

Design Suite to Remove Heavy Hydrocarbons from a Comprehensive Range of LNG Feed Gas Compositions

Wes Qualls
Engineering Fellow
ConocoPhillips Company
925 N. Eldridge Parkway
Houston, TX 77079
281-293-3055
Wes.Qualls@ConocoPhillips.com

Attilio Praderio
Principal Engineer
ConocoPhillips Company
925 N. Eldridge Parkway
Houston, TX 77079
281-293-3046
Attilio.J.Praderio@ConocoPhillips.com

Qi Ma
Principal Engineer
ConocoPhillips Company
925 N. Eldridge Parkway
Houston, TX 77079
281-293-2958
Qi.Ma@ConocoPhillips.com

GASTECH 2019

Abstract

Over the past quarter century, there has been tremendous growth within the LNG industry. Heavy hydrocarbon removal design innovations have accompanied that growth. The industry has experienced a need to process associated gas laden with heavy hydrocarbons, shale and pipeline gas with only a little heavy hydrocarbons, and coal seam gas with almost no heavy hydrocarbons. Each situation presents unique challenges, requiring different design approaches. For a liquefaction facility processing associated gas with large quantities of LPG and NGL components, project economics generally favor an optimized design for high LPG recovery. For pipeline gas, the objective shifts toward removing just enough components to prevent freezing. Even the Curtis Island, Australia LNG facilities that process coal seam methane required a detailed analysis to ensure that no heavies removal system was necessary.

There is no "one-size-fits-all" solution. Designers must address various feed compositions with a suite of design options. One of the most critical decisions of any LNG project is selecting the heavy hydrocarbon removal technology. But, selecting the correct option completely depends on properly quantifying and characterizing the full range of feed compositions. Careful coordination is required between the owner, EPC contractor, and liquefaction technology providers. The design must efficiently and reliably remove enough heavy hydrocarbon components to control the LNG product energy (BTU) content, prevent freezing at all locations within the liquefaction process, and ensure that all LPG and/or NGL products meet specifications.

This paper will present a holistic approach to heavy hydrocarbon removal system designs for LNG liquefaction, beginning with how to properly characterize the feed and ending with a suite of design options that address the wide range of feed gas compositions that may be encountered. Proven design approaches for the unique challenges of processing lean pipeline feed gas through associated gas will be presented.

Introduction

A particularly frustrating question often asked is, "Can we design a one-size-fits-all LNG liquefaction solution?" The question never seems to be about size so much as design, such that it would be more aptly phrased, "Can we provide a one-design-addresses-all LNG liquefaction solution?" The answer is a resounding "No." One would first need to ensure that world-wide gas compositions fall within a narrow band for all reservoirs, all common carrier pipelines, and all associated gas liberated from oil production. One would then need to hold the ambient and/or water temperatures around the globe within narrow bands, as well as all LNG, LPG, and NGL product specifications. It's a safe assumption that these things are highly improbable. There simply is no "one-design-addresses-all" solution. Process Engineers must therefore design to match individual project conditions. With that said, it is possible to generate a suite of options to address the gambit of project conditions that includes as much commonality as possible.

It should be intuitive that process designs must vary with feed gas compositions. However, for multiple and sometimes very good reasons, too little focus is spent on properly "characterizing" the feed gas. Consider that when the LPG and NGL components of an overall gas composition are small, the natural tendency is to minimize design focus on units processing those components. But when heavier components will either result in off-specification LNG production or freeze, they must be concentrated and removed. And, what may appear as very small variations within the LPG and NGL portion of the overall feed gas composition results in very large variations within the heavy hydrocarbon removal system, once the lighter components are removed. Additionally, since component freezing generally occurs in the low parts per million (ppm) and parts per billion (ppb) range, more care than may be intuitively obvious is warranted. The first step of any LNG liquefaction facility design should be a thorough feed gas characterization effort. Unfortunately, skipping this step can lead to costly rework.

The next step is to select the best process design approach. And nothing impacts the process design of an LNG liquefaction facility more than the heavy hydrocarbon removal system, when one is required. Since compositions, ambient conditions, and product specifications do vary around the globe, LNG liquefaction designers must offer options for every contingency. Following a brief discussion regarding feed characterization, a suite of proven heavy hydrocarbon removal options available for the Optimized Cascade® Process (OCP) is presented, addressing everything from reservoir gas, associated gas from oil production, coal seam gas, common carrier gas pipelines.

Feed Gas Characterization

Historically, there have been four main objectives for heavy hydrocarbon removal systems within the LNG industry; (1) remove enough of the heavier hydrocarbon components to maintain the LNG product within specifications, (2) remove components to low enough concentrations to prevent freezing, (3) meet project LPG recovery targets (as applicable) to maximize overall project economics, and (4) maintain all LPG (as applicable) and NGL products within specifications. What is not explicitly stated is an expectation the design will consistently achieve these four objectives with minimal operator interaction across varying feed compositions and ambient conditions without downtime. It is instructive to recall that some components must be removed to the low ppm and others to the ppb levels.

While nothing impacts the process design of an LNG liquefaction facility more than the heavy hydrocarbon removal system (when one is required), nothing impacts the heavy hydrocarbon removal system design more than the feed composition. The quantity, speciation, compositional range, and rate of variation must be accurately defined for the heavy hydrocarbon removal system to function as expected. But it is not always practical to list every component in the feed and even less practical to include in the heat and material balance simulations. To simplify, it is common to group components by carbon number (C5s, C6s, C7s and so on), lump into larger groups (C5+, C6+, C7+ and so on), and/or proportion in some assumed combination. Engineers often assign one component to represent all components in a group, such as (nC5 to represent all C5s) and (nC6s to represent all C6s). But consider that neo-pentane (neo-C5) has the exact same number of carbon and hydrogen atoms as normal or iso-pentane (nC5 or iC5) yet freezes at significantly higher temperatures. Likewise, benzene (C₆H₆) is a C6 that freezes at significantly higher temperatures than either normal hexane or iso-hexane (nC6 or iC6). Similarly, para-xylene (C₈H₁₀) will freeze at significantly higher temperatures than any other C8 component, including ortho or meta-xylene (which are both also C₈H₁₀). Molecular structures dramatically impact freezing temperatures. The resulting freezing point differences can be quite significant, particularly for heavier hydrocarbons. Consider an example from Table 1 where C₁₄H₂₆ compounds, all with the same molecular weight, differ in freezing point temperatures across a range of 130°C (234°F).

Component	Formula	MW	Boiling Point	Density	Freezing Point
		g/mol	°C	g/cm ³	°C
1, 1-dicyclohexylethane	C ₁₄ H ₂₆	194.36	271.17	0.8897	-20.82
1, 2-dicyclohexylethane	C ₁₄ H ₂₆	194.36	272.5	0.8728	11.5
1-nonylcyclopentene	C ₁₄ H ₂₆	194.36	254	0.8212	-50.02
1-tetradecyne	C ₁₄ H ₂₆	194.36	252	0.7874	20.86
3-tetradecyne	C ₁₄ H ₂₆	194.36	255	0.8429	79.99
7-tetradecyne	C ₁₄ H ₂₆	194.36	262.45	0.7991	50.43

Table 1: Freezing Point Differences Between C₁₄H₂₆ Compounds [1]

Accurately defining the phase envelope, particularly the hydrocarbon dew point portion, is also critically important for both the feed pretreatment and liquefaction section designs.

Unexpected hydrocarbon condensation in acid gas removal systems, gas dehydration systems, fuel gas systems, and in the liquefaction section upstream of the heavy hydrocarbon removal system is not uncommon. As those familiar with operation of these systems can attest, unexpected liquid formation can be undesirable.

Component			C14 Extended	C9+ split 60/30/10	C9+	C6+ split 60/30/10	C6+
helium	mol	He	4.9807	4.9807	4.9807	4.9807	4.9807
hydrogen		H ₂	0.9961	0.9961	0.9961	0.9961	0.9961
nitrogen		N ₂	183.2910	183.2910	183.2910	183.2910	183.2910
carbon dioxide		CO ₂	67.7380	67.7380	67.7380	67.7380	67.7380
Methane		C ₁	9298.0325	9298.0325	9298.0325	9298.0325	9298.0325
Ethane		C ₂	283.9018	283.9018	283.9018	283.9018	283.9018
Propane		C ₃	80.6879	80.6879	80.6879	80.6879	80.6879
i-butane		iC ₄	12.9499	12.9499	12.9499	12.9499	12.9499
n-butane		nC ₄	15.9383	15.9383	15.9383	15.9383	15.9383
i-pentane		iC ₅	3.9846	3.9846	3.9846	3.9846	3.9846
n-pentane		nC ₅	2.9884	2.9884	2.9884	2.9884	2.9884
cyclopentane		C ₅ H ₁₀	0.2391	0.2391	0.2391	0.2391	0.2391
n-hexane		nC ₆	2.7892	2.7892	2.7892	3.41274	5.6879
cyclohexane		C ₆ H ₁₂	0.1992	0.1992	0.1992		
benzene		C ₆ H ₆	0.1692	0.1692	0.1692		
n-heptane		nC ₇	0.8965	0.8965	0.8965	1.70637	
toluene		C ₇ H ₈	0.0598	0.0598	0.0598		
n-octane		nC ₈	0.7471	0.7471	0.7471	0.56879	
p-xylene		C ₈ H ₁₀	0.0100	0.0100	0.0100		
n-nonane		nC ₉	0.3287	0.4901	0.8169		
n-decane		nC ₁₀	0.2889	0.2451			
n-undecane		nC ₁₁	0.1096	0.0817			
n-dodecane		nC ₁₂	0.0598				
n-tridecane		nC ₁₃	0.0199				
n-tetradecane		nC ₁₄	0.0100				
Temperature	°F		60.0000	60.0000	60.0000	60.0000	60.0000
Pressure	psig		400.0000	400.0000	400.0000	400.0000	400.0000
	HCDP		85.7°F	56.9°F	38.6°F	8.7°F	-18.4°F
	Press	PSIG	400	400	400	400	400

Table 2: Hydrocarbon Dew Point Values Calculated Using SRK EOS

Consider the example illustrated in Table 2, where lumping components with techniques commonly applied throughout the industry resulted in Hydrocarbon Dew Point (HCDP) temperatures varying over 57.8°C (104°F). [2] [3]

Clearly, another means of predicting phase behavior and freezing is necessary other than lumping or grouping hydrocarbon components. Fortunately, there are "characterization" techniques available to provide better phase behavior and freezing point predictions. However, while "characterizing" crude oils containing large numbers of components is understood and widely used throughout the oil industry, "characterizing" the mid-range boiling components of interest for an LNG liquefaction facility differ. Reservoir engineers routinely characterize crude oils by creating "pseudo components" to accurately represent fractions of the whole. With enough pseudo components for the various boiling fractions (cuts), one can define the behavior of the whole. The same general concept is followed for mid-range boiling components, only using different characterization techniques. For an LNG liquefaction facility, the feed characterization must be done in a holistic manner that predicts both hydrocarbon phase behavior as well as freezing, throughout the entire facility. Since all parties have a vested interest in the outcome, it is highly recommended to involve client, contractor, and liquefaction technology provider Subject Matter Experts (SMEs) familiar with physical property characterization techniques at the beginning of LNG liquefaction projects to complete a thorough feed characterization effort. Coordination between all three parties early in the project can provide higher levels of confidence for the heavy hydrocarbon removal system design and yield great dividends for all concerned over the life of the project.

Heavies Removal Column Options - Two-Column Approach

With an accurately characterized feed composition, the heavy hydrocarbon removal system design, if required, may progress. As established earlier, there is no "one-design-addresses-all" approach. There is however a suite of available options within the Optimized Cascade® Process to address essentially any feed composition. All options requiring heavy hydrocarbon removal presented in this article include a two-column solution, with the first of the two referenced as the "Heavies Removal Column". The available options are:

- None
- Non-Refluxed Heavies Removal Column
- Lean Refluxed Heavies Removal Column
- Rich Refluxed Heavies Removal Column
- Internal Solvent Recovery & Circulation
- External Solvent Injection, Recovery & Circulation

Of course, the simplest LNG liquefaction design does not include a heavy hydrocarbon removal system, applicable for reservoirs, pipelines, or wells consisting predominately of methane with very little LPG and NGL components and no components in high enough concentrations to freeze. The Kenai, Alaska LNG facility processed gas from predominately methane reservoirs for over 47 years without a heavy hydrocarbon removal system. Similarly, the six (6) LNG trains on Curtis Island, Australia brought online between 2014 and 2016 process predominately methane feed gas streams with no need to remove heavy hydrocarbons.

When a heavy hydrocarbon removal system is required, a two-column approach is generally recommended. The first column must remove enough heavier hydrocarbon components to maintain LNG product specifications and prevent freezing in downstream operations. Since the column overhead is condensed to form LNG, it is particularly advantageous to operate at pressures as high as possible to conserve refrigeration power requirements. Unfortunately, it is more difficult to separate components by fractionation at higher pressures. Fractionation requires both liquid and vapor phases such that it is not possible to separate components by fractionation over the critical point. The general approach is therefore to push the column operation as close as possible to the critical pressure and temperature and still achieve the required separation. And as established earlier, the column must remove some components to low ppm and even low ppb levels. To meet the stringent separation requirements at high pressures, it is necessary to allow a fairly significant volume of lighter components like methane and ethane to exit the bottom of the first column.

The second column operates at lower pressures, where the lighter components from the first column bottoms are more easily separated and returned to the LNG process. The primary functions of the second column are to (i) ensure that there are no component concentrations high enough to freeze in streams returned to the LNG process, and (ii) ensure the bottoms, side, and overhead product specifications are met. If there are significant LPG products, the column may be configured as a Deethanizer (DeC2) with the bottoms stream routed to further fractionation. If LPG or NGL components are not present in financially attractive recoverable quantities, the column is often configured as an NGL Stabilizer where the bottoms condensate must simply meet a Reid Vapor Pressure (RVP) specification.

A third column overhead stream may be integrated into the liquefaction design in some circumstances to improve efficiency. However, the efficiency improvements not substantial enough to justify the additional equipment. The most common heavy hydrocarbon removal options for LNG liquefaction within the OCP are described in the sections that follow.

Expander/Recompressor & Expander Option(s)

An expander/compressor (componder) configuration is often employed in gas plants to reduce feed pressures low enough to promote separation and then recompress the remaining gas to pipeline pressures. This works very well for gas plants where there are significant LPG and NGL components to remove. In such cases, the feed is expanded and fed to a column where the liquids are removed, and the remaining gas is recompressed. The energy from the expansion is usually sufficient to recompress the gas stream to pipeline delivery pressures. However, for many LNG liquefaction facilities, there are not as many liquids to remove, such that the expansion energy extracted may be insufficient to recompress the remaining overhead gas to the pressures required for efficient liquefaction. If a combined expander/compressor (componder) were selected in such cases, a second booster compressor would also be required, adding additional rotating equipment. There are however times when an expander/compressor option works well such as that presented later in Figure 6.

On the other hand, incorporating a gas expander upstream of the heavy hydrocarbon removal system without the gas recompression step is relatively common for high feed gas delivery pressures, particularly when high enough concentrations of NGL and LPG components are present to justify separate vapor and liquid feeds to the Heavies Removal Column. Several OCP trains are in operation with this Heavies Removal Column inlet configuration. Refer to Figure 1.

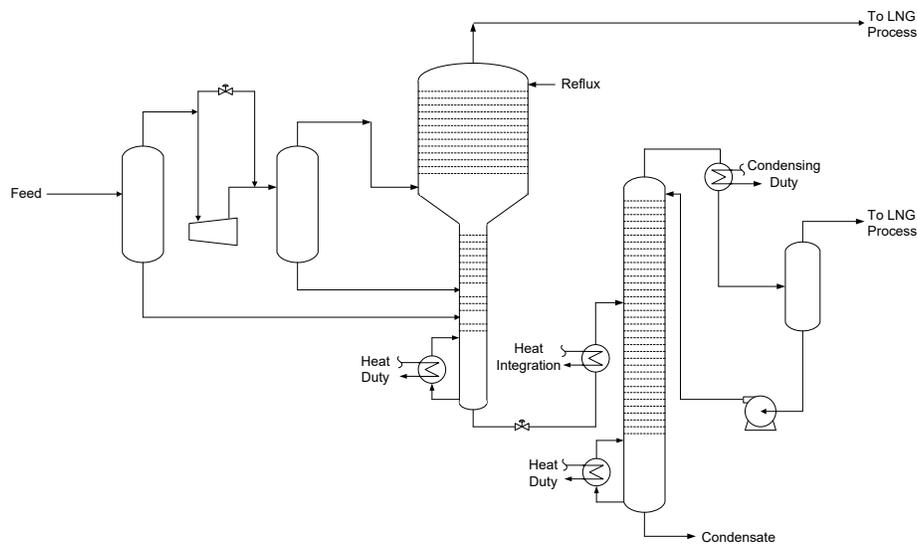


Figure 1: Expander Upstream of Heavy Hydrocarbon Removal System

Non-Refluxed Heavies Removal Column

A non-refluxed Heavies Removal Column is generally recommended for feed gas compositions with few recoverable LPG components, no components in high enough concentrations to freeze, but enough NGL components to require removal to control LNG product energy (BTU) specifications. Refer to Figure 2.

