ELNG Success Story – Plant Turndown Ratio

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Abstract

The Egyptian LNG facility is operated by Egyptian LNG (ELNG), consisting of two LNG trains owned by Shell, Petronas, EGas and Engie. Both trains utilize the ConocoPhillips Optimized Cascade® LNG process with a nameplate capacity of 3.6 MTPA. Train 1 was brought online in May 2005 with Train 2 following in October 2005.

Since mid-2013, ELNG encountered severe supply limitations and frequent feed gas interruptions, due to national grid demands. Several challenges were incurred with maintaining only one train online with stable operation at very low feed gas rates, when available. Other challenges incurred were maintaining plant readiness for the offline train, as well as both trains during periods with no feed gas supply. For example, 60 feed gas interruptions occurred from January 2014 to December 2016, with each interruption requiring a shutdown and restart. Although each train was contractually designed to achieve 35% turndown of feed rates (around 225 MMSCFD), the turndown achievable proved much higher, around 13% and lower (90 MMSCFD). The two-trains-in-one approach employed for the refrigeration turbine/compressor strings helped minimize efficiency losses at high turndown.

Since mid-2018, due to several large offshore discoveries, the feed gas rates have been increased from around 13% with frequent interruptions to around 50% with substantially less interruptions. As a result of several relatively recent large offshore discoveries, there are optimistic plans to increase production further to 100% of design.

This paper focuses on how the high turndown capability, coupled with the ability to achieve rapid shut downs and restarts, allowed ELNG to sustain facility operation with sufficient revenue to justify remaining online with full staffing throughout the time period of severe feed gas supply limitations and frequent interruptions, mid-2013 to early-2018. During that period there were 705 on-stream days producing 3.1 million m3 of LNG equivalent (21 cargos). The paper will further outline operations at high turndown during this time frame, with a focus on the associated economics and key challenges incurred. Some of the key challenges discussed are equipment thermal cycling, corrosion under insulation, maintaining offline equipment and piping with conditions that facilitate rapid restarts, and maintaining core competencies for the operations and maintenance staff.

Introduction

The overall turndown contractual design basis for each LNG train at ELNG was 35% of the feed gas, a common LNG industry turndown design basis. However, due to the wide compositional variation between the lean and rich feed compositions provided for the original design basis, there was a need to design the NGL Recovery Tower (V-1702) for 10% turndown (based on the average or design composition) to address operation with the lean gas composition. The selection of 35% turndown design basis for the remainder of equipment was somewhat arbitrary, based on par for the industry. As part of the design effort, the equipment was checked to ensure the design basis would be met, with the compressor operating points on the surge control line, the pumps in minimum flow, sufficiently wetted packing for the packed columns, and satisfactory tray loads for the trayed columns. However, the arbitrary 35% turndown ratio in the contractual design basis proved to be conservative in actual operation. ELNG has managed to successfully operate at much higher turndown ratios with all critical process variables in control and with all process equipment maintained within safe operating envelopes.

However, regarding sustained operation at high turndown ratios for longer periods (mid-2013 to mid-2018), there were several key challenges to address. One such challenge was how to consistently operate within the The Standards of the Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association (ALPEMA). The ConocoPhillips Optimized Cascade® Process (OCP) utilizes BAHXs throughout the LNG liquefaction process. Other key challenges faced were corrosion under insulation for both piping and equipment and how to manage excessive thermal stresses on the LNG loading and cooldown lines.

A detailed Management of Change (MOC) process was triggered with a cross-functional team of personnel with the necessary expertise to study operation at prolonged turndown. Several Hazards Identification (HAZIDs) and risk assessments were conducted, which included all stakeholders, ConocoPhillips as the liquefaction technology licensor, Bechtel as the ELNG project EPC contractor, Linde as the BAHX and cold box manufacturer, and GE as the turbo machinery manufacturer and service provider.

By satisfactorily addressing these key challenges, ELNG was able to sustain turn down at around 13% of design feed gas rates, which avoided a total facility shutdown and the associated need for equipment and piping preservation, as well as maintaining full facility staffing. This ability placed ELNG in a good position to simply ramp up production when additional feed gas became available in mid-2018. The key challenges addressed are presented below.

