LNG2019 SHANGHAI
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LESS IS MORE: FLARE MINIMIZATION DURING COOLDOWN

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During the startup of a new LNG facility, it is common to flare natural gas as the plant is brought on-line. This flaring consumes excess feed gas as well as creates environmental concerns. With new plants being built in more environmentally sensitive areas, there is a desire to reduce flaring during startup. This paper describes practical approaches to substantially reduce flaring including a new cooldown method and refrigerant conservation strategies.

The new cooldown method has been successfully implemented in several operating facilities. The new method has the added benefit of faster, more consistent start-ups. When coupled with an innovative automated cooldown method, the liquefaction unit can be successfully cooled down with minimal flaring and reduced thermal stress on the equipment. This new cooldown method can be implemented on both new projects and existing facilities.

For extended shutdowns, refrigerant conservation strategies will be described that allow for recovery of refrigerant throughout the liquefaction area, storage, and then reintroduction upon restart. For shorter shutdowns, liquefaction design considerations will be discussed that allow for simple and fast restarts that reduce the need to de-inventory refrigerants.

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INTRODUCTION

In October 1972 the first AP-C3MR™ main cryogenic heat exchanger or MCHE was commissioned and cooled down in Lumut, Brunei. In the 47 years since that start-up, this proven and effective method has been used successfully for nearly all MCHEs employing Air Products' technology. It consists of two manually controlled steps: a precooling step to bring the MCHE down to the propane precooling temperature of approximately -30°C followed by final cooldown where the mixed refrigerant flow is circulated throughout the process. The precooldown step flares the cooling gas while final cooldown flares the off-spec or warm LNG. Current environmental concerns and permitting requirements have resulted in a desire for reduced flaring during cooldown of LNG facilities. Many of the North American LNG plants are tolling facilities who purchase their gas from pipelines which means any flaring is a cost to the project or owner. These project requirements have led to the development of a new MCHE cooldown method.

A new method, Reduced Flaring Cooldown, has been successfully used to cooldown several AP-C3MR LNG trains. This new method eliminates the precooldown step resulting in less flaring and faster, more consistent start-ups. Reduced Flaring Cooldown can be utilized on new and existing facilities as no additional hardware or instrumentation is required. The method controls the precooling temperatures of the mixed refrigerant (MR) and the feed entering the MCHE by manipulating the propane system.

The next logical improvement in cooldown would be to automate the process to control to the optimal cooldown rate. An automated cooldown process has been developed to support this and will be discussed as well. Refrigerant conservation strategies should be developed to recover refrigerants and help with flare reduction.

THE AP-C3MR LIQUEFACTION PROCESS

The AP-C3MR liquefaction process cools and liquefies natural gas using two refrigeration loops. See Figure 1. Natural gas is fed to the precooling section where it is cooled from ambient temperatures to approximately -30°C with a multi-pressure level propane refrigeration loop. The pre-cooled feed gas then enters the MCHE which is a coil wound heat exchanger or CWHE. For more information on the MCHE see References 4 and 5. The natural gas is then liquefied using a mixed refrigerant or MR which is a combination of nitrogen, methane, ethane/ethylene, and propane. The LNG exits the cold end of the MCHE before being sent to the LNG storage tank.

In the MR refrigeration loop, the high-pressure MR is cooled by propane to approximately -30°C, and it partially condenses. The MR is separated in the HP MR separator into MR liquid (MRL) and MR vapor (MRV). The MRL enters the warm end of the MCHE where it is subcooled. The MRL is removed at an intermediate point of the MCHE, reduced in pressure and sent to the MCHE shell side. The MRV enters the warm end of the MCHE where it is liquefied and subcooled. The MRV exits the cold end of the MCHE before being reduced in pressure and returned to the shell side. The MRV and MRL boil on the shell side, providing the refrigeration to liquefy and subcool the incoming natural gas and MR. Superheated vapor MR exits the warm end of the MCHE before being compressed.

