LNG FRACTIONATION PROCESS AND OPTIMIZATION OF THE TURBOEXPANDER UNIT

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ABSTRACT

An extensive infrastructure is currently being developed to receive LNG from production sources throughout the world. Many of these new terminals will be built in industrialized nations where the lighter hydrocarbons (ethane and propane) can be utilized as feedstock for chemicals production and fuel usage. This provides a strong incentive for recovering these components from the LNG prior to, or as a part of, vaporization. This also provides the added benefit of reducing the heating value of the vaporized gas stream, which may be required prior to injecting into the gas transmission pipeline.

Ortloff has developed the LNG Fractionation Process (LFP) for efficient fractionation of the LNG stream to recover an NGL and/or LPG product. This is a turboexpander based process which offers the significant advantage of recovering the desired components and returning the predominately methane residual stream to the vaporizers in liquid form using only pumping power instead of external compression. This provides considerable energy savings. The process is required to be very flexible to accommodate a wide variety of LNG feed stocks. This paper focuses on the equipment sizing strategies used to provide optimum recovery over this wide range. Specifically, the turboexpander design will be highlighted, with the optimization aided by a specialized turboexpander module for Aspen HYSYS®.

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INTRODUCTION

With the dramatic increase in LNG production and shipping worldwide, increased attention is being focused on the processing of these products on the receiving end. In industrialized locations it is desirable to extract the lighter hydrocarbons, to recover a valuable saleable product and also control the heating value of the pipeline gas.

With Ortloff's LNG Fractionation Process (LFP) product recovery is accomplished using only pumping power with no external compression [1]. This provides considerable energy savings over competing processes. The process is very flexible and has the ability to accommodate a wide variety of LNG feed stocks. With this process, a plant can be designed for either NGL or LPG recovery or both. In either case, the process is capable of very efficient ethane recovery as well as full ethane rejection. This process has been applied to a plant designed and currently being constructed in the U.S. One of the key components within the process is the use of a expander-compressor unit for power recovery within the process.

In this application, high pressure pumps provide LNG at the plant inlet at a fixed pressure. Vaporization of the LNG is accomplished using a mixture of submerged combustion vaporizers (SCVs) and / or air vaporization units. The heating medium for the NGL recovery section of the plant is provided from the closed loop air vaporization system (tempered for cold weather operation) that is integrated into the final vaporization step. Heating medium flow is automatically directed to the NGL recovery section or the final vaporization step depending on the mode of operation. The heating medium for column reboiling is provided from a heated glycol/water loop. A block diagram of the overall process with a summary of the process performance is shown in Figure 1 below.

