Maximising LNG revenue by operating at peak performance

Brian Barr, Robin Pearsall, Jim Bronfenbrenner
Air Products and Chemicals Inc.
7201 Hamilton Boulevard
Allentown, PA 18195-1501

Meshal Hassan Al-Mohannadi
RasGas Company Limited
Doha, Qatar

Maximising LNG Revenue by Operating at Peak Performance

Brian Barr, Robin Pearsall, Jim Bronfenbrenner

Air Products and Chemicals, Inc.

Meshal Hassan Al-Mohannadi

RasGas Company Limited

Abstract

Air Products' AP-OptiPlus™ Liquefier Optimisation and Training Programme ("Optimisation Programme"), provides guidance for troubleshooting and optimising performance of the liquefaction unit of a Liquefied Natural Gas (LNG) plant. It incorporates process licensor expertise into an easy-to-use software program that collects data from the plant historian and assesses the condition of the liquefaction unit through monitoring of key process parameters. The Optimisation Programme helps an engineer/operator adjust the liquefaction unit to operate at peak performance. It is also a very useful training aide for both inexperienced and experienced engineers/operators in the operation and optimisation of the Liquefaction Unit.

To achieve and maintain peak performance, the Optimisation Programme is customised to each individual LNG facility with specific target values for key process variables to ensure optimal operation. The Optimisation Programme can be applied to Air Products' AP-X®, AP-C3MR™, AP-DMR™, AP-N™ liquefaction technologies . The development and deployment of the Optimisation Programme is accomplished through close dialogue and collaboration with the operations and technical personnel at a LNG facility. This ensures all specific goals and requirements of the LNG facility are achieved.

RasGas LNG has implemented the Optimisation Programme on both the AP-C3MR™ and an AP-X® LNG Process trains in Qatar with great success. The Optimization Programme has helped RasGas identify process improvements and equipment operation concerns very quickly. The Optimisation Programme provides structured problem solving solutions, allowing safer, more optimum and more reliable liquefier operation. With the help of the Optimisation Programme, RasGas is able to produce LNG more efficiently and more easily meet their annual LNG production targets.

Introduction

Obtaining the best performance from existing LNG facilities helps maximise LNG revenue for the owner. Small improvements in plant performance can create a large economic benefit. Performance of the liquefaction unit depends on external factors (e.g. feed composition, ambient temperature), desired LNG production, equipment constraints (e.g. maximum available gas turbine power), and human factors. Air Products' AP-OptiPlus™ Liquefier Optimisation and Training Programme ("Optimisation Programme"), a computer based optimisation tool, was developed to aid operators and engineers to quickly identify issues affecting peak performance, to provide guidance on how to adjust the liquefaction process to optimise performance for the current plant conditions, and also to proactively identify potential equipment issues.

Why is an Optimisation Programme needed? In a typical plant there are many items that demand attention. The Distributive Control System (DCS) has the information, but it is scattered across many screens. A simple temperature difference might require going to separate DCS pages and then subtracting them. This takes time and parameters that are out of range could be missed. The DCS does not optimise or provide any guidance on adjusting the plant. Different engineers or operators might have different ways of operating the plant based on their previous experience, knowledge level, and preference. A few people at site may have a lot of knowledge and expertise, but they are not always available to continuously help in optimisation of plant operation.

How does the Optimisation Programme solve these issues?