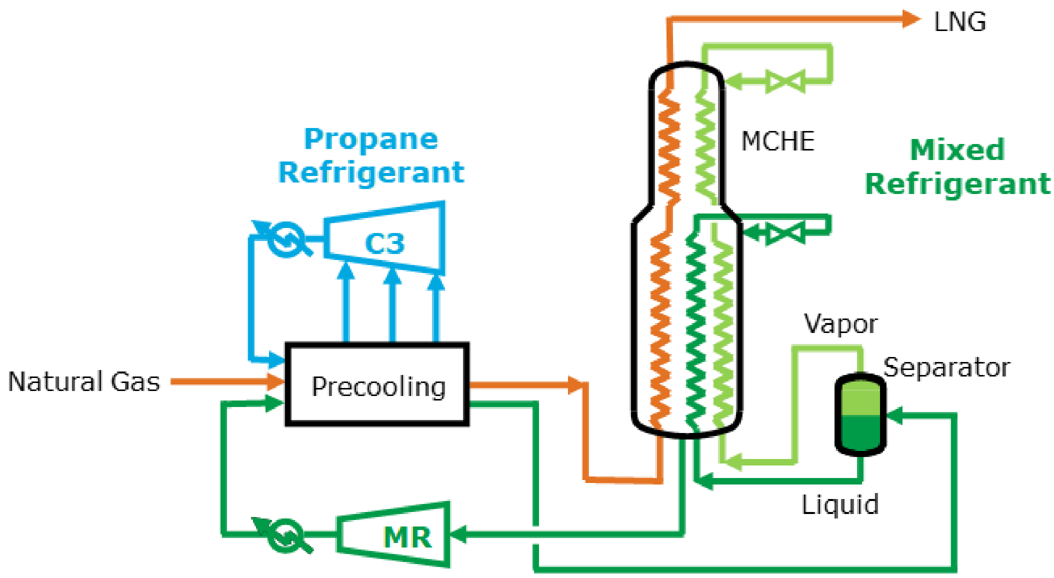

Figure 1: Air Products' AP-C3MR LNG Process

PREPARATION FOR COOLDOWN

The heart of the LNG process is the main cryogenic heat exchanger where the natural gas is cooled and liquified. The LNG exits the MCHE at temperatures colder than -140°C where water, CO2, or BTX can freeze out in the exchanger, on strainers, or across control valves. It is critical in the commissioning of an LNG facility to properly inert and defrost the equipment. Traditionally defrost has been accomplished with feed gas, but heated nitrogen can be used preferentially in place of feed gas to eliminate flaring while defrosting. Regardless of which defrost gas is used, all equipment should be warmed to 50°C first before confirming dew points less than 10 ppmv. This highly effective defrost method along with monitoring of the dehydration unit and the immediate correction of any issues will help avoid unnecessary shutdowns. After the entire liquefaction train has been warmed and defrosted and the acid gas removal, dehydration, and mercury removal pretreatment units are operational and meeting specification, the equipment can be cooled down.

TRADITIONAL COOLDOWN

In the traditional cooldown method for the AP-C3MR process, the MCHE and associated piping and equipment are first precooled with clean, dry feed gas that is cooled in the feed propane chillers to -30°C. The cooled gas is blended with warmer feed gas to match the temperature of the exchanger. It then enters the low-pressure MR return line as shown in Figure 2 where it flows on the shell side of the MCHE from the bottom to the top and exits through the shell side vent valve. The cooling gas flows through the shell side and over the outside of the process tubes. The cooling gas is gradually lowered in temperature until the final pre-cooling temperature of -30°C is achieved. This is done to avoid thermally stressing the equipment. While the MCHE is being precooled, the HP MR separator vessel is also cooled to -30°C. The time to cool the MCHE is typically 4-8 hours while the HP MR Separator can take up to 12 hours. During this activity the cooling gas is flared. After the MCHE and HP MR Separator reach -30°C, the precooling valves are closed, and the equipment is prepared for final cooldown.