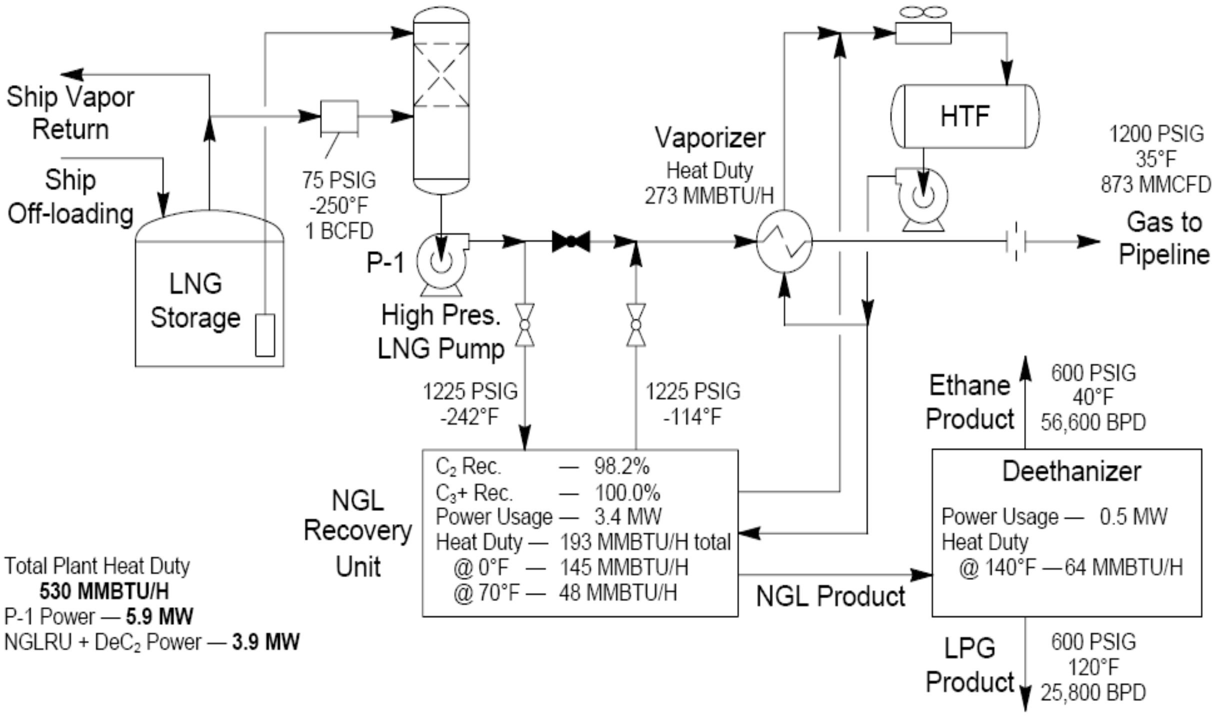


Figure 1: NGL Recovery

This design produces a C2+ stream (NGL recovery) that is then fractionated into a purity ethane stream and a C3+ stream (Figure 1). The Demethanizer column bottom temperature is controlled to provide a typical C1:C2 NGL product specification, while the Deethanizer column bottom temperature is controlled to provide a typical C2:C3 LPG product specification. The LFP plant is operated the same whether in ethane recovery or ethane rejection mode. In ethane rejection mode, all or a portion of the ethane is re-injected back into the lean LNG stream before being vaporized and sent to the pipeline. This allows the plant operator to easily fix the heating value of the vaporized residue gas to provide pipeline-quality gas at the most economical conditions. There is little additional operating cost for continuous operation of the Deethanizer column since all of its overhead cooling and condensing is provided by the inlet LNG and no external refrigeration power is required.

This plant is designed for ultra-high ethane recovery (98%). As discussed above, the actual ethane recovery is variable from approximately 2% (the amount allowed in the LPG product) to the maximum 98%. For an inlet LNG rate of 1 BCFD (gas equivalent), the power required within the NGL recovery unit and Deethanizer is 3.9 MW for pumping the lean LNG to the vaporizers for final vaporization. There is no external compression used in the process. By comparison, the power requirement for residue gas recompression in a conventional gas plant processing the vaporized LNG would be approximately 46.6 MW, illustrating the much greater efficiency of LNG fractionation relative to refrigerating natural gas to recover the liquids.

As previously discussed, one of the key components of the LFP plant is design and operation of the expander-compressor unit. This unit provides all of the compression power within the process to allow for total condensing and pumping of the final LNG product. Design of this unit is critical to the overall efficiency of the plant and allows for operation over a wide range of operating conditions and inlet LNG compositions.

TURBOEXPANDER DESIGN

A turboexpander-compressor is used in this process to provide the necessary driving force for complete condensation and sub-cooling of the residue gas product to allow for pumping of the residue stream to pipeline pressure instead of external compression. The turboexpander produces refrigeration efficiently by removing energy directly from the gas. This is accomplished by accelerating the gas through inlet nozzles, using pressure drop to develop angular velocity. This angular momentum is removed as the gas passes through the turbine blades[2]. The angular momentum removed is translated directly into torque in the expander shaft, which is used to drive the centrifugal compressor.