- The Optimisation Programme provides an efficient way to analyze the DCS data. By interfacing with the data historian and only focusing on the process parameters that are important to the liquefaction process, a large amount of data can be sorted, organized, and summarized. Temperature differences or flow ratios can be calculated. Measured and calculated parameters that are outside of the optimal range can be quickly identified
- The Optimisation Programme also suggests what changes could be made to optimise the process. This helps the engineer or operator achieve and maintain optimal performance. The guidance for achieving optimal performance is customised to each individual LNG facility with specific target values for key process parameters that are set up through collaboration with plant staff and the process licensor.
- The Optimisation Programme also helps to maintain consistency with operation between shifts and between operators. It captures the knowledge and expertise of both the plant staff and process licensor, and makes this knowledge available to the operating staff on a continuous basis.
- The Optimisation Programme can be applied to Air Products' AP-C3MR™, AP-X®, AP-DMR™, AP-N™ liquefaction technologies . Developing and deploying the Optimisation Programme is accomplished through close dialogue and collaboration with the operations and technical personnel at the LNG facility and the process licensor. This ensures all specific goals and requirements of the LNG facility are achieved.
- The Optimisation Programme also transfers knowledge from process licensor and the experienced plant staff to those operating the liquefaction facility. By working together jointly in the collaboration phase of the project, the knowledge and optimal operation is documented in the development of the tag deviation guides and the logic diagrams. These logic diagrams and tag deviation guides are useful training tools for new engineers and operators. AP-OptiPlus™ Optimisation Programme was implemented at the RasGas LNG facility for both the AP-X® and AP-C3MR™ LNG Processes. It was also successfully implemented at two additional operational LNG plants.

The Optimisation Programme consists of three main parts:

> **Process Dashboard** – This is a custom built interface that monitors the key process parameters. It highlights any parameters that are out of the normal operating range. The

dashboard can be configured to have different operating ranges and process alarms for different operating modes.

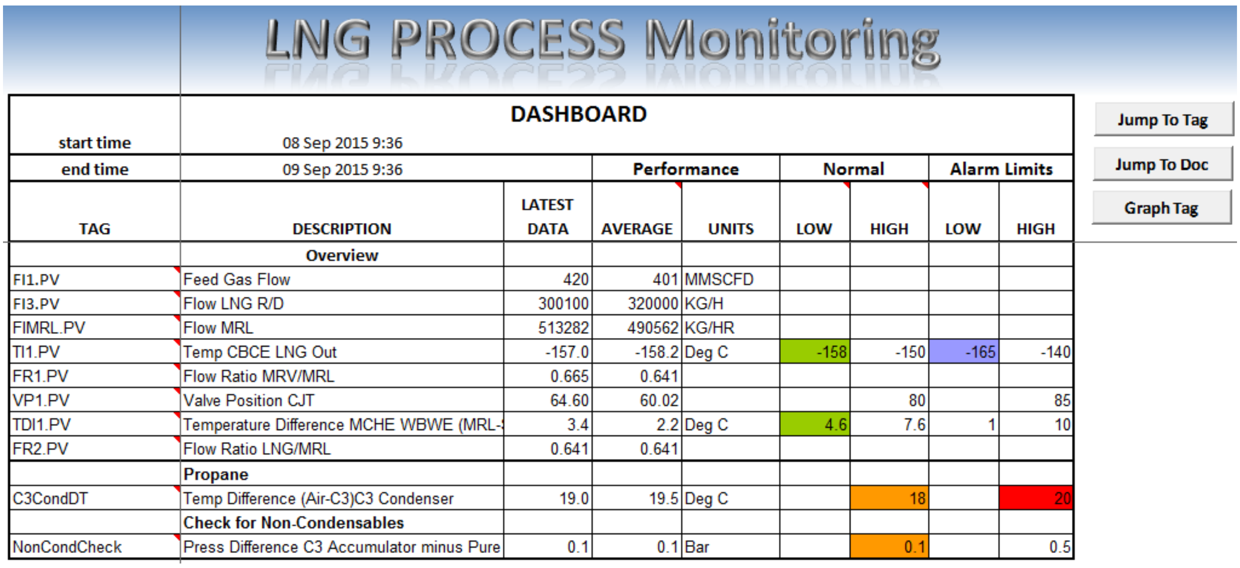
Tag Deviation Guides – The deviation guides gives the optimal range for each parameter (tag) and possible causes and remedies if the parameter is outside the optimal range.

Process Logic Diagrams – These are flow charts that step through how to adjust the process to obtain peak performance. Logic diagrams are developed for several key areas including the precooling system (Propane System in a C3MR plant), mixed refrigerant system (including the main cryogenic heat exchanger, MCHE), and the end flash system.

The paper will now discuss each of these in more detail.