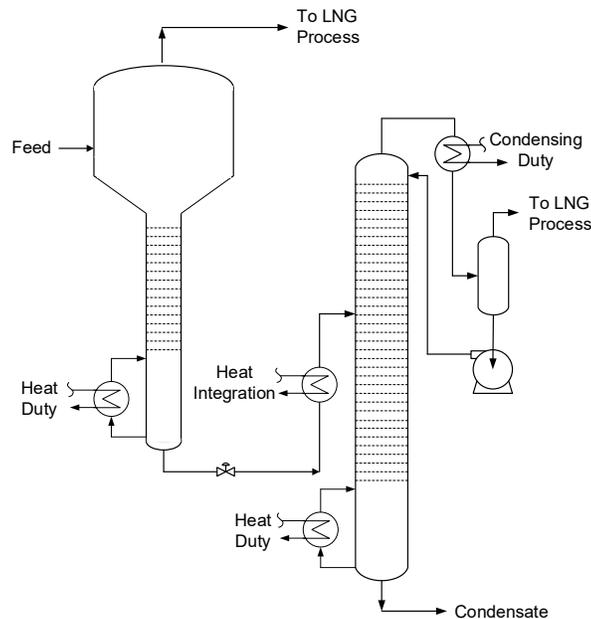


Figure 2: Non-Refluxed Heavies Removal Column System

In this configuration, heavier NGL components are removed in the bottoms stream of the first column and routed to the second column where the NGL is stabilized by removing lighter components before routing to condensate storage. The lighter components are returned to the LNG process through the second column overhead. The configuration may be equipped with a feed expander if the project economics justify. However, when NGL components are present with none in high enough concentrations to freeze, an upstream expansion step to recover LPG and NGL components has generally already occurred. Further expansion for liquids removal within the downstream LNG liquefaction train is usually not justified in such cases and the resulting condensate stream is quite small. One OCP facility is in operation with this configuration.

Lean Refluxed Heavies Removal Column

Multiple OCP facilities are in operation utilizing lean reflux for the Heavies Removal Column, making it the most prevalent option. Refer to Figure 3. In this configuration, a predominately methane stream is utilized to reflux the Heavies Removal Column. The reflux stream may originate from condensing a portion of the column overhead in a typical refluxed column approach, from recycling/pumping a portion of the liquids collecting in a downstream vessel, or by condensing a portion of a methane recycle stream in the process. The origin of the lean reflux stream is selected from the most optimal location, which primarily depends on the concentration of freezing components that must be removed and how much nitrogen (N_2) is in the plant feed. The lean reflux configuration is typically selected under the following circumstances.

- Relatively few LPG and NGL components in the feed
- Insufficient components within the C2 to C5 range to establish a rich reflux stream
- Ethane recovery is required

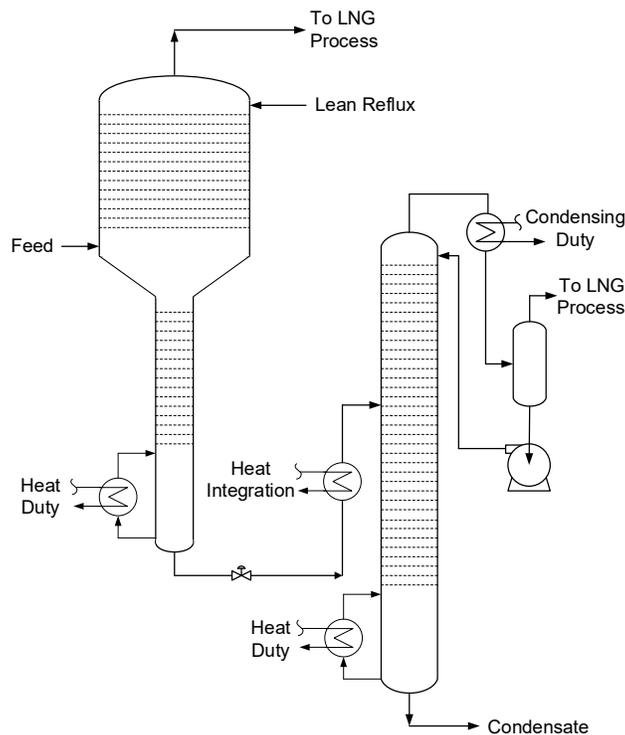


Figure 3: Lean Refluxed Heavies Removal Column System

Rich Refluxed Heavies Removal Column

When there are “consistently” enough components in the C2 to C5 range contained within the facility feed gas, a rich stream may be created from the overhead of one or more downstream columns and refluxed to the first column (Heavies Removal Column). Refer to Figure 4. By utilizing a richer reflux stream for the Heavies Removal column, comprised of a mixture of components in the C2 to C5 range and no components in concentrations that will freeze in downstream equipment, the column critical pressure is significantly increased. As mentioned earlier, it is advantageous to operate the Heavies Removal Column at as high a pressure as possible, without exceeding the critical point where distinct vapor and liquid phases no longer exist. With a higher critical pressure, the operating pressure may be higher, making the Heavies Removal Column overhead stream easier to condense, which conserves refrigeration horsepower that may then be utilized to produce more LNG. This configuration is utilized when one or more of the following conditions exists.

- Sufficient components within the C2 to C5 range are contained within the facility feed gas to establish a rich reflux stream for the Heavies Removal Column
- There are recoverable LPG and NGL components

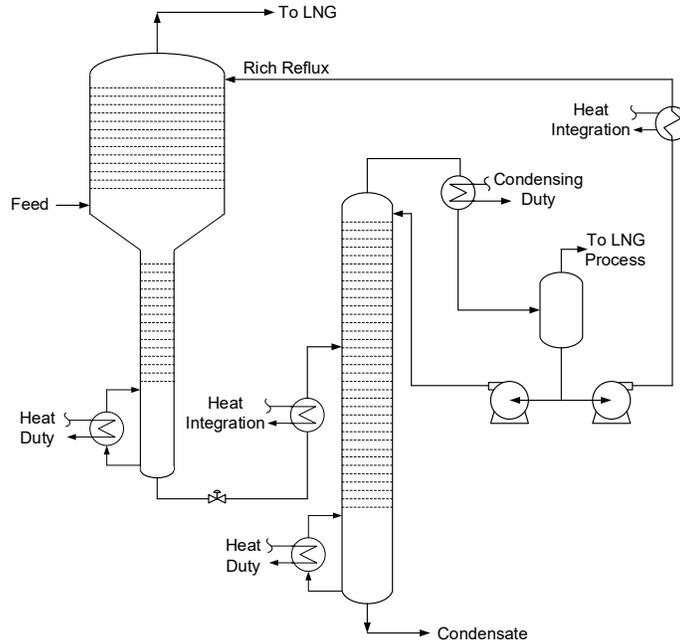


Figure 4: Rich Refluxed Heavies Removal Column System

The relative operational and economic advantages of an ethane rich reflux as compared to non-refluxed and lean refluxed options have been presented elsewhere. [3]

Internal Solvent Recovery & Circulation

When there are feed gas components that may freeze upstream of the Heavies Removal Column, but not in concentrations high enough to justify moving the Heavies Removal System to a location further upstream in the process, a portion of recovered liquids may be recycled to the process to act as a solvent. Refer to Figure 5. Hydrocarbon components that do not freeze within LNG liquefaction facilities, such as propane, butanes, and both iso and normal pentane tend to act as solvents, which help keep components in solution that would otherwise freeze. It should be noted that a lean refluxed Heavies Removal Column would typically be utilized in this situation since it is normally low concentrations of feed gas C2 to C5 components that drive the need for internal solvent circulation. This configuration would be used when there are:

- small amounts of heavy components that will freeze upstream of the Heavies Removal Column,
- insufficient C2 to C5 components within the feed gas to keep the freezing components in solution, and
- enough components in the C2 to C5 range within the feed gas to concentrate and recycle as a solvent.

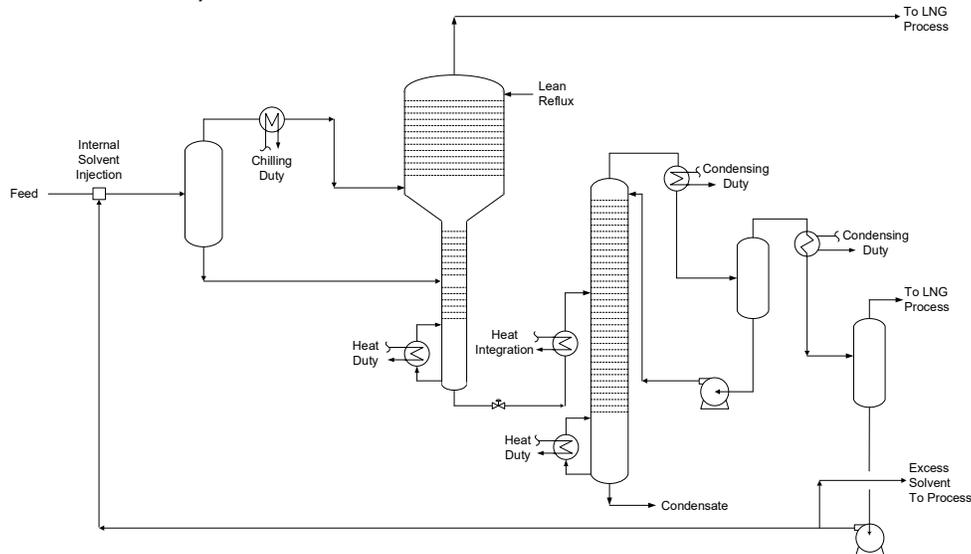


Figure 5: Internal Solvent Recovery & Circulation

It should also be noted that the origin of the solvent recycle stream in Figure 5 is for conceptual purposes and may originate from alternate locations than that shown. The actual origin of the solvent recycle may vary substantially, depending on composition.

External Solvent Injection, Recovery & Circulation

When feed gas components may freeze upstream of the Heavies Removal Column and there are insufficient components within the C2-C5 range to concentrate and recycle as a solvent, an external solvent may be utilized. Refer to Figure 6. For this option, an external solvent may be purchased, such as isopentane (iC5). The solvent should be absent of contaminants in high enough concentrations to freeze, such as neo-pentane (neo-C5). Water or moisture should also be removed from the solvent to avoid freezing or hydrate formation within the LNG liquefaction process. Mercury and organometallic mercury compounds should be removed to prevent mercury and aluminum amalgamation. Other organometallic compounds, such as trimethylarsine may freeze within the LNG liquefaction process and should also be removed if present.

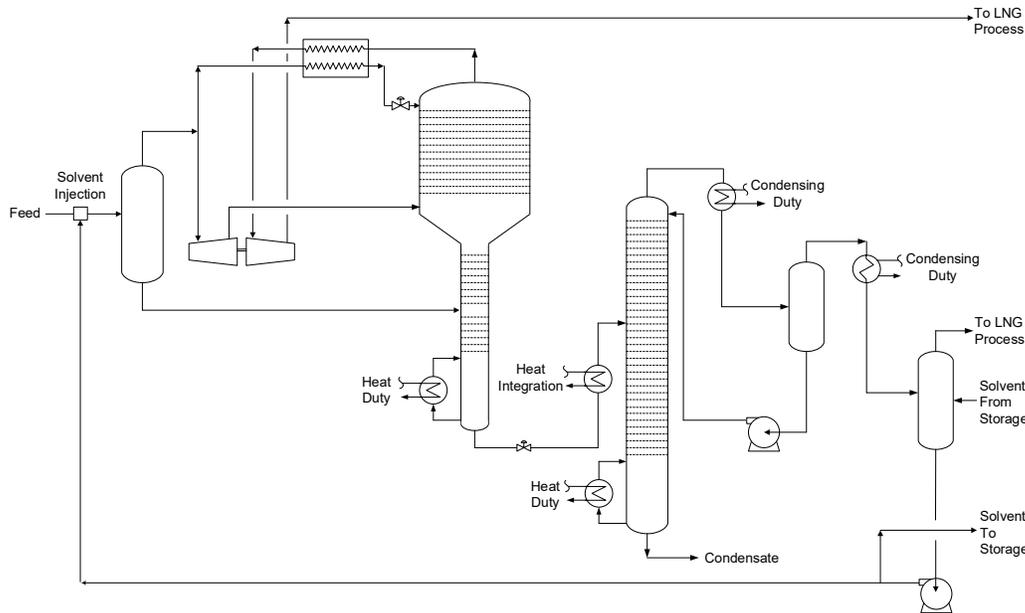


Figure 6: External Solvent Injection, Recovery & Circulation

With this configuration, the solvent circulation generally ensures that there are enough non-freezing components to allow a split-feed approach to the Heavies Removal Column. With a split-feed approach, a portion of the feed is condensed using the column overhead and fed as liquid to the top of the column, where liquids act in like manner to rich reflux. Heavier hydrocarbon components are separated and removed from the bottom of the second column and routed to condensate storage. Lighter components are separated from the heavy components and the solvent and routed to the LNG liquefaction process through the second column overhead. The solvent is recovered and circulated back to the feed with any losses made up from outside battery limits (OSBL) storage.

Hybrid Options

There are other options to remove very small trace quantities of heavy components in the feed pretreatment system through molecular sieves and other means that are beyond the scope of this article. Additionally, while the lean and rich Heavies Removal Column reflux options, as well as the internal and external solvent circulation option were presented separately, it is possible to create mixtures or hybrids, along with the ability to switch from one to another. However, the general recommendation is to select a single design that works across all feed and ambient conditions to avoid the need for constant setpoint and/or operational mode changes.

Discussion and Conclusion

The heavy hydrocarbon removal system, when required, is the most important process design consideration for an LNG liquefaction facility. A suite of options has been developed for the ConocoPhillips Optimized Cascade® Process to address the wide range of feed compositions encountered in the industry. The best option for individual projects relies upon the concentration of freezing components to be removed and the quantity of components within the C2 to C5 range. Figure 7 below provides a graphical illustration of the generalized selection process.

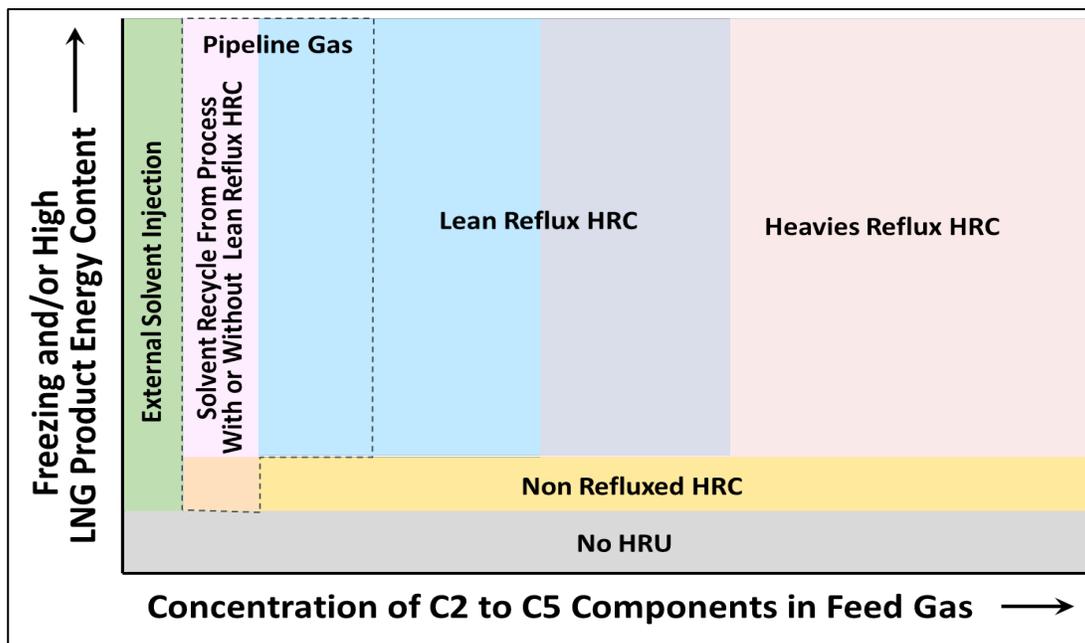


Figure 7: Heavy Hydrocarbon Removal Options for the Optimized Cascade® Process

Except for the internal and external solvent circulation options, all other options have been successfully applied across the LNG liquefaction industry. A project utilizing the external solvent circulation option is currently in the Front-End Engineering Design (FEED) phase.

References

1. Yaws – “The Yaws Handbook of Physical Properties for Hydrocarbons and Chemicals”, 2nd Edition, Table 1, Gulf Professional Publishing © 2015 Elsevier Inc.
2. Herring – “Hydrocarbon Dew Point is a Critical Consideration for Pipeline Operations”, Pipeline & Gas Journal, Volume No. 237, Number 7, July 2010
3. Herring – “Hydrocarbon Dew Point – Critical Considerations for Natural Gas Turbine Installations”, www.naturalgasconsultant.com, © Mitchell Instruments, Inc., 2008
4. Elliot, Qualls, et al – “Benefits of Integrating NGL Extraction and LNG Liquefaction Technology”, AIChE 2005 Spring National Meeting, 5th Topical Conference on Natural Gas Utilization (TI), Session 16c – Gas. © 2005 ConocoPhillips.