The radial inflow, variable nozzle arrangement allows the turboexpander to operate efficiently across a wide range of conditions. As the process changes, the turboexpander speed changes, tending to float with the plant duty. In the LFP process, the operating pressures do not change dramatically across the different operating cases. Since the expander flow remains balanced with compressor flow, the unit will tend to run near the optimum efficiency.

The variable speed of a turboexpander also provides a challenge for the process engineer who must estimate performance. It is common practice to model an expander-compressor by simply equating the power produced by the expander with the power absorbed by the compressor, as shown in Figure 3.

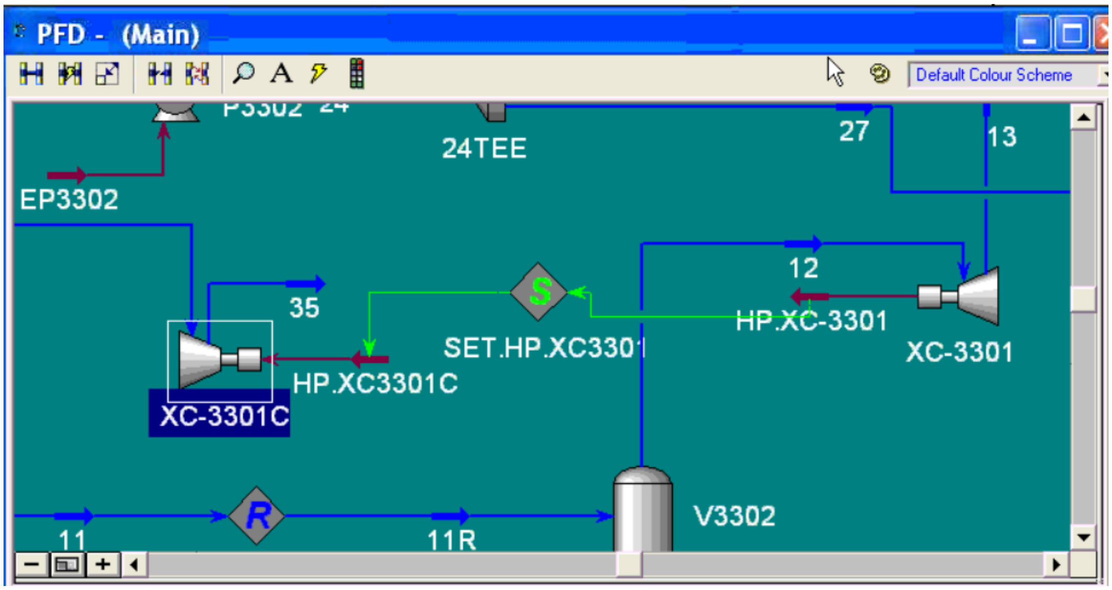


Figure 3: Typical Expander-Compressor Simulation

However, in actual operation, the expander-compressor speed and bearing losses are integral to the power balance. Without considering turboexpander speed in the model, the process engineer must simulate the plant based on approximate, and possibly erroneous efficiency values. The general relationship between process variables, operating speed, and expander-compressor efficiency is shown in Figure 4.