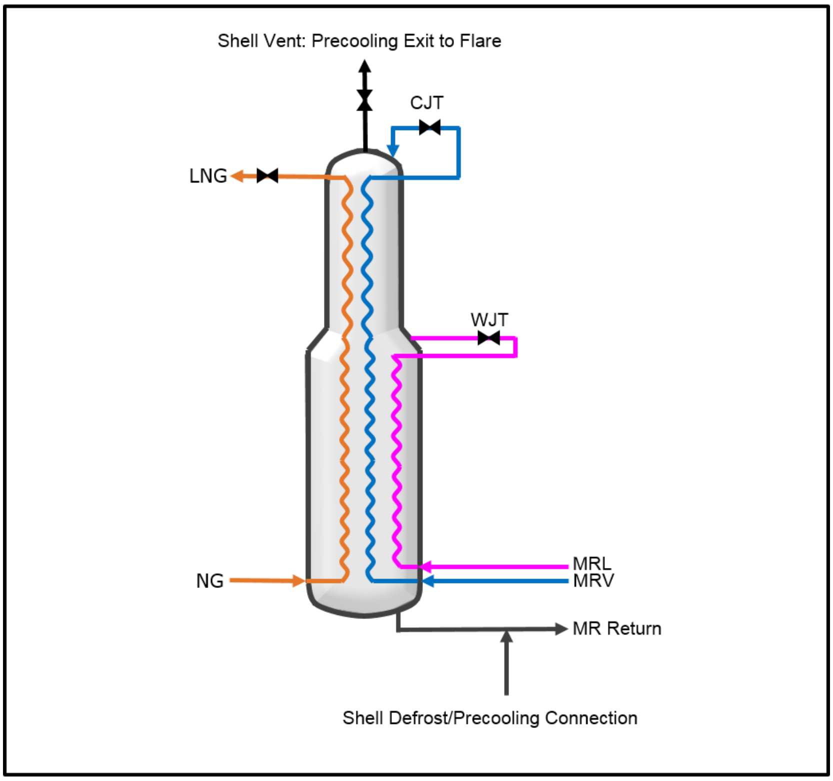

Figure 2: Precooling Flow Path

After the MCHE has been precooled and the flow to the MR return line is stopped, the mixed refrigerant flows are started in the normal flowing direction by opening the cold and warm MR Joule-Thompson (J-T) valve to begin final cooldown. Initially, with the MR inventory consisting of feed gas which is mostly methane, the available circulating refrigeration will be limited. The MR composition is gradually adjusted with the addition of C2 and C3. During the early stages of the cooldown process, there is no feed flow through the MCHE. As C2 and C3 are added to the mixed refrigerant, liquid MR will start to form at the outlet of the J-T valves and provide increased refrigeration to the process. Feed flow is initiated when this occurs to help control the MCHE rate of cooling. The feed gas exiting the MCHE can be used to cool downstream equipment or flared depending on what simultaneous operations are occurring. Eventually the gas exiting the MCHE will be cold enough to liquefy and can be sent to the storage tank if it has been temperature conditioned. Nitrogen is added to the MR inventory when the cooldown step is nearly complete and is necessary to achieve the desired subcooled LNG temperature exiting the MCHE.

REDUCED FLARING COOLDOWN

The Reduced Flaring Cooldown method eliminates the pre-cooldown step which reduces the total quantity of feed gas that is flared and shortens the total cooldown time. It is used for the initial start-up and after major outages. Reduced Flaring Cooldown is accomplished using feed gas in both the feed and MR circuits. All flows through the MCHE are in the normal flow direction. Feed and MR streams enter the MCHE warm end and flow up through the tube circuits. There is no reverse flow through the shell as there is with the traditional precooling step. The MR and Feed temperatures entering the MCHE are gradually reduced by adjusting the propane chiller performance.

Cooling begins with the opening of the cold J-T valve as the MRV starts to circulate. The warm J-T valve is opened after the cold front starts to move down from the cold end (top) of the MCHE towards the warm end (bottom). Figure 3 shows a simplified PFD for the AP-C3MR process and captures the normal flow path for the mixed refrigerant circulation. With the MR inventory consisting mainly of methane (feed gas), the cooldown rate is limited due to the quality of the refrigeration and the system conditions. C2 and C3 make-up components are added to the

MR to maintain the desired cooldown rate. A small feed flow is established early in the MCHE cooldown process which can be used to cool downstream equipment including end flash units and rundown lines.