BAHX Thermal Cycles

Brazed Aluminium Heat Exchangers (BAHX) are utilized extensively throughout the ConocoPhillips Optimized Cascade® Process (OCP). Two inescapable facts about BAHX exchangers are (i) there are no definable endurance limits, and (ii) stresses are cumulative. As such, excessive thermal cycles are generally to be avoided. ALPEMA does offer guidelines that if followed allow long exchanger life. Among these guidelines are to operate below a maximum temperature difference of 50°C between adjacent passes for an ideal situation with single phase and steady state conditions, dropping to a maximum temperature difference of 20 to 30°C for more realistic conditions. Regarding the maximum temperature rates of change, short term changes of 2 to 3°C/minute are acceptable but should be controlled to lower average rates of change of 1°C/minute (60°C/hr) or less over longer time durations. [1] The life span of a BAHX depends on the care with which it is operated and maintained, especially with respect to thermal gradients.

The actual configuration of BAHX streams within the OCP is proprietary and cannot be shown or discussed in detail. However, what can be stated is that the adjacent streams within most of the BAHXs remain proportional to one another as feed gas rates are increased or decreased. Thus, at varying feed gas rates, the adjacent pass-to-pass temperature profiles for most of the BAHXs passes are retained, regardless of feed rate or how fast the feed is increased or decreased. This fact makes turndown relatively easy to achieve for those exchangers, along with the ability to rapidly ramp production up and down as required without excessive thermal stresses. However, the time period with the greatest potential for unbalanced thermal stresses are while warming up from cold conditions or while cooling down from warm conditions. Warm up and cool down rates must therefore be carefully controlled to avoid excessive thermal gradients. A DCS screen image is included in Figure 1 to show the added pass to pass adjacent differential temperature indication.