Process Dashboard

The process dashboard is the user interface that provides the operator or engineer with a tool where they can quickly get an overview of the liquefaction process and rapidly identify any problems. It is not just a snapshot; it highlights any process parameters that are out-of-range at any point during the time being evaluated. This is a significant time savings over searching through many DCS screens and trends. The dashboard is quick linked to the templates to aid in troubleshooting when a process parameter is outside of the desired range. Figure 1 shows a typical dashboard. Note that the dashboard can be custom configured by each user to show the parameters they feel are most important.



LNG PROCESS Monitoring

DASHBOARD

Jump To Tag
Jump To Doc
Graph Tag

start time	08 Sep 2015 9:36							
end time	09 Sep 2015 9:36		Performance		Normal		Alarm Limits	
TAG	DESCRIPTION	LATEST DATA	AVERAGE	UNITS	LOW	HIGH	LOW	HIGH
	Overview							
FI1.PV	Feed Gas Flow	420	401	MMSCFD				
FI3.PV	Flow LNG R/D	300100	320000	KG/H				
FIMRL.PV	Flow MRL	513282	490562	KG/HR				
TI1.PV	Temp CBCE LNG Out	-157.0	-158.2	Deg C	-158	-150	-165	-140
FR1.PV	Flow Ratio MRV/MRL	0.665	0.641					
VP1.PV	Valve Position CJT	64.60	60.02			80		85
TDI1.PV	Temperature Difference MCHE WBWE (MRL-	3.4	2.2	Deg C	4.6	7.6	1	10
FR2.PV	Flow Ratio LNG/MRL	0.641	0.641					
	Propane							
C3CondDT	Temp Difference (Air-C3)C3 Condenser	19.0	19.5	Deg C		18		20
	Check for Non-Condensables							
NonCondCheck	Press Difference C3 Accumulator minus Pure	0.1	0.1	Bar		0.1		0.5

Figure 1

Figure 1 shows the process alert values that were established. The values highlighted in green are out of range. To minimize the number of process alerts, only parameters that should be optimised are given ranges. The dashboard has additional sheets that pull in the data and also allow the engineers to adjust the operational ranges and process alert values as further information is gathered. There is also the ability to add additional tags to the system. It is important to note here that the alert is used to warn that a variable is not in its peak performance range and not necessarily an operating alarm.

The capabilities also exist to change target and ranges, depending on the operating modes. This allows for a different set of operating ranges to be specified for a different mode of operation. As an example, different operating ranges can be established for operation in holding mode (no ship loading) and loading (during ship loading).

Tag Deviation Guides

Each process parameter has a tag deviation guide developed that describes the parameter, its target range and possible causes for any sub-optimal deviation. Figure 2 shows a typical tag deviation guide.

Parameter **Tag #**	**Temp C3 Accumulator** TI-XXXXXXX	**System**	**C3 Refrigeration**
Target / Design	Design: XX.X °C	**Analysis Frequency**	**DCS**
Description	Propane accumulator X-XXXXX inlet temperature		

Deviation	**Causes**	**Verification**	**Corrective Actions**
Temperature is high	Air temperature to C3 condenser fans is greater than XX°C design air temperature.	TI-XXXXXX air temperature to C3 condenser fans warmer than design XX°C	May have to reduce feed gas in hot weather when air temperature is greater than design XX°C.
	C3 condenser temperature difference (Deviation Guide #) between condensed propane temperature TI-XXXXX fan inlet air and TI-XXXXXX is greater than XX°C.	TI-XXXXXX C3 accumulator temperature warmer than design	Make sure all fans are on at design speed and fins are clean.
Temperature is low	Normal operation		Normal Operation
	Propane condenser E-XXXXX fan inlet air temperature during cool season is less than XX°C design air temperature.	TI-XXXXXX air temperature to C3 condenser fans is colder than design	Normal operation. If air temperature is too low, the (Highest C3 Discharge Name) compressor discharge pressure drops and moves the compressor operating point toward stonewall (choked flow). Follow standard operating procedures to address this which may include turning fans off to move away from stonewall.
	C3 condenser temperature DT (Deviation Name) between condensed propane TI-XXXXXX and fan inlet air TI-XXXXXX is low.	TI-XXXXXX C3 accumulator temperature cooler than design	None except as noted above if the temperature is too cold.