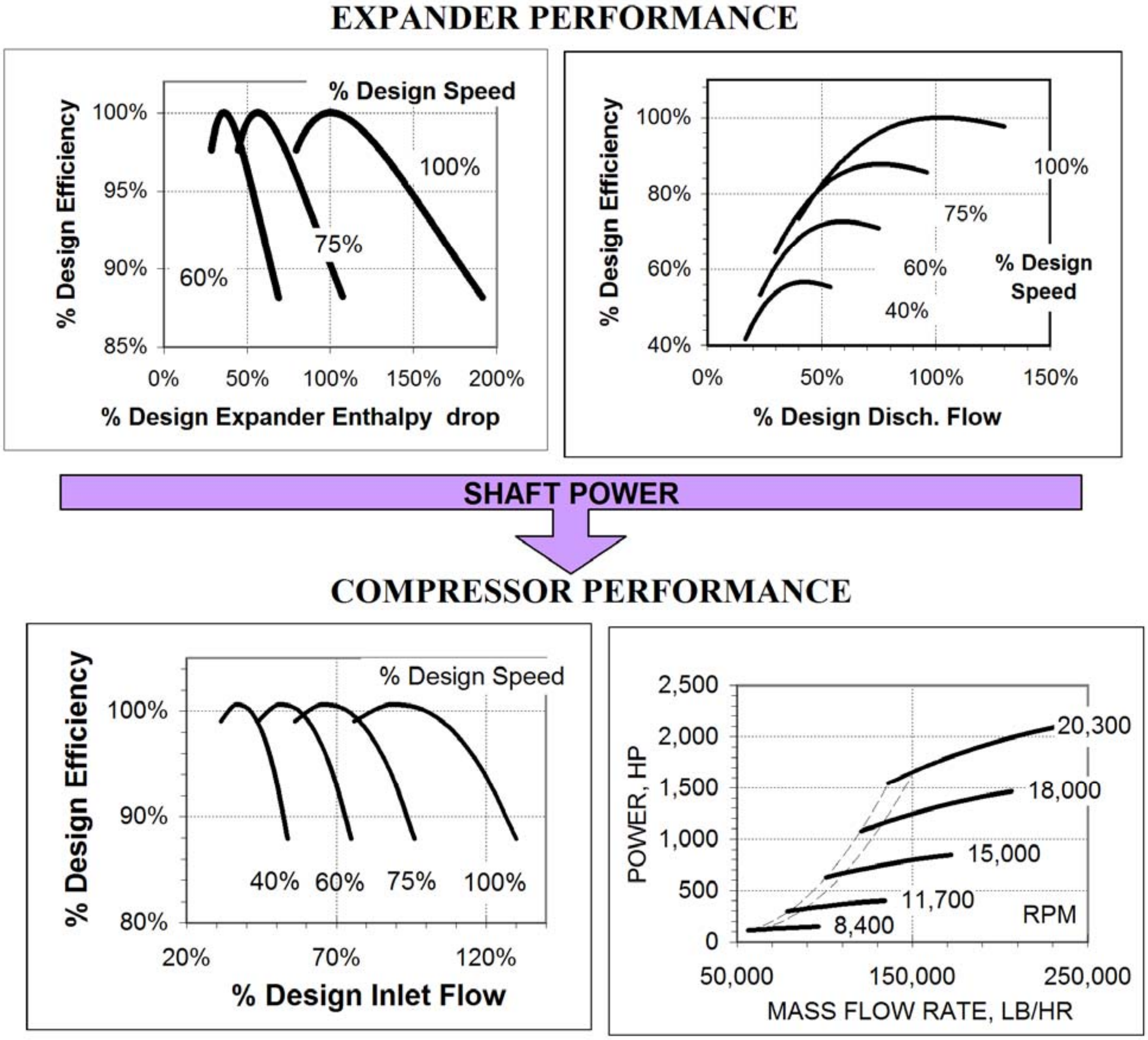