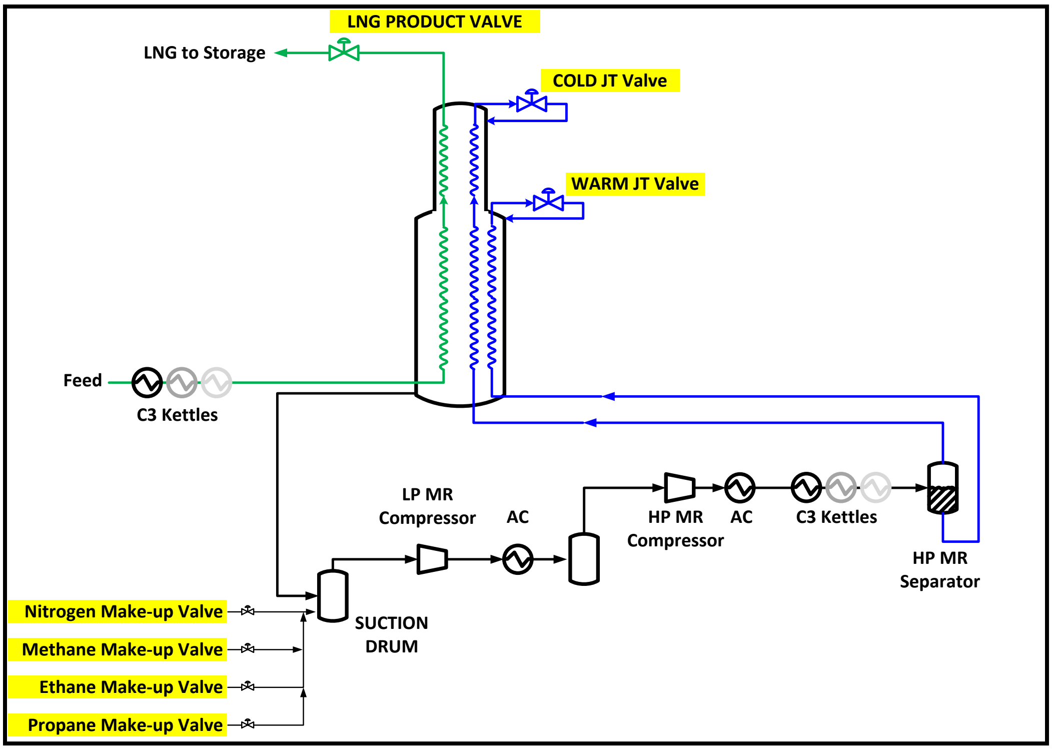

Figure 3: Simplified AP-C3MR PFD

Cooling with the propane chillers is required to complete the cooldown. The MR and Feed propane chillers are brought sequentially into service starting from high pressure to low. There are two possible methods for controlling the temperatures exiting the kettles: propane liquid level or propane pressure control. Level control in the kettles is possible if the valves used for level control are designed for tight shutoff. Pressure control can be used to back pressure the kettles and raise the boiling point of the propane, but this requires that the equipment is designed for higher pressure and the appropriate valves are in place for pressure control. The successive introduction of each propane chiller occurs when the bottom of the MCHE starts to cool. This maintains the proper temperature differential into the MCHE.

As cooldown progresses, adjustments are made to maintain the proper cooldown rate.

- The MR inventory system is continually charged with C2 and C3.
- Methane is added to maintain the MR compressor suction pressure as the system cools and MR condenses in the tubes.
- The MR J-T valves are adjusted to control the amount of refrigeration flowing into the MCHE.
- The compressor operation is adjusted with anti-surge valves and compressor speed.

Within 12-24 hours the system will be cooled down and LNG produced.