Related Surveillance Parameters	TI-XXXXXX inlet air temperature to C3 condenser fans. (Deviation Tag Name) condenser temperature difference between C3 accumulator inlet air to fans and C3 accumulator
Comments	Cooling air temperature sets the propane accumulator inlet temperature. This sets C3 compressor discharge pressure, which then sets low Pressure C3 suction pressure based on each compressor stage performance curve. C3 compressor suction pressure then determines the coldest C3 temperature. Non-condensable components raise the C3 discharge pressure above the pure C3 bubble point pressure at the condenser temperature TI-XXX; butanes raise the lowest Press C3 temperature above the pure C3 dew point temperature in the lowest pressure C3 evaporators.

Figure 2

Figure 2 shows the tag deviation guide for the Propane Accumulator Temperature. In some cases this is enough to get back to the desired range. In other cases the tag deviation guide will refer to the Process Logic Diagram to optimise the process. A tag deviation guide is generated for every process parameter that is determined to be important. This is typically between 80 and 120 parameters depending on the type of process being monitored.

Process Logic Diagrams

The Process Logic Diagrams (PLDs) are flow charts that are used to optimise the process (Figure 3 shows part of a typical logic diagram). The LNG plant engineers and Air Products engineers collaborate to develop the PLDs. The logic diagrams have specific values to help in the optimisation and are developed for the specific plant being monitored. Logic diagrams are developed around key process areas and provide a guideline to optimise plant performance. The logic diagrams step the user through answering a series of questions to determine how the process may be optimized.

The logic diagrams can be used as a training tool for new engineers or operators. For a typical C3MR process there are logic diagrams around key areas that are optimised, which typically include

- Propane System
- LNG Temperature
- Warm End Temperature Difference
- LNG Rate.

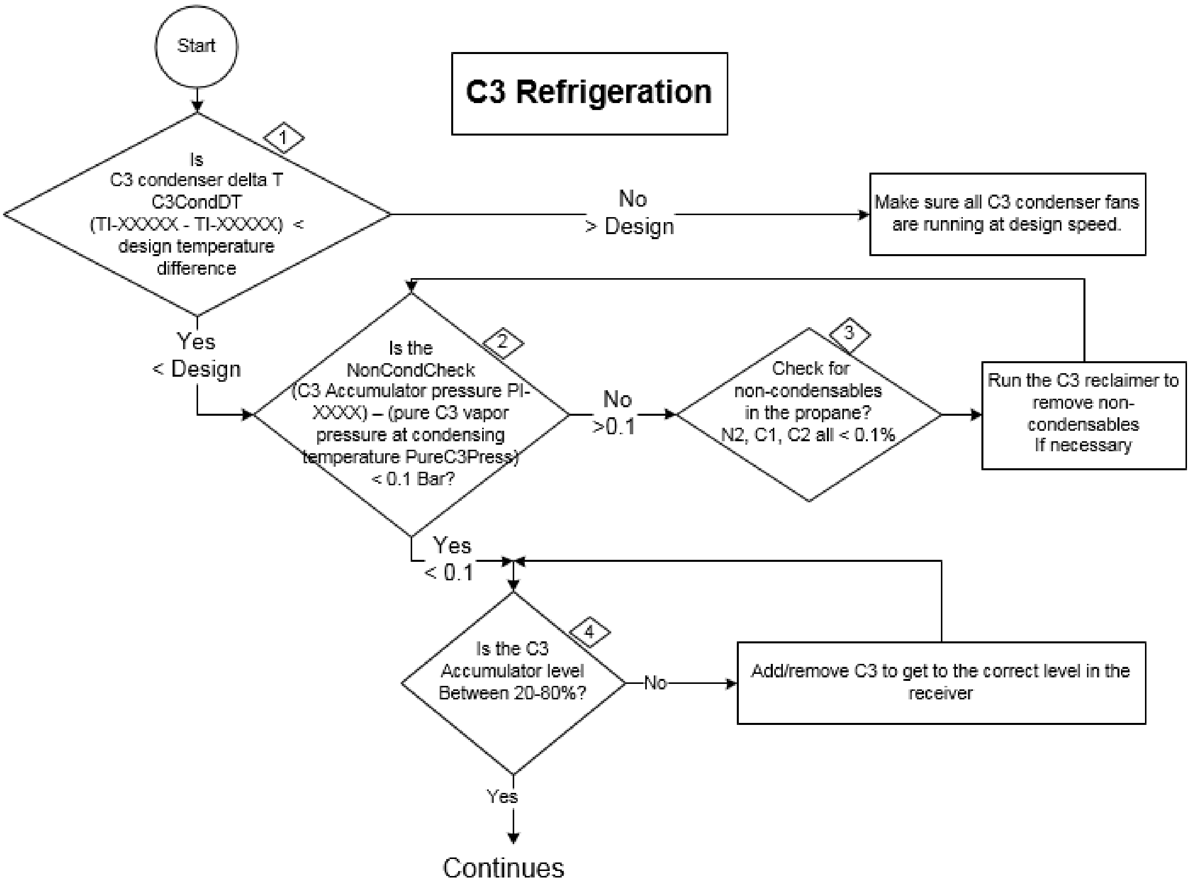


Figure 3

Further clarification of each node corresponds to the numbers in the diamonds in the logic diagram. The description portion of the logic diagram is shown in Figure 4. The Propane System is used as an example here. Logic diagrams concerning the LNG flow and outlet temperature involve more complicated logic surrounding the warm and cold Joule-Thomson (JT) valves.

C3 Refrig References:

1. Check propane condenser cold end temperature difference between the entering fan air and the condensed propane to ensure it is at XX°C design or less.

2. Check for non-condensables (N2, C1, C2) in the propane by comparing the pure C3 vapor pressure at the C3 accumulator temperature (read from attached graph 1) to the actual pressure measured at the reclaimer outlet. (Make sure the reclaimer is not in operation when checking). Non-condensables make the actual pressure much higher than the pure C3 vapor pressure.

3. If reference 2 indicates high dP, non-condensables are present. Run C3 reclaimer to remove them. C3 accumulator vapor sample at the reclaimer sample point can be sent to the lab to determine the non-condensables - N2, C1, C2 if needed. Make sure to draw a vapor sample!

4. The propane level in the C3 accumulator must be high enough to seal the outlet with liquid and low enough to *not* seal the condenser breather pipe inlet to the accumulator. This breather pipe equalizes the C3 condenser and C3 accumulator pressures as well as provides a path for non-condesables to reach the accumulator.

CONTINUES

Figure 4

Example on Using the System

Figure 5 shows a typical C3MR Process which can be used as a reference in the example.

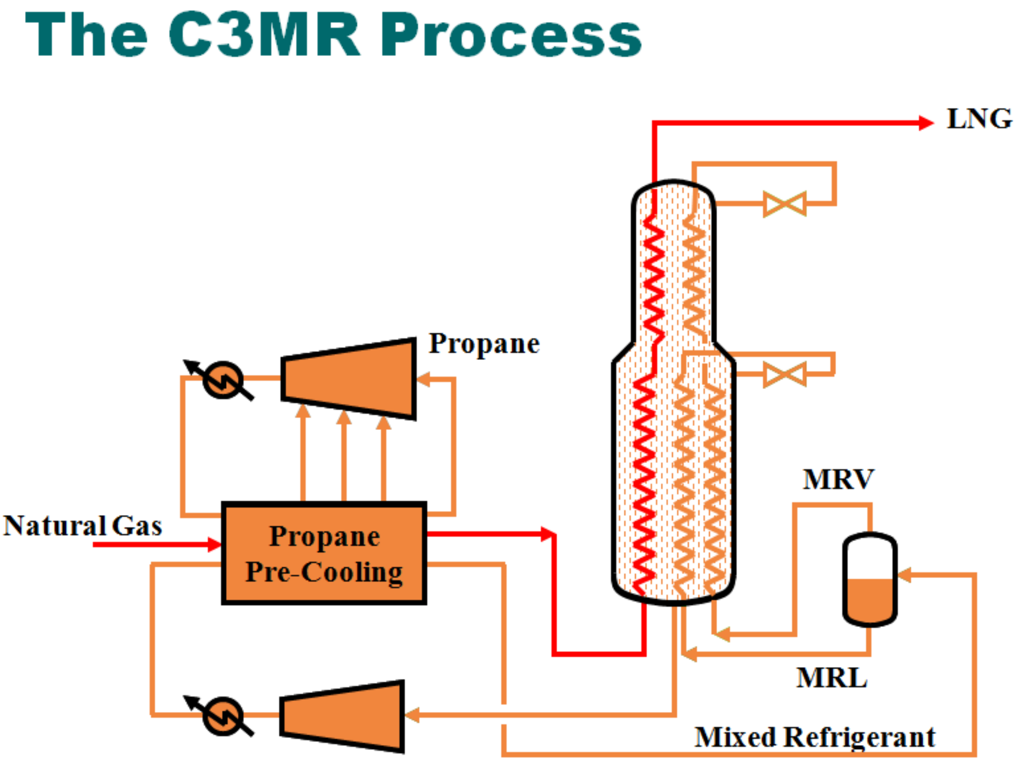


Figure 5

The following example shows how the tool can help to identify a problem in the C3MR liquefaction process and return the plant to optimum performance. The dashboard in Figure 6 monitors the key parameters in the Propane System refrigeration loop. Each morning the previous 24 hours of data is run to look for any parameters that are outside of the normal operating range. On a particular day the engineer notices that a value is outside of the normal operating range. Figure 6 shows the dashboard relating to the Propane System.

LNG PROCESS Monitoring

DASHBOARD (2)

Jump To Tag | Jump To Doc | Graph Tag

start time	08 Sep 2014 9:36							
end time	09 Sep 2014 9:36		Performance		Normal		Alarm Limits	
TAG	DESCRIPTION	LATEST DATA	AVERAGE	UNITS	LOW	HIGH	LOW	HIGH
	Propane							
C3CondDT	Temp Difference (Air-C3)C3 Condenser E-144	23.2	24.0	C		23		25
	Check for Non-Condensables				(1)			
NonCondCheck	Press Difference C3 Accumulator minus Pure	0.3	0.2	Bar		0.2		0.5
PI-1	Press C3 Condenser/Accumulator	12.5	13.0	BAR				
PureC3Press	Pure C3 vap pres at Accumulator temp	12.7	12.8	barg				
	Check for C4+ components							
C4PlusCheck	Temp Difference LPC3 Comp Suction minus F	0.5	0.6	C		2		
TI-1	Suction Temp LPC3 Comp	-40.9	-40.1	°C		-36.6		-30
PureC3Temp	Pure LP C3 Boil pt temp at PI-2	-41.4	-40.4	C				

Figure 6

The dashboard shows that pressure difference between the Propane (C3) accumulator and the pure Propane vapor pressure at the accumulator temperature is greater than 0.2 bar. This causes the value to be highlighted showing it is out of the expected operating range (see circled area "(1)" in Figure 6). By selecting the row and then clicking on the "Jump to Doc" button (area (2), Figure 6), the Tag Deviation guide opens (shown in Figure 7).

Parameter **Tag #**	**Press Difference C3 Accumulator minus Pure C3 Vapor Press** **NonCondCheck**	**System**	**Propane**
Target / Design	Design: 0 bar Target:<0.20 bar	**Analysis Frequency**	**DCS Calculation**
Description	C3 vapor pressure difference - C3 accumulator pressure less (pure C3 vapor pressure at condensing temperature)		

Deviation	**Causes**	**Verification**	**Corrective Actions**
C3 vapor pressure difference is high	Non-condensables in propane circulation are making the C3 compressor HPC3 discharge pressure higher than pure C3 vapor pressure at condensing temperature.	Laboratory analysis of C3 reclaimer /condenser discharge vapor sample point.	Run C3 reclaimer/condenser to rid propane circuit of non-condensable N2, C1, C2. Refer to C3 Logic Diagram.
C3 vapor pressure difference is low	Normal operation; non-condensables are very low	Laboratory analysis of C3 reclaimer/condenser discharge vapor sample point	None

Related Surveillance Parameters	PI-XXXXX C3 condenser/accumulator pressure when C3 reclaimer/condenser is not running. TI-XXXXX C3 condensing temperature at the C3 accumulator inlet.
Comments	Sources of non-condensables are off spec propane and C3 compressor seal buffer/seal gas at startup. This variable is a DCS calculation.