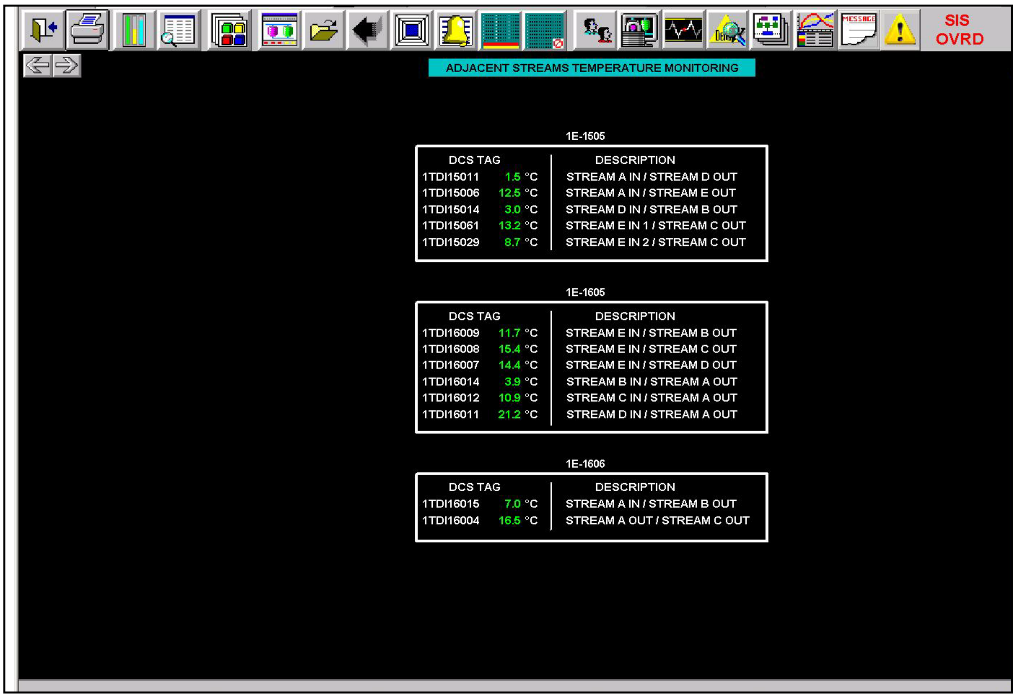

Figure 1: Temperature Differences Between Adjacent BAHX Passes

There are exceptions where more care was required. For example, a couple of small BAHXs were used as part of a heat integration scheme between fractionation columns within the heavy hydrocarbon removal system. Thermal stresses in this service have proven problematic for ELNG, due to temperature rates of change resulting from sudden feed compositional changes. In fact, as an ELNG lessons learned, ConocoPhillips no longer utilizes BAHXs within heavy hydrocarbon removal systems. But for ELNG, they remain in service and the thermal stresses must be managed accordingly, including those related to high turndown. The management of these thermal stresses is primarily addressed through start-up, shut down, and operational procedures. A joint effort was undertaken between ELNG and ConocoPhillips LNG Engineering to study and implement procedural changes. While procedural changes have improved exchanger reliability within the heavy hydrocarbon removal system, longer term plans are to simply replace the small BAHX exchangers with more robust exchangers.

ELNG has addressed excessive BAHX thermal gradients by:

- Configuring new alarms BAHX adjacent streams
- Configuring temperature rate of change alarms
- Revising the heavy hydrocarbon removal system start-up, shutdown, and operational procedures

Corrosion Under Insulation (CUI)

Another key challenge during the high turndown period between 2013 and 2018 was Corrosion Under Insulation (CUI). CUI is external corrosion of piping and equipment underneath external insulation due water penetration that becomes trapped on the metal surface. If precautions are not taken, CUI can remain undetected until the insulation is removed to inspect or worse when leaks occur. Corrosion usually occurs through metal dissolution, with damage manifesting as general or localized, gradually increasing thickness loss until failure occurs. For carbon and low alloy steels, the deterioration mechanism is generally external corrosion and/or pitting. For stainless steels the deterioration mechanism is generally stress corrosion cracking (SCC) and/or pitting. CUI generally occurs at metal temperatures between the freezing and boiling points of water (0°C to 100°C). It is however typically recommended to consider a broader temperature range of -12°C to 185°C to account for differing operational modes, temperature fluctuations, loss of insulation properties, and heat loss across equipment and longer piping runs. Water should remain well frozen below -12°C and is normally not present above 185°C in quantities to promote CUI. The CUI temperature range of interest also varies for different metallurgies as Table 1 illustrates.

METALLURGY TYPE	CUI TEMPERATURE RANGE
Carbon Manganese Steels & Low Alloy Steels	-12 to 175 °C
Austenitic Stainless Steels	50 to 185 °C
Duplex, Super Duplex & High Molybdenum Stainless Steels	138 to 185 °C

Table 1: CUI Temperature Ranges of Interest for Different Metallurgies at ELNG

The temperature conditions of all equipment and piping throughout the facility were identified, including the temperatures expected when out-of-service for significant time periods. Piping and equipment that would cycle in and out of the CUI temperature range were included within the study.

An inspection work plan was then developed for each equipment and piping item identified, based on the results a Risk Based Initiative (RBI) analysis. The work plan addressed the level of risk, nature of damage, potential failure modes, and other key risk factors, while also defining the inspection techniques, inspection intervals, and specific regions to examine. The inspection intervals selected were based on assigned risk ratings with intervals of 2 years for higher risk ratings, 4 years for medium risk ratings, and longer for lower risk ratings.

One particularly nice feature of the OCP is that much of the cryogenic piping and equipment for the ethylene and methane refrigeration system is contained within cold boxes. The cold boxes are filled with perlite, which maintains the equipment and associated piping temperatures cold for long time periods before refrigerant and other contained liquid deinventory is required. The cold boxes are also continuously purged with dry nitrogen, which eliminates moisture and any associated CUI concerns. However, the propane refrigeration system piping and equipment is not included within a cold box and was identified as an area of concern for CUI.