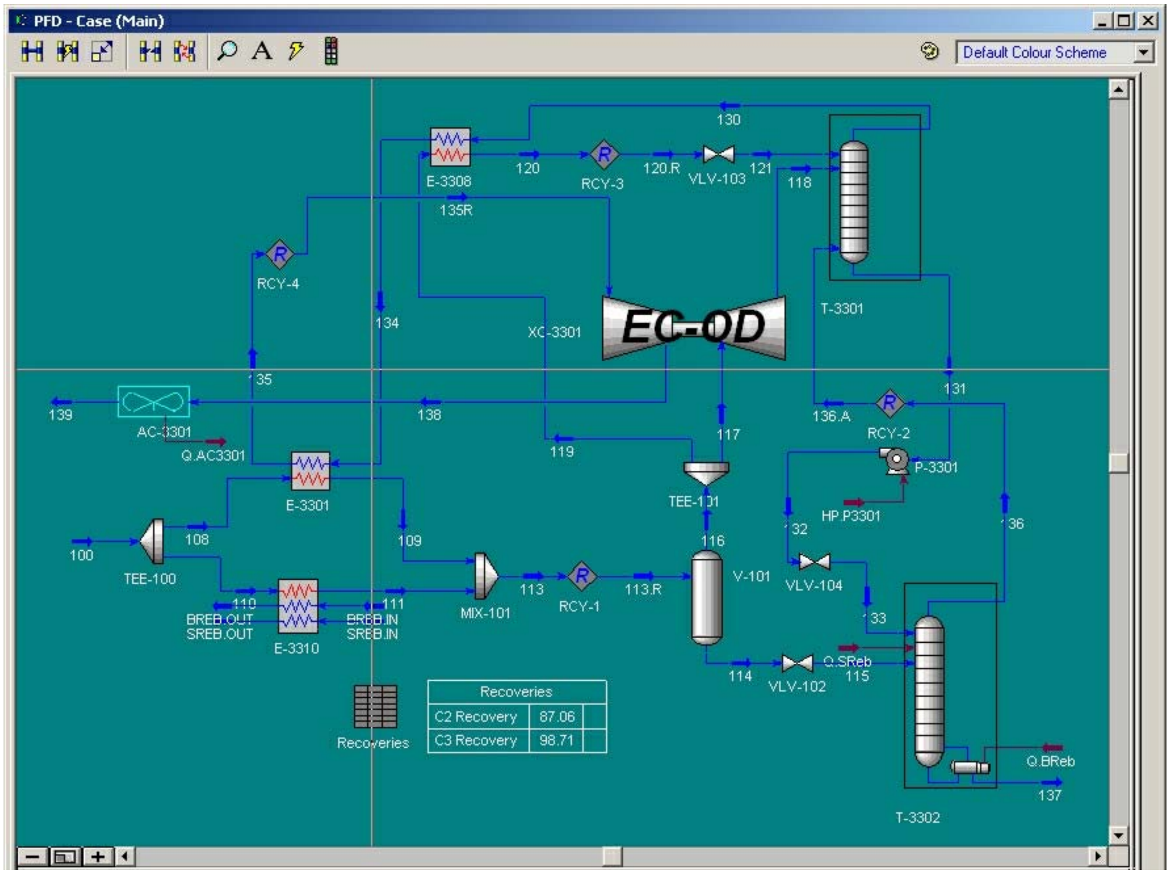