Figure 7

From the tag deviation guide it shows this discrepancy is most likely caused by non-condensables accumulating in the Propane System. This can be verified by taking a sample of the Propane at the reclaimer / condenser vapor sample point. The corrective action is to vent the non-condensables. The deviation guide refers to the logic diagram which gives some additional information on the Propane System in the corrective action block. The first part of the logic diagram for the Propane System is shown in Figure 8.

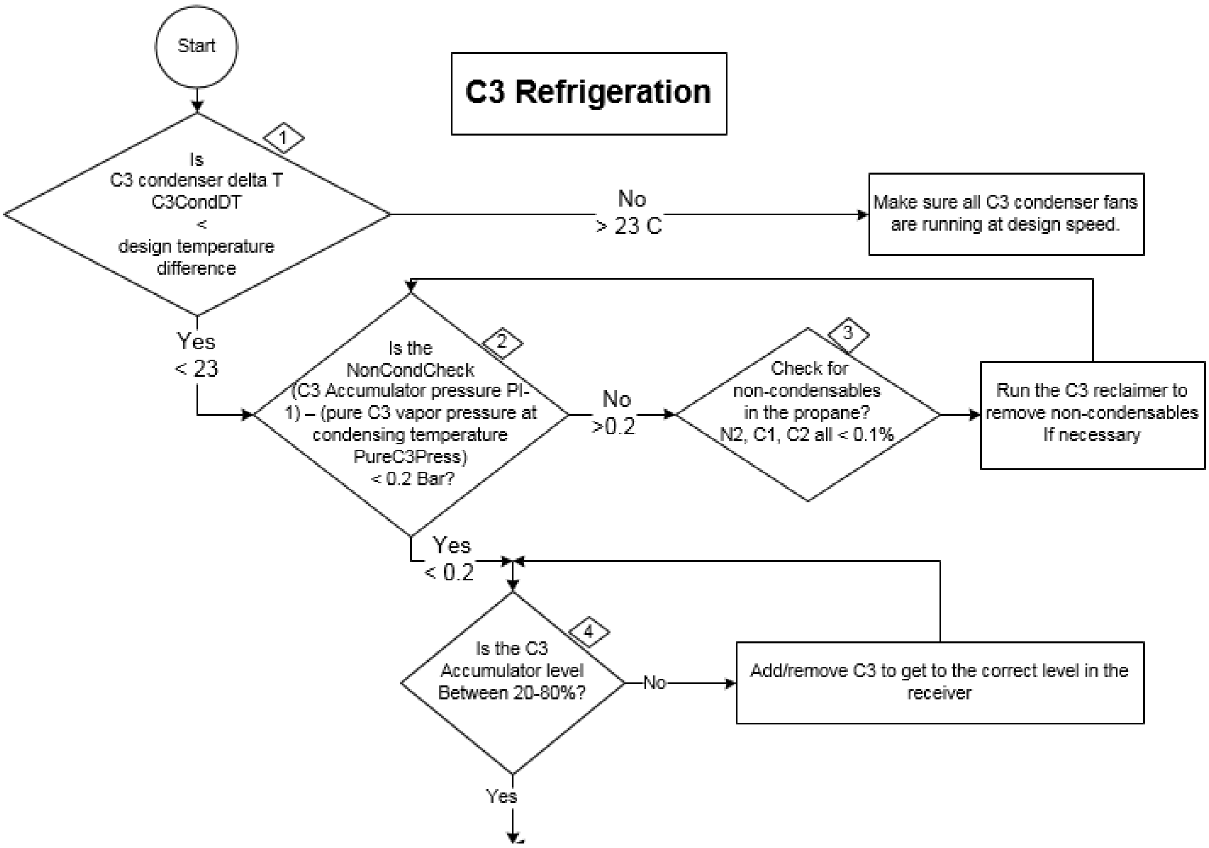


Figure 8

Based on this logic diagram, the user first looks at the condenser approach temperature. This is within the design limits (i.e., less than 23^{o}C) so the non-Condensable check is next. This is not less than 0.2 barg, so the logic diagram guides the user to check for non-condensables. A laboratory sample can be taken to confirm the presence of non- condensables and they can be removed by running the C3 reclaimer. After running the reclaimer and removing the non-condensables the non-condensable check should improve to less than 0.2 bar.

The rest of the Propane System logic diagram is not shown but it continues to address the optimisation. If the plant is not constrained by the Propane System the logic diagram refers to the LNG Production Rate Logic diagram which provides guidance on increasing LNG production.

Developing an Optimisation Programme

To develop an optimisation programme, engineers from the operating facility work closely with Air Products to determine the scope of the project and the important parameters to monitor. Piping and Instrumentation Diagrams/Drawings (P&IDs) of the liquefaction section of the process are provided to Air Products and the critical tags are identified and discussed. Tag deviation guides and logic diagrams are generated by Air Products and reviewed by the plant engineers.

The Process Dashboard is the last phase of the project to be developed. Development of this works best if there is a way to remotely access the data historian. This allows Air Products to test the program and verify that the data for all the parameters are being pulled in correctly. After the initial development of the dashboard, the process and alarm ranges for the critical process parameters are configured. These can easily be adjusted by the customer as the process is further refined.

RasGas Experience Using the Optimisation Tool

In late 2008 Air Products began to develop a tool to help RasGas optimise the AP-C3MR™ liquefaction process being utilized at their facility. Throughout 2009 Air Products developed the software. In October of 2009 the programme was delivered and Air Products was on site to conduct training on the use of the tool.

