The development of shale oil and associated gas has changed the market landscape for lighter hydrocarbons, especially ethane. Suppliers have an increasing need to liquefy ethane, ethane/propane mixtures or even ethylene for shipment. Furthermore, the product slate may change over time or even be cyclic. This article presents a new equipment arrangement and liquefaction process that accommodates this emerging need.

For over 50 years, natural gas has been liquefied for ease of transport in plants that have been designed and optimised for that single product. The main goal of this work was to develop a process and equipment arrangement that can flexibly process different feed compositions to handle changing market needs and feed availability. For example, a facility may need to temporarily or permanently alter its product slate from liquefying ethylene to ethane or to liquefy both simultaneously.

The challenge is that different products have different thermodynamic properties. Overcooling a product beyond what is required for storage adds power cost or risks collapsing the storage tank. Alternatively, if the product
enters the storage tank too warm, vapour will flash in the tank, leading to excessive product loss or the need for additional equipment for compression and re-liquefaction. To liquefy multiple feed streams with different properties and store them in low-pressure storage tanks, with minimum or no flash, requires the product streams to leave the main cryogenic heat exchanger (MCHE) at different temperatures. This is a challenging process and equipment design problem, particularly when combined with the ever-changing product mix.

There are two options for overcoming these challenges. A product slate of pure ethane and ethylene will be used to illustrate the option features. One option to resolve this problem would be by controlling the temperature at the exit of the MCHE so that the heavier component (ethane) is cooled enough such that there is no tank flash and the ethane is not subcooled entering the storage tank. In this ideal example, 10% of the ethylene would flash off in the tank or intermediate vessel and need to be compressed for recycle to the warm end of the exchanger. This is depicted as the green line in Figure 1a.

The other option is to subcool the heavier stream to the temperature needed for the lighter product (ethylene). To avoid sending subcooled ethane to the storage tank, warm ethane is by-passed from the warm end of the MCHE to the cold end. For this example, 4.5% of the warm ethane feed would bypass the MCHE and blend in with cold product to get the desired ethane storage temperature. This is depicted as the red line in Figure 1b. To avoid over-pressurising the storage tank, the flash occurs in a separate vessel and at pressures slightly higher than the tank pressure.

One advantage of recycling end flash gas is that a warmer refrigeration is needed, which increases the efficiency of the liquefaction. One disadvantage is that it requires a recycle compressor. However, if the plant requires that fuel be generated from the process then this compressor can be staged with the fuel gas compressor. Also, for larger production facilities, the refrigeration from the flash gas can be recovered in an exchanger against warm feed (as seen in many LNG plants), further increasing efficiency. In addition, if the product purity needs to be adjusted, such as removing methane from the ethane, an end flash process can facilitate the composition adjustment. This is analogous to removing N₂ from LNG in natural gas liquefaction.

The advantage of bypassing the heavier products is that recycle compressors are not needed. The tradeoff of eliminating the recycle compressor for increased power consumption to cool the MCHE to colder temperatures might be advantageous for smaller facilities.

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Figure 1. A) a sketch showing feed bypass (green) and B) end flash gas recycle (red).

Table 1. Product slates for complex example

<table>
<thead>
<tr>
<th>Name</th>
<th>Ethane</th>
<th>Ethane/propane 81/19</th>
<th>Ethylene</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 (original design)</td>
<td>2.25 million tpy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode 2 (rating MCHE)</td>
<td>1.25 million tpy</td>
<td>&lt;0.625 million tpy</td>
<td>0.625 million tpy</td>
<td></td>
</tr>
<tr>
<td>Mode 3 (rating MCHE)</td>
<td></td>
<td></td>
<td></td>
<td>≥0.4 million tpy</td>
</tr>
</tbody>
</table>
Example of a multiple product and product slate system

A system employing a coil wound cryogenic exchanger is depicted in Figures 2 – 4. The same exchanger can be used for many product slates, given in Table 1. In this example, the MCHE has three warm circuits (A, B and C) to accommodate the various product. Circuit A is the largest circuit with 50% of the tubes while circuits B and C each have 25% of the tubes. For some product slates, a feed may be cooled in multiple circuits. For this example, three product slates are examined. All slates are accomplished with the same coil wound heat exchanger (CWHE).