LNG Loading and 8" Cooldown Lines

The jetty loading and return lines can warm up during periods of significant downtime, resulting in a need to either cool down every time a shipment is required or to maintain in a cold state. The latter is of course the preferred option to avoid excessive thermal cycling. Both LNG trains at the ELNG facility include 8” cool down lines, taken from the LNG transfer line at the discharge of the LNG transfer pumps, to maintain the jetty loading line cold. When one of the LNG trains is offline, there is a need to keep the LNG transfer line from the train to the LNG tanks cold. An LNG tank ship loading pump may be used to circulate LNG to the loading arm isolation valve, back through the 8” cool down line to the transfer line, and back to the tanks. Thus, the 8” cooldown line is bidirectional, with the direction depending on whether or not the train is in service. The 8” cool down line was constructed using vacuum jacketed piping, for which multiple sections have failed to maintain vacuum. The reliability of this system was therefore an area of concern for prolonged downturn when the system must be maintained cold. Several actions as outlined below were taken to enhance the original design to ensure reliability.

- Additional Temperature Indication – Added 13 temperature elements along the loading line with indication routed to the Distributed Control System (DCS). The DCS connections were made using wireless HART technology through a new wireless HART gateway located near the loading substation.
- Additional Pressure Transmitter – Added 1 new pressure transmitter.
- Updated Instrumentation Systems – Updated all systems to include the new tags and information.
- Updated Procedures - Developed detailed procedures to cover all possible cool down scenarios with or without using the 8” loading line.

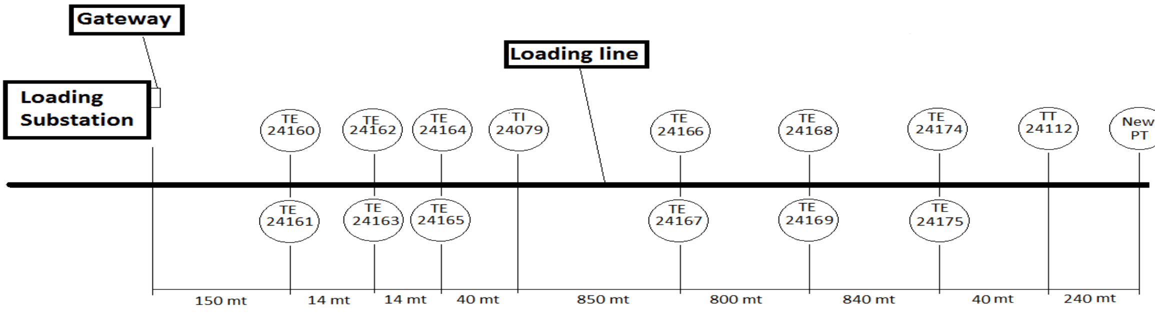

Figure 2: Additional Instrumentation for LNG Loading Line

Mode of Operation at High Turndown

ELNG was able to satisfactorily address all high turndown operational concerns, with the key concerns cited above, and establish comfortable operation of one (1) train at 13 to 15% of design feed rates, much lower than the contractual 35% turndown of design feed rates. However, ELNG is a two (2) train facility and there was insufficient feed gas to sustain both trains at 13 to 15% of design rates. ELNG therefore adopted a philosophy of maintaining one (1) train in operation at high turndown and the other train offline, switching between trains every two (2) months. The operating train was able to provide cooling for the jetty loading lines as well as the offline train's tank transfer line. Although with much less frequency, ELNG was also able to continue with ship loading activities.

The strategy cited above minimized excessive thermal cycling of the trains and CUI concerns. The ability to easily restart the Optimized Cascade process and the ability to maintain equipment cold within the cold boxes for long periods proved quite useful. Adopting this strategy allowed ELNG to maintain the integrity of both trains, while minimizing maintenance costs and maintaining all operational and maintenance staffing. One unintended benefit was that the frequent start-ups provided excellent operational training for the ELNG staff. Some key variables of the operating units are provided below.

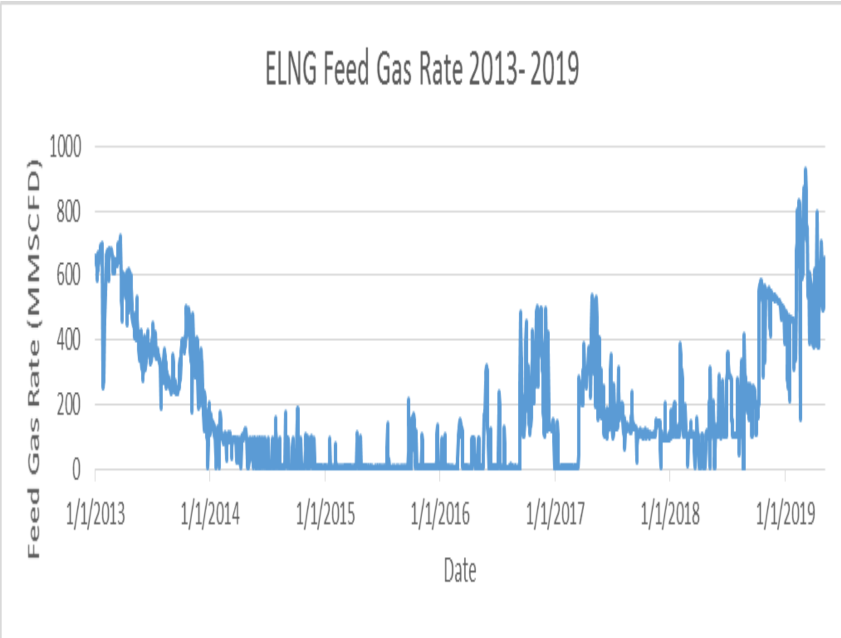

Figure 1: ELNG Feed Gas From 2013 Through 2018

Operational excellence

Another significant challenge during the high feed gas turndown period was how to maintain the competency of the operation team. ELNG applied a strategic plan to achieve and maintain high competency metrics.

ELNG developed and applied a Competency Assurance Management System (CAMS) maintain the competency for all stuff. Within CAMS the capability of each person is assessed to ensure that all tasks may be completed safely and efficiently. At the core of the CAMS system are two basic levels, the first of which is to assess knowledge and the second to assess practical application.

ELNG also maintains an Operator Training Simulator (OTS), where initially one of the main purposes was to train both DCS and field operators. However, the OTS served a valuable purpose during the high turndown period of maintaining and assessing DCS operator competencies. Safety drills were routinely performed to simulate how to safely shutdown, depressure, and start-up the trains. The OTS also proved a valuable tool in testing out new procedures as they were developed to improve shutdown, start-up, and operation efficiency.

The ELNG management team assigned a cross-discipline start-up team to provide support and technical advice to the operations teams, particularly during the start-up periods. A detailed start-up report was prepared and reviewed within two (2) days of each start-up to review and analyse the start-up sequence, with particular focus on the cool down rates and adjacent pass differential temperatures. Any problems were identified and addressed, with lessons learned applied to the procedures and training as part of a continual improvement process. Quarterly awareness reviews were also scheduled to review and analyse any deviations or upset events.

The data presented in Tables 2 through 8 below provides the results realized from these efforts.

Table 2: Pipeline Receiving & Metering Unit

Parameter	Min Value	Max Value	Avg Value
Feed Gas Flow Rate	90 MMSCFD	100 MMSCFD	95 MMSCFD
Feed Gas Pressure	46 barg	46 barg	46 barg
Feed Gas Temperature	27°C	37°C	32°C

Table 3: Acid Gas Removal Unit Pipeline Receiving & Metering Unit

Parameter	Min Value	Max Value	Avg Value
Amine (DGA) Flow	105 m^3/h	105 m^3/h	105 m^3/h
Absorber Ovhd Cooler Outlet Temp	26°C	28°C	27°C
Regenerator Ovhd Temp	105°C	110°C	108°C
Regenerator Bottoms Temp	127°C	128°C	127°C
Absorber Differential Pressure	0.003 barg	0.005 barg	0.0045 barg
Regenerator Differential Pressure	0.0029 barg	0.004 barg	0.003 barg