PLANT EXPERIENCE WITH REDUCED FLARING COOLDOWN

The new cooldown method has been used at several facilities, all of which have expressed positive feedback. The cooldown time has been reduced by up to 25% with 12 hours of reduced flaring. As this was practiced for the first time at a few of the locations, further reductions are probable as more experience is gained. The new method produced a very smooth cooldown and was accomplished with minimal resources. The operating staff at LNG facility expressed extreme pleasure with the new method because it gave the board operator complete control to accomplish cooldown.

AUTOMATED COOLDOWN

The next progression in cooldown improvements and flare reduction is automation of the process. Air Products has developed and patented the AP-AutoCool™ Program which allows the MCHE to be cooled automatically with minimal human intervention. See Reference 3 for additional information. This produces a more consistent operation that approaches the optimal cooldown rate while keeping within manufacturer's operating guidelines. This method was developed to use the existing valving and instrumentation for ease of implementation. The AP-AutoCool Program can be used on many different LNG process cycles including the AP-C3MR, AP-DMR™, AP-SMR™, AP-X®, and AP-C1™ LNG Liquefaction Processes.

Automated MCHE cooldown eliminates the need for the operator to determine and control circulating refrigerant flow rates, refrigerant component addition, feed gas flow rate, and refrigerant compressor operating points. The AP-AutoCool Program manages all of these to provide a cooling duty that achieves the maximum recommended cooling rate. The available refrigeration changes with MR composition, flowrate, and pressure profile as the cooling progresses. A feedback control loop uses feed flow as a heat load to balance against the refrigeration duty to maintain the desired cooldown rate. This is the primary controller with secondary controllers adjusting the MR flow rates, composition, and propane precooling.

In the traditional cooldown method there are only seven valves that are controlled during cooldown:

- Cold J-T valve
- Warm J-T valve
- LNG product (J-T) valve
- Nitrogen make-up valves to MR inventory
- Methane make-up valve
- C2 make-up valve
- C3 make-up valve

Automating the new Reduced Flaring Cooldown process requires the addition of a control loop on each of the propane chillers.

BENEFITS OF THE AP-AUTOCOOL PROGRAM

The automated cooldown methodology was developed using dynamic simulation, but the concept has been validated in an operating facility. Figure 4 shows the expected benefits of automated cooldown compared to manual. It shows a large reduction in the time to cooldown. Automated cooling eliminates variability on cooldown and any temperature excursions outside the recommended guidelines.

