Benefits of improved expander performance for cryogenic air separation units

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Commissioning of an Air Products compander pair at a plant in Chandler, Arizona

Abstract

A cryogenic air separation unit requires refrigeration to compensate for heat ingress to the cold equipment as well as for the difference in heat content among the feed air, the effluent gas, and the liquid products. A turbo expander is used to expand air or nitrogen from a higher pressure to a lower pressure to produce refrigeration for the process. Various expander configurations are possible. The best choice depends on the quantity and pressure of the high-pressure gaseous products and whether or not liquid co-production is required. In general, higher expander flow increases the energy consumption required to produce a given set of products. The efficiency of the turbo expander directly affects the flow required to produce the required refrigeration.

By improving the efficiency of the expander, an operating plant can achieve either a reduction in total energy cost to produce the same amount of product or increase the amount of product produced for the same energy cost. A case study was undertaken to quantify the benefits of improving expander efficiency for three different air separation cycles.

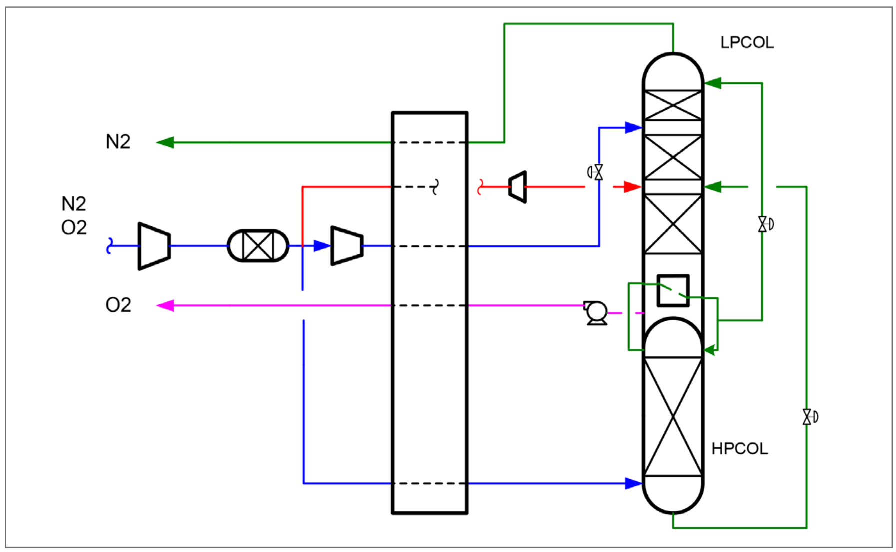
Case 1:

Pumped liquid oxygen cycle – expand air to low pressure column

For a typical air separation unit (ASU) designed to produce mainly gaseous products at low to moderate pressure, a portion of the feed air was expanded into the low pressure column. **Figure 1** below shows the process flow diagram (PFD) for such an ASU. The PFD shows an ASU that produces oxygen using the pumped liquid oxygen (LOX) or internal compression cycle, but the discussion applies equally to ASUs that produce oxygen as a gas directly from the low pressure column. The expander flow bypassed the high pressure column and reduced both the boil up and reflux to the low pressure column, which made the separation more difficult. A higher expander flow negatively affected the plant oxygen recovery **(See Figure 2 below)**.

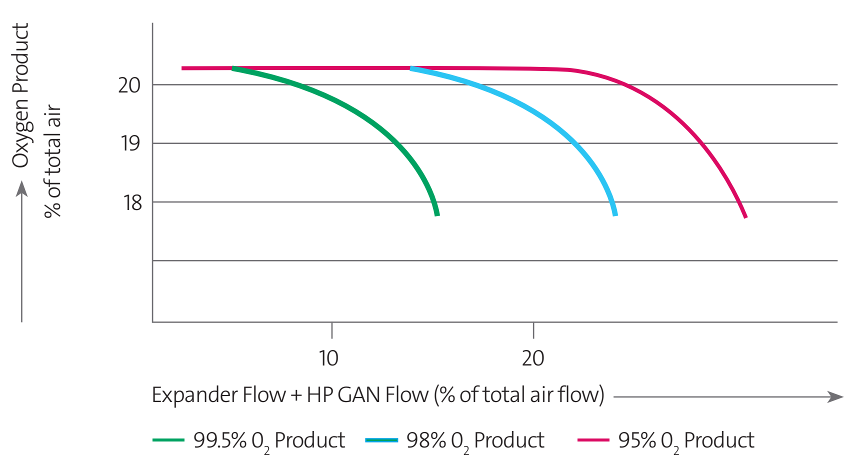
If co-product nitrogen was produced directly from the high pressure column, the boil up and reflux available was similarly reduced, which made minimizing the expander flow even more important to achieving the best plant efficiency.

