

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	 SOLUTIONS, STANDARDS AND SOFTWARE www.klmtechgroup.com	Page : 1 of 650
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KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru	Petrochemical Manufacturing Reports Natural Gas Processing 502	Editor / Author
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SECTION 1 INTRODUCTION

Natural gas was, for a long time, an unwanted by-product of oil production. Without economic ways of bringing it to market, gas was mostly flared or released to the atmosphere. However, in recent decades, natural gas's abundance and its low carbon content compared with other fossil fuels have considerably bolstered interest in natural gas.

The natural gas industry began to expand rapidly in the 1970s, following technological breakthroughs in the transportation of gas (e.g. steel pipelines and liquefaction) and in end uses of gas (e.g. jet-engine gas-turbine technologies applied to power generation), and as a result of concerns over security of energy supply. In 2013, natural gas demand reached 3.5 tcm and accounted for 21% of primary energy supply. It continues to lag behind coal and oil as a primary energy source, but represents an increasing share of the production portfolio of the majors. Going forward, growth in the natural gas industry is likely to be supported by new conventional discoveries and by the development of unconventional sources of gas, which began in earnest in the 2000s, increasing and diversifying available gas supply

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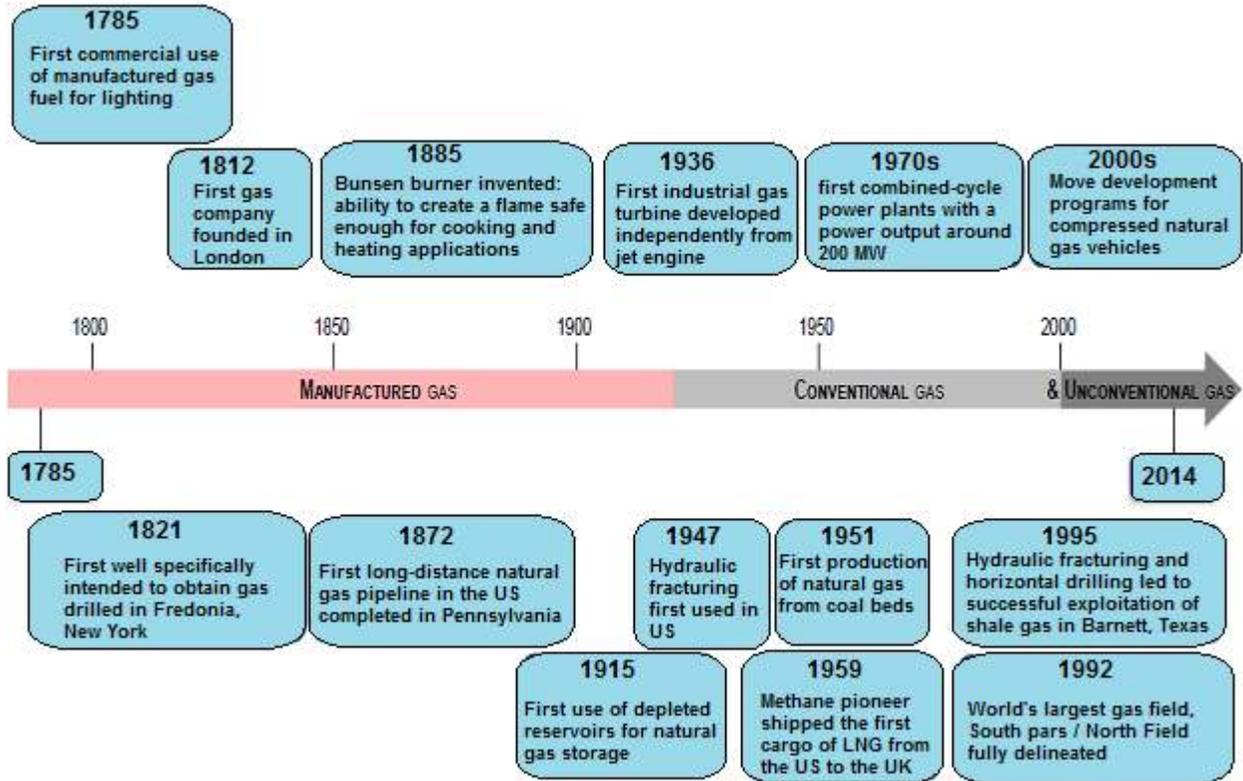


Figure 1.1: Natural gas development timeline

As with oil, natural gas is formed by the gradual decay of organic matter under specific geological heat and pressure conditions. Organic matter, such as the remains of recently living organisms (e.g. plants, algae, animals, plankton...), is the origin of all the hydrocarbons generated in the earth. A very small portion of this organic matter is deposited in poorly oxygenated aqueous environments (seas, deltas, lakes...), where it is protected from the action of aerobic bacteria and is mixed with sediments to form the source rock. Overtime, the weight of gradually accumulating organic material and debris causes source rock to subside to great depths, where its organic contentment rapped In a mud-like substance known as kerogen, is subject to increasing temperature and pressure. These conditions lead to the thermal cracking of kerogen's long molecular chains into smaller and lighter hydrocarbon molecules.

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Soon after being buried, the organic matter may be converted into dry gas under the action of methane organic bacteria, in a phase known as diagenesis (under 50°C). This dry gas usually leaks into the atmosphere. During the catagenesis phase (50-150°C), kerogen bounds are gradually cracked into oil or into wet gas depending on the kerogen type. As temperatures rise in proportion with depth, hydrocarbon molecules become lighter as depth beneath the surface increases.

During a last stage, known as meta genesis, additional heat and chemical changes eventually convert most of the remaining kerogen into methane and carbon residues. Hydrocarbon molecules are then expelled from the source rock during a “primary migration” phase, mainly as a consequence of high pressures. Hydrocarbons will then set off a “secondary migration” phase, making their way upward through rocky layers. If stopped by an impermeable layer of rock, also referred to as seal, hydrocarbons may accumulate in the pores and fissures of a reservoir rock. Otherwise, they may escape from the surface or solidify into bitumen.

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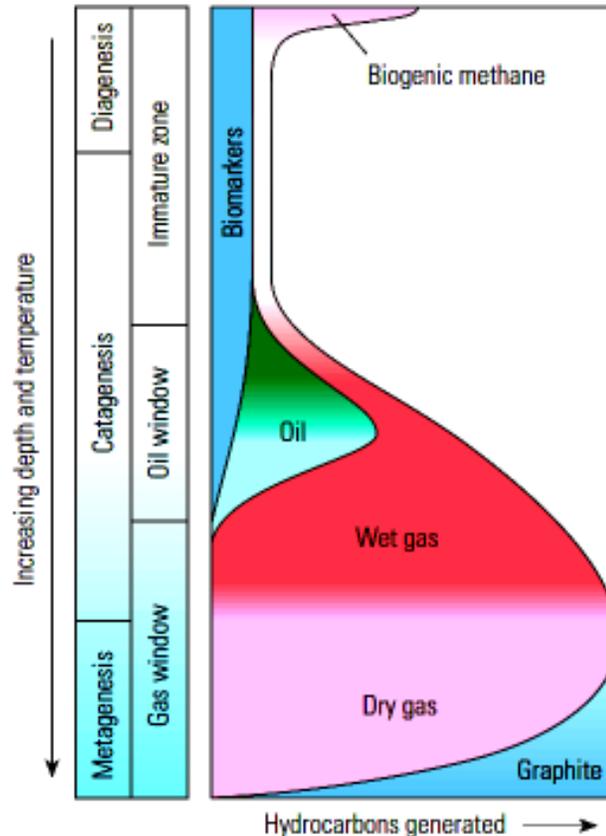


Figure 1.2: Thermal transformation of kerogen

There are primarily three sources for “raw” natural gas. These are recognized as:

1. Crude oil wells
2. Gas wells
3. Condensate wells

Natural gas that comes along with crude oil is normally known as associated gas. It can exist separately from crude oil, forming what is known as a gas cap or dissolved in the crude oil. