because isobutane and normal butane have similar boiling points and require a large number of stages and a high reflux ratio to separate.

A conventional NGL fractionation process requires about 73 MBtu/Bbl of hot utility to reboil the distillation columns.

3. Recycle Coupled Deethanizer and Depropanizer

Figure 2 shows a McCabe-Thiele diagram for the conventional depropanizer in figure 1. The column is well designed for the feed of about 48 mole percent propane and lighter components, and the diagram shows little opportunity for improvement. However, the temperature - composition diagram, shown in figure 3 for the conventional deethanizer in figure 1, shows that propane is “remixed” with the normal butane and heavier components near the bottom of the column at temperatures above about 190°F. The remixing occurs because butanes are

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Table 1  Specifications for NGL Fractionation

<table>
<thead>
<tr>
<th>Liq Vol %</th>
<th>Feed</th>
<th>Ethane</th>
<th>Propane</th>
<th>Isobutane</th>
<th>N-butane</th>
<th>Gasoline</th>
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<tr>
<td>Methane</td>
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<td>1.36</td>
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<td>2.00</td>
<td>95.00</td>
<td></td>
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<td></td>
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<tr>
<td>Butanes</td>
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<td>2.50</td>
<td></td>
<td>3.00</td>
<td></td>
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<tr>
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<td>33.13</td>
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<tr>
<td>Pentanes</td>
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<td>N-pentane</td>
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<td>Deg. F</td>
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<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Psig</td>
<td>600</td>
<td>1600</td>
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<td>1000</td>
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</tr>
</tbody>
</table>

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Figure 1  NGL FRACTIONATION

FIGURE 1  NGL FRACTIONATION

CONVENTIONAL PROCESS

[Diagram showing conventional process]
drawn up the column when propane is reboiled to drive off ethane. These butanes must then be refluxed down the column along with the propane.

This unnecessary mixing and separation may be avoided by using a “recycle coupled” deethanizer and depropanizer (Manley, 1996) as shown in figure 4. In the figure 4 process the deethanizer is reboiled by recycling a vapor sidedraw from the downstream depropanizer. The “remixing” occurring in the conventional process is then shifted into the depropanizer where it properly belongs. In order to avoid compression of the recycled vapor it is necessary to lower the pressure of the deethanizer to slightly below the depropanizer pressure of about 250 psia. Figure 5 shows the temperature - composition profile for the low pressure, recycle coupled deethanizer which eliminates the “remixing” shown in figure 3. Because of the lower pressure, the temperatures in figure 5 are somewhat lower than those in figure 3.

Figure 6 gives a McCabe - Thiele diagram for the recycle coupled depropanizer in the figure 4 process with a feed considerably richer in propane in comparison with the conventional process shown in figure 2. As a result the reflux ratio for the recycle coupled depropanizer is significantly reduced with commensurate
savings in reboiler hot utility. The savings are a direct consequence of the improved thermodynamic efficiency due to the elimination of remixing in the deethanizer and do not depend upon its pressure.

4. Deethanizer Side Stripper

As shown in figure 5, propane is also separated from the butanes in the rectification section of the deethanizer between about 75°F and 50°F. However, the propane is then refluxed back down the column into the butanes so that it may be produced in the bottoms product. The propane and butanes must then be "reseparated" in the downstream depropanizer - whether or not it's recycle coupled with the deethanizer.

Figure 7 shows how a deethanizer side stripper (DESS) may be used to eliminate unnecessary remixing of propane with butanes in the deethanizer rectification section. In the figure 7 process sufficient propane is refluxed past the side stripper feed tray and down the deethanizer to remove butanes from the side stripper feed, so that the side stripper bottoms meets propane product specifications. The remaining propane with dissolved ethane is fed to the side stripper so that the ethane may be removed. Since the side stripper bottoms meets propane product specifications and is at essentially the same pressure as the depropanizer, the side stripper may be reboiled using a propane vapor product from the depropanizer overhead. This eliminates the need for a separate side stripper reboiler, saves energy, and reduces the size of the depropanizer condenser. At least 25% of the propane in the feed may be recovered through the deethanizer side stripper without passing through the depropanizer.

A deethanizer side stripper may be used with or without a recycle coupled depropanizer, but the most thermodynamically efficient configuration is to use both simultaneously.

5. Thermomechanically Integrated Deethanizer

In order to be recycle coupled with the depropanizer, the deethanizer in the figure 7 process must be operated at the depropanizer pressure of about 250 psia. As may be seen by a comparison of figures 3 and 5, the deethanizer condenser temperature of about 15°F in the recycle coupled process is considerably lower than the condenser temperature of about 55°F in the conventional process. This lower condenser temperature requires lower temperature refrigeration and will incur precipitation of hydrates if the process gases are not sufficiently dried.

Figure 8 shows how the deethanizer condenser refrigeration system may be replaced with a thermomechanically integrated process which also keeps the process temperatures high enough to preclude formation of hydrates. In the figure 8 process, the overhead vapors from the "butanes rejection" portion of the deethanizer and
the overhead vapors from the deethanizer side stripper are combined and compressed in two stages before feeding a high pressure deethanizer rectification section. The liquid refluxed from the high pressure rectification section is then flashed and partially vaporized to provide refrigeration for the overhead condenser. The partially vaporized reflux is then separated, the vapor recompressed, and the liquid used as reflux for the deethanizer and side stripper. The recompressed vapor is partially condensed with cooling water to reject the heat absorbed in the condenser and is fed to the bottom of the high pressure rectification sections. In addition to keeping the process temperatures above about 50°F, the thermodynamically integrated refrigeration process in figure 8 is highly efficient and requires minimal power to operate in comparison with a conventional refrigeration process.

In addition to being more thermodynamically efficient when combined with recycle coupling, side stripper, and thermomechanical integration; a low pressure deethanizer has the additional cost advantage of being smaller in diameter and wall thickness in comparison with a conventional, high pressure deethanizer.

6. Depropanizer Side Stripper

Considering the temperature - composition diagram for a conventional depropanizer shown in figure 9, it is apparent that the same strategies used in the deethanizer improvements may be applicable. Above about 230°F butanes and gasoline are remixed as pentanes are reboiled up the column along with the propane and butanes. These pentanes must then be refluxed back down the column. And between about 155°F and 175°F butanes are remixed with pentanes as they’re rejected from the propane product in the condenser.

Recycle coupling with the downstream debutanizer in figure 1 would eliminate the remixing in the depropanizer stripping section. However, the debutanizer pressure would have to be raised to about 250 psia, or the depropanizer pressure would have to be lowered to about 70 psia, or a compressor would have to be used to compress the recycle vapors from the debutanizer to the depropanizer. None of these alternatives is economically viable so this possibility is not recommended. A high pressure debutanizer would be too expensive and would require a much higher temperature hot utility, a low pressure depropanizer would require refrigeration and couldn’t be recycle coupled with the deethanizer, and an additional compressor would be too expensive to purchase and operate.

A depropanizer side stripper (DPSS) to recover gasoline free butanes from the depropanizer rectifying section is sometimes worthwhile and is shown in figure 10. The side stripper bottoms product contains isobutane and normal butane, and their composition is somewhat enriched in isobutane in comparison with the depropanizer bottoms product. Consequently, it is advantageously fed to a different location in the downstream deisobutanizer from the feed location of the debutanizer overhead, and the deisobutanizer reflux ratio is reduced in comparison with a conventional unit.

The depropanizer side stripper therefore improves the process thermodynamic efficiency in two ways. Since at least 25% of the butanes bypass the debutanizer, its size and duties are considerably smaller. And, because the butanes are partially separated in the side stripped depropanizer, the deisobutanizer size and duties are reduced. However, the side stripped depropanizer requires a few more stages to efficiently reject gasoline from the side stripper; and, of course, the side stripper itself adds complexity to the process. As the capacity of the overall process increases, the economic benefit of the added efficiency becomes more significant in spite of the increased complexity.

7. Normal Butane Distributor

The temperature - composition diagram for a conventional debutanizer, shown in figure 11, shows that isobutane and normal butane are “remixed” in both the stripping section between about 150°F and 205°F and in the rectifying section between about 110°F and 100°F. This is thermodynamically inefficient since these two components must be separated in the downstream deisobutanizer as
The process may be improved by using a recycle coupled normal butane distributor (NBD) column to separate isobutane from gasoline while distributing the normal butane between the overhead and bottoms products as shown in figure 12. The process in figure 12 is the well documented Petlyuk configuration (Petlyuk et. al., 1965) except that a reboiler is used on the deisobutanizer column to improve heat integration. The thermodynamic efficiency is improved in comparison with a conventional debutanizer and deisobutanizer by eliminating remixing of isobutane and normal butane in the debutanizer and by allowing the debutanizer to directly provide at least part of the reboil vapor required to drive the deisobutanizer.

Figure 13 shows how a partitioned column may be used simplify the mechanical design for the Petlyuk configuration (Lestak and Collins, 1997) when the deisobutanizer reboiler is not used and all the hot utility is used in the debutanizer reboiler. A large column is vertically partitioned into three sections corresponding to the normal butane distributor, debutanizer, and deisobutanizer in figure 12. This mechanical combination reduces installation costs significantly since fewer pieces of equipment are required.

8. Partial Effect Deisobutanizer

The debutanizer in the figure 12 process operates closer to minimum reflux and thus requires more stages than the debutanizing portion of the figure 13 process. This allows some of the reboiler energy to be moved to the much lower temperature deisobutanizer reboiler and reduces overall process energy consumption. However, the additional stages make it difficult to accommodate in a single partitioned column with a uniform diameter. In other words, because of the relatively high reflux ratio in the deisobutanizer, its diameter is much larger than the debutanizer designed for the most economical approach to minimum reflux. A partial effect deisobutanizer system, as shown in figure 14, provides one solution to this problem.

In the figure 14 process the overhead product from the partial effect deisobutanizer (PEDIBR) is only partially enriched in...
isobutane. Consequently, the number of stages and reflux ratio in the partial effect deisobutanizer are considerably less than in a conventional deisobutanizer, and the partial effect deisobutanizer may be optimally reboiled using a vapor overhead stream from the debutanizer. This makes the process ideally suited for the partitioned column configuration of figure 13. However, the partial effect deisobutanizer overhead must be further fractionated in an additional downstream deisobutanizer (LPDIBR). If the downstream deisobutanizer is operated at a lower pressure than the partial effect deisobutanizer, then the reboiler of the low pressure deisobutanizer may be driven with heat from the condenser of the partial effect deisobutanizer. The energy from the debutanizer reboiler is then used three times as it cascades through the debutanizer, partial effect deisobutanizer, and low pressure deisobutanizer, and the overall process is very efficient thermodynamically. And, because the normal butane distributor column eliminates the remixing occurring in the conventional debutanizer, the efficiency is enhanced even more.

9. Economically Optimal Process

The thermodynamic improvements discussed above and innovative mechanical designs incorporating partitioned columns may be combined as shown in figure 15 to produce an overall configuration which minimizes both capital and operating costs. In the figure 15 process the low pressure deethanizer (DER) is partitioned to include the deethanizer side stripper (DESS) within the column shell, and the high pressure thermomechanically integrated rectification section (TMIR) of the deethanizer is stacked vertically on top of the low pressure section. The refrigeration compressor is thermomechanically integrated with the dual pressure column to avoid using separate compressors and to improve energy efficiency. An interreboiler is shown on the deethanizer stripping section to recover low level heat from the hot normal butane and gasoline products.

The deethanizer and deethanizer side stripper in figure 15 are recycle coupled with the downstream depopropanizer (DPR) which is also partitioned to include the depopropanizer side stripper (DPSS) within the column shell. An interreboiler is shown on the depopropanizer stripping section to recover intermediate level heat from the hot gasoline product.

The depropanizer bottoms feeds a lower pressure normal butane distributor (NBD) section which is mechanically integrated with the debutanizer (DBR) and partial effect deisobutanizer (PEDIBR) in a vertically partitioned column. This column operates at a sufficiently high pressure so that heat from its condenser may be used to reboil the downstream low pressure deisobutanizer (LPDIBR) column.

The low pressure deisobutanizer is fed by butanes mixtures from the depopropanizer side stripper bottom and partial effect deisobutanizer overhead. The low pressure deisobutanizer operates at a pressure such that cooling water may be used in its condenser.

10. Summary

Table 2 compares several size parameters for the conventional NGL fractionation process shown in figure 1 and the optimum NGL fractionation process shown in figure 15. Because of the improved thermodynamic efficiency, the hot utility consumed in the reboilers is reduced by 66%. Not shown, but commensurate with this by energy balance, is a corresponding reduction in cooling water consumption. Some additional power is required for the distributed process because of the low pressure deethanizer. However, the cost associated with this is largely mitigated by a large reduction in the wall thickness and consequent cost of the low pressure deethanizer. Because remixing and reseparation are largely omitted in the distributed process, total heat exchange is reduced by 41% with a corresponding reduction in capital costs. The column volume increases slightly; but, because of the mechanical partitioning, the number of columns remains the same.

A more detailed comparison of the capital and operating costs for the conventional and distributed NGL fractionation processes is not available, but a moderate reduction in capital cost and a large reduction in operating cost are typical for processes incorporating the improvements in thermodynamic efficiency proposed.

References