Figure 1: Process Flow Diagram for Case 1



Pumped-Lox: Expand Air to LPC

Figure 2: Effect of Expander Flow on O_2 Recovery



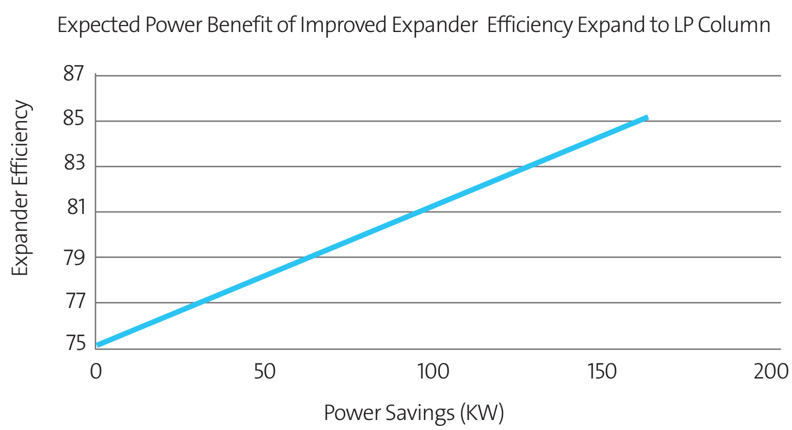
The purity of the oxygen being produced as well as expander flow affect the oxygen recovery. When only 95% pure oxygen is to be produced, there is not much benefit to be gained from operating with an expander flow of less than 20% of the feed air. The "free" refrigeration available is much less, however, when producing 99.5% pure oxygen **(See Figure 2)**. There is often value in producing liquid oxygen or nitrogen in addition to gaseous products, to realize a benefit of improved expander efficiency by producing more liquid products at the same overall energy consumption. A case study was undertaken to quantify power savings from improved expander efficiency for an oxygen plant producing 8200 NM^3/hr (281 MT/D) of gaseous oxygen at 95% purity and 3.5 bar gauge pressure. Co-product liquid oxygen was also produced at a rate of 500 NM^3/hr (17 MT/D). The results are shown below in **Figure 3**. A base case expander efficiency of 75% was used for the study.

In evaluating the capital expenditure necessary to achieve an expected power savings, both the cost of power and the expected life of the equipment should be considered. Using $0.12/KWH and a 3 year straight payback can justify an investment of about $3000 per KW saved.

The benefit shown in **Figure 3** was for a plant producing about 300 MT/D of total oxygen. The expected benefit for a larger or smaller plant may be estimated by scaling with total oxygen production.

Air Products compander installed at a plant in Chandler, Arizona

Figure 3: Calculated Power Savings for Case 1



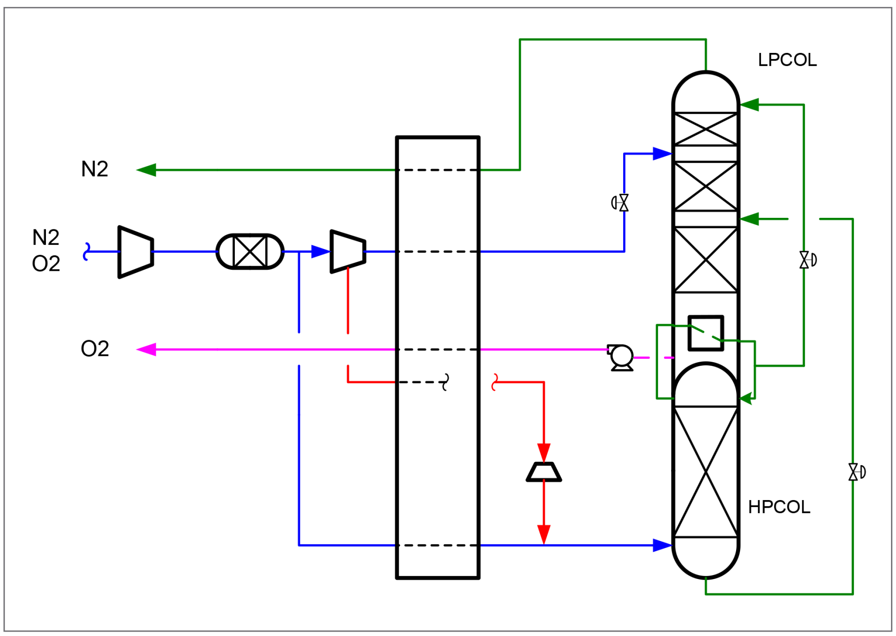
Case 2:

Pumped liquid oxygen cycle – expand air to high pressure column

Some ASUs are designed to produce large quantities of liquid products. If the refrigeration requirements are large, it is not economical to expand a portion of the feed air to the low pressure column. To produce high pressure gaseous oxygen or nitrogen directly from the cold box, a booster air compressor (BAC) is used to compress a portion of the feed air to a pressure higher than that of the high pressure column. This higher pressure air can efficiently vaporize oxygen that has been pumped to the required pressure. A portion of the high pressure air can also be expanded into the high pressure column.

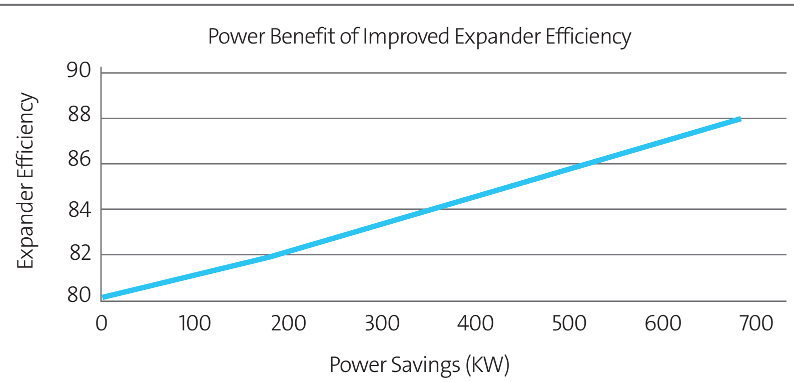
In this case the oxygen recovery was nearly independent of the expander flow, but the BAC power was reduced if the expander flow was reduced. **Figure 4** shows a PFD for an ASU designed to produce high pressure gaseous products via internal compression. A large quantity of co-product liquid can be produced by appropriately sizing the BAC and expander. The best choice for the expander inlet pressure depends on the total refrigeration requirement as well as the best machinery fit. The expander flow may be taken from between BAC stages, or downstream of the BAC. The power savings that resulted from improved expander efficiency for Case 2 are shown in **Figure 5** below. The second case study was based upon an oxygen plant producing 60,000 NM³/hr (2060 MT/D) of gaseous oxygen at 40 bar gauge pressure at 99.5% purity, along with 2000 NM³/hr each of liquid oxygen and liquid nitrogen. For this larger plant, a base case expander efficiency of 80% was used.

Figure 4: Process Flow Diagram for Case 2



Pumped-Lox: Expand Air to HPC

Figure 5: Calculated Power Savings for Case 2



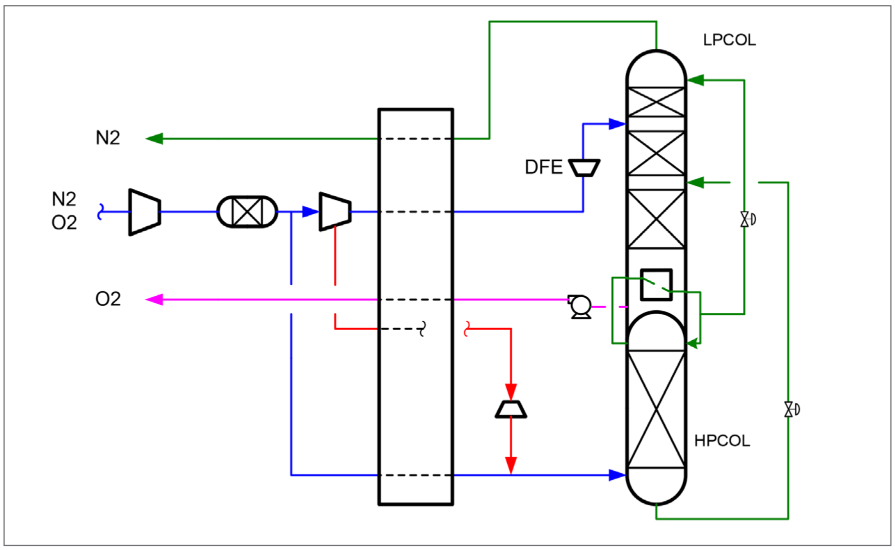
Case 3:

Expand air to high pressure column and install dense fluid expander

The BAC power becomes a significant fraction of the total plant energy consumption for large plants producing high pressure oxygen and/or a large quantity of liquid oxygen. Plants designed to produce a large quantity of liquid are even more energy intensive. (Improving the expander efficiency from 84% to 90% for a typical dual expander nitrogen recycle can save approximately 5% of the plant's total power usage.) If the flow of condensed air let down from BAC discharge pressure is large, it may be economical to replace the let down valve with a dense fluid expander (DFE). This device is similar to a pump running backwards producing electric power. Because less refrigeration is needed to cool the high pressure air going to the DFE, the BAC power saving is approximately 4 times the power recovered by the DFE. For the 60,000 NM³/hr plant studied, adding a DFE saves an additional 900 KW. A DFE may clearly be a good investment for a plant with a large high pressure BAC.

As an alternative to a power recovery DFE, a dissipative DFE can be utilized. Rather than recovering power via a generator, a dissipative DFE shears oil to dissipate the power as heat. The dissipative DFE can provide the same BAC power savings as a power recovery DFE, but does not provide the additional benefit of power recovery. The capital cost of a dissipative DFE is often lower than a power recovery DFE, making it a potentially attractive choice for lower power applications.

Figure 6: Process Flow Diagram for Case 3



Pumped-Lox: Expand Air to HPC, with DFE

Conclusion

The state of the art turbo expander has changed significantly over the last 40 years. Utilizing advanced modeling tools such as computation fluid dynamics and finite element analysis coupled with the latest manufacturing processes, efficiencies for older expanders can be significantly improved. An improvement of up to 6% efficiency can be expected for newer designs when compared to designs from the 1990's. Additionally, these advanced modeling and manufacturing techniques allow newer expander designs to maintain high efficiencies over a wider range of process conditions compared to older designs.

Significant energy savings are possible by improving the efficiency of the expander in older air separation units. Large plants that produce high pressure oxygen via internal compression and/or a significant quantity of liquid can experience the highest benefit. Plants currently operating with low expander flow and high oxygen recovery may be missing an opportunity to produce a valuable co-product. When co-production is properly valued, even smaller plants could benefit from improved expander efficiency. A cryogenic plant assessment should be completed in order to fully understand the benefits of improving expander efficiency for each unique plant design.

Author:

Mr. Bruce Dawson has over 38 years of experience with Air Products, and has held positions of increasing responsibility in Process Engineering and Advanced Process Control. He has designed numerous air separation plants ranging in size from 10 to 3000 MT/D. He has many years experience in cryogenic plant startup, operation and optimization.

Air Products compander installed at a plant in Miami, Arizona

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