Mode 1: producing liquid ethane

The MCHE was designed based on the mode 1 product slate and all other product slates used the same exchanger design. Since there is only one product, all three circuits were used for the ethane liquefaction. The feed and product compositions are given in Table 2. The feed has over 4% methane and the customer wanted to reduce the methane to below 1.5%. The product exits the MCHE at a temperature of -87°C and is let down in pressure to 1.25 bara to flash off methane. The liquid from the flash tank is then sent to the storage tank where there was some additional flash as the product is further let down in pressure to 1.05 bar. The vapour from the storage tank was low enough in methane that it could be recycled to the front end. The flash gas from the first flash could not be recycled because of the large methane concentration in the gas, but could be used as fuel or returned to the pipeline. The circuit arrangement is given in Figure 2 and the (MR) composition is given in Table 3.

Mode 2: three products: liquid ethylene, liquid ethane and liquid ethane/propane mixture

Three different feeds are liquefied in this example. The largest feed is ethane, which was liquefied in circuit A. Ethylene is liquefied in circuit B and a mixture of 81% ethane and 19% propane is liquefied in circuit C. Ethylene is the lightest component and there is no need to create end flash to adjust its composition, therefore the streams exited the MCHE at a temperature (-108°C) that allows for the ethylene to be at bubble point as it enters the storage tank. Both the ethane and ethane/propane mixture need to be flashed to remove methane. This flash occurs after the bypass addition. For these feed compositions, only one flash stage was needed to remove the methane. If additional stages are needed, the back end can be modified to achieve higher levels of separation.

The CWHE feed circuit configuration is shown in Figure 3, the feed inlet and product outlet compositions are given in Table 4 and the MR composition is given in Table 3. The ethane circuit was configured as in mode 1. The mixture of ethane/propane also had an intermediate flash at 1.25 bara to remove methane. For this product, the additional flash as the product was further let down to the tank pressure of 1.05 bar is not recycled in this example.

Figure 3. MCHE operation for mode 2, three separate products.

Figure 4. MCHE operation for mode 3, LNG production.
Mode 3: producing LNG

Finally, the use of this exchanger for making LNG from a natural gas feed was investigated. For this example, there is no need for light component (such as nitrogen) removal from the LNG so all the end flash gas can be recycled. To increase the LNG production, the refrigeration in the end flash gas was recovered in the end flash exchanger before it was recycled. This is a common practice in operating LNG facilities. In this operating mode, the circuits, A, B and C in the MCHE were used for the natural gas feed. The configuration is shown in Figure 4.

The feed and product flows are given in Table 5 and the MR composition is given in Table 3.

MR composition

In each of the products, the MR composition is optimised for efficiency and desired outlet temperature. A comparison of the resulting compositions is given in Table 3. For modes 1 and 2, propane was not used in the composition optimisation as a customer request. Often, propane is not required for efficiency if ethane and both butane and iso-butane are used.

In mode 1, the temperature of the ethane product out of the MCHE was determined by the requirement to remove methane from the product. In mode 2 it was determined by the requirement to have saturated ethylene entering the storage tank. For mode 3, the outlet temperature was an optimisation to maximise the LNG production within the constraints of the MCHE and power available.

Coil wound exchangers for multiple product systems

In the foregoing examples, the MCHE used is a two-bundle CWHE. CWHE’s are uniquely suited for multiple products and changing product slates. They are well proven in the LNG industry for their safety, reliability, and small footprint. Also, it has been demonstrated that they can operate stably over a wide range of productions including deep turndown. For one floating LNG (FLNG) plant currently in operation, the CWHE simultaneously produces both LNG and liquid nitrogen. This is a simple application of the multiple product approach.

As shown in the presented example, the circuits can be multipurposed to accommodate a wide range of compositions and feeds as market needs change. The composition of the MR can be optimised for any product slate. Also, because the boiling refrigerant flows in the downward direction, the operation of a CWHE is inherently stable at low production rates. The modified SMR cycle using CWHEs can accommodate a variety of products and production rates and are suitable for this unique application.

For more information, please contact Air Products at +1-610-481-4861 or email us at info@airproducts.com