Figure 4: General Relationship of Expander-compressor Performance Variables

The expander efficiency is affected by enthalpy drop, speed and discharge volumetric flow. Note that expander pressure ratio and flow rate are independent of each other. The compressor efficiency is primarily derived from speed and inlet volumetric flow rate. The relationship between mass flow, power and speed allows the power balance to be determined.

To facilitate this expander-compressor speed-dependent performance calculation, an expander-compressor off-design module has been developed for Aspen HYSYS®. This module, EC-OD™, allows the process engineer to simulate the expander-compressor via a single unit operation. The module uses logic based on Mafi-Trench's turboexpander off-design equations and empirical guidelines. With this tool, the approximate model of Figure 3 is replaced with a simpler and more precise model shown in Figure 5. This allows the expander to be modeled directly in the plant simulation, eliminating the iteration loop between the process engineer and the turboexpander manufacturer. With this module, the expander and compressor design point is chosen, and subsequent performance calculations are carried out. Having such an off-design module can be advantageous, especially in instances where expander performance must be analyzed for a significant number of operating cases. The LFP process, for example, benefits from this approach.



Recoveries		
C2 Recovery	87.06	
C3 Recovery	98.71	

Figure 5: Expander-Compressor Module in Aspen HYSYS® Simulation

For this process twenty-four (24) operating cases were defined. These twenty-four cases were comprised of eight (8) different LNG sources, each source having three (3) distinct operating conditions. A wide variation in flow rate between the three operating conditions was the predominant characteristic. This was an ideal application for an expander-compressor modeling tool that operates within the plant simulation, to predict off-design performance.

Initially, for each LNG source, the plant was simulated based on the high mass flow case as the expander-compressor design point. This is a sensible approach in many typical gas-processing situations, where the plant performance is guaranteed for the high flow operation, and low performance during turn-down operation is tolerable. The expander-compressor off-design performance for each of the twenty-four cases was calculated by EC-OD. As the following "Original Design" curve (shown in Figure 6) attests, this resulted in poor expander and compressor performance during periods of lower flow operation. These turn-down cases are clearly penalized due to the choice of the high flow design point. For this process, maintaining high expander efficiency and compressor performance during turn-down, for every source of LNG, is critical. Compressor boost is of primary concern. It must be noted that the curves in Figure 6 are not operating curves, but only trendlines which show the general trend of the specific operating cases, relative to the process conditions.

By inspection of the "Original Design" trendlines, it is apparent that a more "intermediate" design point for the turboexpander would be better suited to optimizing the expander-compressor performance across the spectrum of LNG sources and operating conditions. Accordingly, a lower flow design point, approximately 80% of the high flow case, was chosen. The turboexpander off-design performance for each of the twenty-four cases was again calculated by EC-OD. By inspection of the "New Design" trendline (Figure 6), it is clear that the new design point provides much better expander and compressor performance at low flow. This is accomplished with only a small reduction in performance at the high flow operating points.

Another goal of good expander design is to minimize the recycle flow for the compressor. This recycle flow, necessary during low flow operation to prevent surge, also results in reduced boost and wasted energy. The recycle calculation is built into EC-OD, allowing for a quick check of the recycle flow required. The recycle point is also plotted on the graph of Figure 6, shown as three lines. For every flow point to the left of the black lines, some recycle flow will occur. The change to the design point allowed the recycle flow to be reduced by 20%.

In a plant which will see such a wide range of operation, it is clearly beneficial to model many operating points. These techniques allow the process engineer to gain a clear understanding of the expander-compressor operating map, without being a turboexpander specialist.