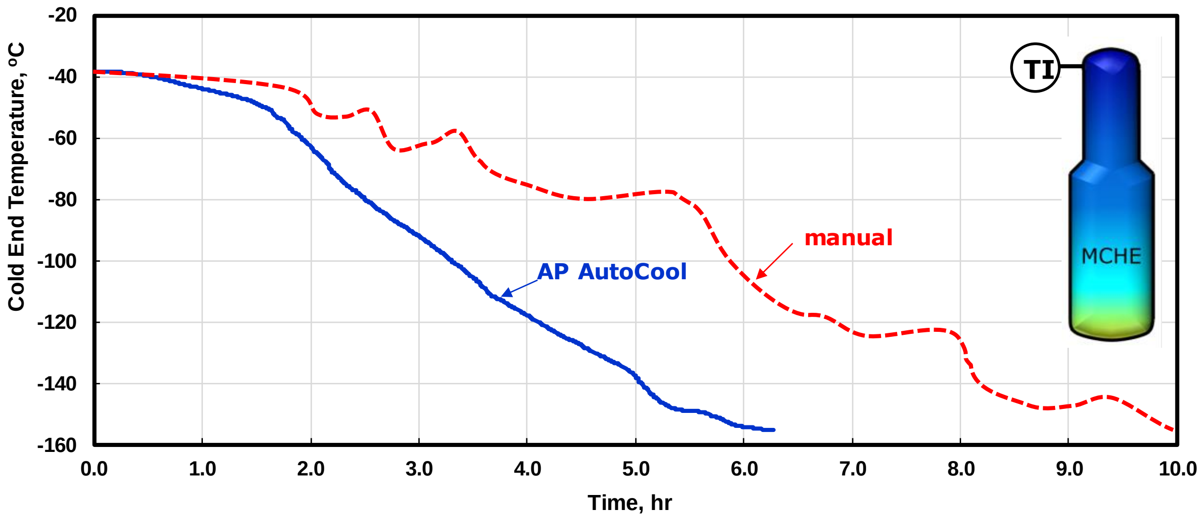

Figure 4: Automated vs Manual Cooldown

An operating facility was successfully cooled down using methods that replicated the AP-AutoCool program but was done manually. Each control concept was verified through this manual execution. The test results showed that the automated cooldown program can achieve the maximum cooldown rate in a controlled manner while minimizing thermal stresses on the MCHE. The AP-AutoCool program will provide a simplified and repeatable MCHE cooldown method that reduces flaring and produces LNG in the fastest manner possible.

ADDITIONAL FLARE REDUCTION OPPORTUNITIES

Using Reduced Flaring Cooldown and the AP-AutoCool program together simplifies start-ups and greatly reduces flaring, but a highly reliable plant with a high on-stream time will contribute the most towards reduced flaring. Plant and equipment reliability should be analyzed. Fault tolerance should be designed into the facility to eliminate single points of failure that can shut down the facility. There are several other design and operational considerations that could further assist with flare reduction.

REFRIGERANT DRIVER/COMPRESSOR SELECTION AND CONFIGURATION

Careful consideration should be given to the selection of the refrigerant driver/compressor type and configuration. For example, parallel compressor strings can increase the liquefaction train availability. If one string trips and the other stays online, the liquefaction equipment stays in operation at a reduced production rate. This reduces or eliminates flaring during the trip and simplifies the return to full production once the offline compressor string is available. See Reference 6 for more information on parallel compression availability. The choice of multi-shaft refrigerant drivers can also assist with reduced flaring. This allows for the compressor to restart at settle out pressure, i.e. no torque limitations are encountered that would require depressurization.

LNG RECYCLE

The best time to address flare reduction is during the project development phase of new LNG facilities. Figure 5 below shows a typical LNG facility block diagram. As previously discussed in the cooldown section, a large portion of flaring occurs from warm LNG. The backend of the plant is not always ready to receive LNG and warm LNG can be even more problematic. Compressor issues with the BOG, Endflash or Fuel compressors could result in flaring of LNG vapors.

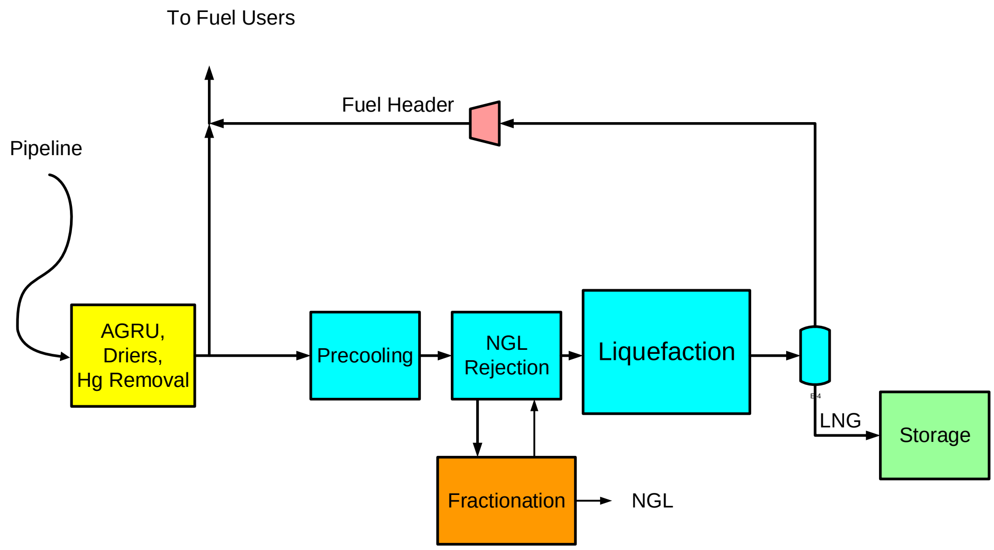

Figure 5: Typical LNG Plant Block Diagram

These effects can be mitigated by including the ability to recycle LNG back to the front end of the process. Figure 6 shows a simplified block diagram with this recycle line. The LNG and LNG vapors are cold and may require a vaporizer/warming heat exchanger. The block diagram shows a separate recycle compressor but if the design conditions are appropriate, it is possible to combine the recycle duty with the feed booster compressor.

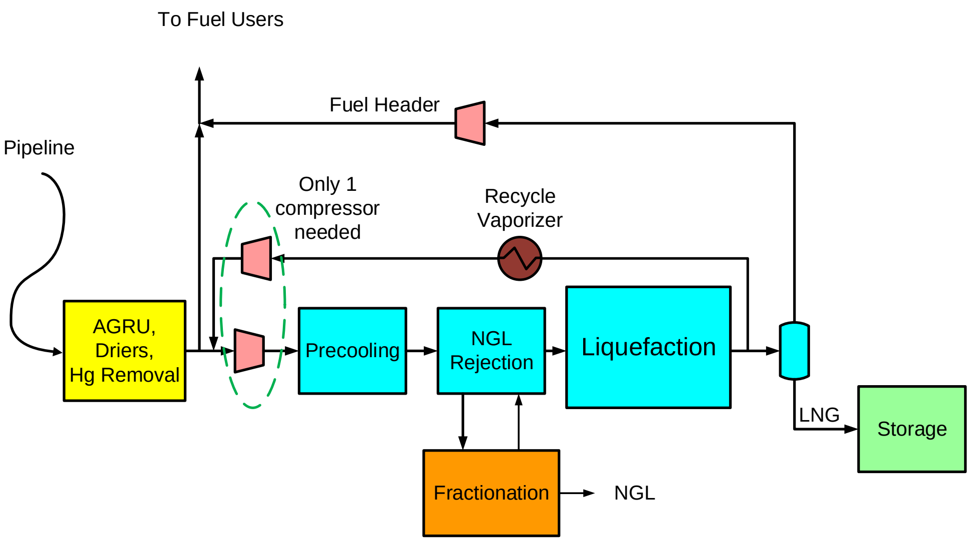

Figure 6: Reduced Flaring LNG Block Diagram

MIXED REFRIGERANT INVENTORY MANAGEMENT

There are occasions when the mixed refrigerant composition must be adjusted due to seasonal or operational variations. Composition adjustment is accomplished by venting from different locations to optimize individual component removal. The removed MR inventory is either flared, sent to fuel, mixed in with LNG, or sent to the fractionation unit. A mixed refrigerant recovery vessel is an option to capture any cryogenic liquids which can then be pumped back into the circulating MR system when needed. There are also maintenance situations where the propane or MR drivers/compressors are shut down for maintenance. Instead of flaring the refrigerants, systems can be designed for recovery. The propane storage system should be designed for bi-directional flow while the MR can be recovered using one or more of the methods mentioned above.

CONCLUSIONS

A new method, Reduced Flaring Cooldown, has been successfully used to cooldown several AP-C3MR LNG trains. This new method eliminates the precooldown step resulting in less flaring and faster, more consistent start-ups. Reduced Flaring Cooldown can be utilized on new facilities or easily retrofitted to existing facilities. The method controls the precooling temperatures of the mixed refrigerant and feed entering the MCHE by manipulating the propane system as the flows circulate through the exchanger.

An automated cooldown process, AP-AutoCool Program, has been developed that allows the MCHE to be cooled automatically with minimal human interaction for a more consistent cooldown with reduced flaring. The AP-AutoCool Program can be used with both traditional and Reduced Flaring Cooldown methods. Additional flare reduction opportunities include optimized refrigerant driver/compressor configuration, the recycle of LNG during cooldown, and mixed refrigerant inventory management.

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