Table 4: Dehydration & Mercury Removal Unit

Parameter	Min Value	Max Value	Avg Value
Drier Regen Gas Temperature	18°C	270°C	167°C
Drier Inlet Feed Temperature	19°C	29°C	21°C
Regen Gas Heater Flow	33 KNm^3/h	39 KNm^3/h	36 KNm^3/h
Dry Gas CO2 Analyzer	0 ppmv	0.1 ppmv	0 ppmv
Wet Gas CO2 Analyzer	5.4 ppmv	11 ppmv	7.2 ppmv
Dry Gas H2O Analyzer	0 ppmv	0 ppmv	0 ppmv

Table 5: Liquefaction Exchanger Diff. Pressures (To Monitoring Freezing)

Parameter	Min Value	Max Value	Avg Value
Exchanger A Differential Pressure	0.31 barg	0.31 barg	0.31 barg
Exchanger B Differential Pressure	0 barg	0 barg	0 barg
Exchanger C Differential Pressure	0 barg	0 barg	0 barg

Since the liquefaction technology is proprietary, equipment numbers and descriptions are excluded. However, if freezing occurs, it will generally in one (1) of three (3) exchanger passes downstream of the heavy hydrocarbon removal system, which will manifest as a high differential pressure across the associated exchanger pass. Freezing did not occur at any time throughout the high downturn period.

Table 6: Heavy Hydrocarbon Removal System Separation Performance

Parameter	Min Value	Max Value	Avg Value
Stream A C6+ from Heavies Removal	0 ppm	0.4 ppm	0.1 ppm
Stream B C6+ from Heavies Removal	1 ppm	5.8 ppm	3.4 ppm

Analysers on the two streams exiting the heavy hydrocarbon removal system to the LNG process reveal that the columns maintained their separation efficiency quite well during the turndown period.

Table 7: Heavy Hydrocarbon Removal System BAHX Monitoring

Parameter	Min Value	Max Value	Avg Value
Exchanger D Hot Side Diff. Temp	7°C	17°C	12°C
Exchanger D Cold Side Diff. Temp	12°C	18°C	15°C
Exchanger E Hot Side Diff. Temp	1°C	13°C	6°C
Exchanger E Cold Side Diff. Temp	23°C	32°C	27°C

As stated earlier, two small BAHXs included as part of the heat integration design within the heavy hydrocarbon removal system have proven particularly problematic. The adjacent pass differential temperatures, as well as temperature rates of change are difficult to maintain. While ELNG has longer term plans of replacing these two small BAHXs, it is necessary to address the issues procedurally until such time. The above table demonstrates that most of the adjacent pass differential temperatures have been maintained within the ALPEMA, except for the cold side differential temperature of Exchanger E noted in Table 7, which exceeded the ALPEMA guidelines of 20-30°C by 2°C.

Table 8: LNG Production

Parameter	Min Value	Max Value	Avg Value
LNG Production	0.1 Km^3/h	0.3 Km^3/h	0.2 Km^3/h
LNG Temperature	-154°C	-153°C	-153°C

The minimum, maximum, and average LNG production and temperature values included in Table 8 above reveals quite stable production throughout the turndown period.

Financial Considerations

The ability to achieve a high turndown ratio of 13 to 15% of design feed gas rates resulted in 705 onstream days and a total LNG production of approximately 3.1 MM cubic meters between mid-2013 and mid-2018 that would have otherwise not been realized. Approximately 21 LNG cargoes were produced during this period, providing approximately $354 MM. This proved sufficient to maintain the two LNG trains at ELNG in a state of operational readiness until the production ramp-up in mid-2018 when additional feed gas was made available, as well as to maintain full operational and maintenance staffing and associated competencies.

References

1. ALPEMA – "The Standards of the Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association", Third Edition 2010, ©2010

2. Qualls – "Design Considerations for Efficient LNG Liquefaction Turndown", Gastech 2018