Since the initial project RasGas LNG has implemented the Optimisation Programme on both the AP-C3MR™ and AP-X® LNG Process trains and is implemented on a total of five different LNG Trains. RasGas is using the Optimisation Programme Tool on a daily basis to support process engineers doing Process Surveillance. Process deviation, alerts and advice are issued to the Operation Team. The tool helps the Operations Team efficiently operate the Main Cryogenic Heat Exchanger (MCHE) within a given operating range and gives guidance on how to return the plant to optimal performance.

Each morning the engineers use the tool to monitor key parameters such as the MCHE pressure drops, MCHE temperature differentials, and mixed refrigerant compressor suction temperature. This helps to insure that the plant is running within the parameters and alerts the engineers if something is not within the agreed range.

Based on the current operating data the tool helps the Operations Team adjust Mixed Refrigerant (MR) composition and MR circulation etc. This helps to maintain the proper temperature profile in the MCHE and to operate within the parameters. It assists in the adjustment of molecular weight of mixed refrigerants, MR circulation, and MCHE pressure drop. The program also helps to maintain the required LNG temperature at the outlet of MCHE.

This program helped to:
1) improve the integrity and reliability of liquefaction system;
2) minimise the energy requirement for the compressors;
3) debottleneck constraints; and
4) guide the operator during plant start-up, shutdown, and upsets.

The tool makes it easy to compare the operation and performance across the LNG trains, optimise LNG operation towards minimising energy requirement, and improve LNG yield.

Conclusion

The AP-Optiplus^{TM} computer tool guides troubleshooting and optimising performance of the liquefaction unit of an LNG plant. It incorporates Air Products expertise into an easy-to-use software program that collects data from the plant historian and assesses the condition of the liquefaction unit through monitoring of key process parameters. The Optimisation Programme advises an engineer/operator on adjusting the liquefaction unit to operate at peak performance and maximum LNG production. It is also a very useful training aide for both inexperienced and experienced engineers/operators in the operation and optimisation of the Liquefaction Unit.

For more information, please contact us at:

Corporate Headquarters
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195-1501
T 610-481-4861
F 610-481-6329
info@airproducts.com

tell me more
airproducts.com/LNG