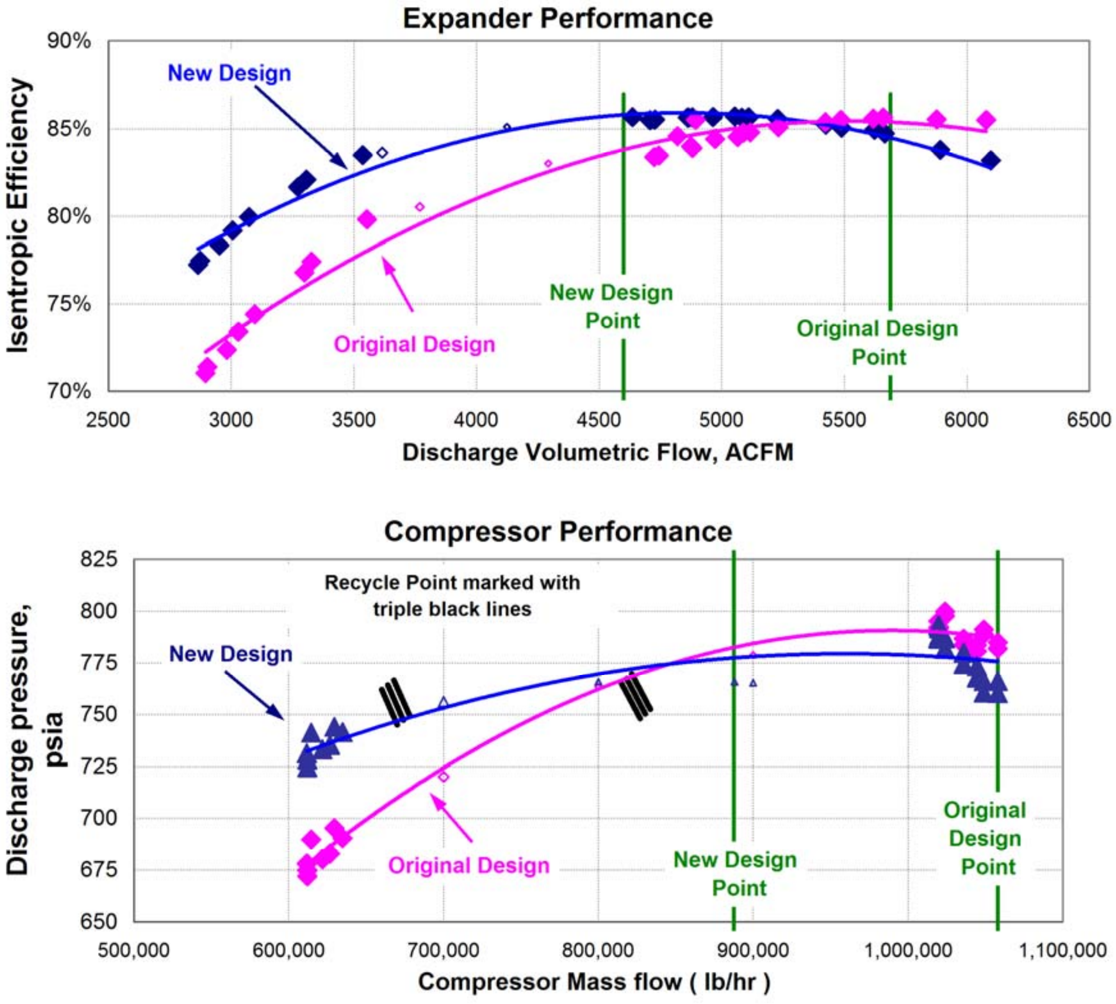


Figure 6: Expander-Compressor Performance curves

CONCLUSIONS

One of the most notable features of the LFP process is that changing LNG composition is easily handled within the plant. Since there is adequate refrigeration available in the LNG feed, wide ranges in the LNG composition can be processed with the same plant design simply by varying the heat input. This gives the terminal operator the flexibility to process LNG cargos from anywhere in the world.

In addition, by use of the expander-compressor, no external compression is required. By taking advantage of the refrigeration available in the LNG itself, the external compression step is eliminated to make the overall energy requirements very low for this process.

A turboexpander, whose speed can adjust to changing plant conditions, is an ideal component of this system, providing consistent recovery over a wide range of operating conditions. However, due to the speed variation, it is difficult with common methods to accurately model a turboexpander across a wide variation in operating conditions.

The Aspen HYSYS® expander-compressor off-design module (EC-OD) allows the process engineer to accurately model the expander-compressor off-design performance in the plant simulation, with a minimum of iterations with the expander manufacturer, saving time in the process design cycle.

The first LFP plant has been designed and is currently under construction on the U.S. Gulf Coast with start-up expected in the first quarter of 2009. The turboexpander for this plant was designed using the methods described in this paper.

REFERENCES CITED

1. Cuellar, K.T., Hudson, H.M., and Wilkinson, J.D., “Economical Options for Recovering NGL/LPG at LNG Receiving Terminals”, Gas Processors Association Annual Convention, March 2007.

2. Nordwall, G., Jumonville, J., and Matthews T., “ Desktop use of Computational Fluid Dynamics to design and troubleshoot compressors and Turboexpanders”, Turbomachinery Symposium, September 2003.

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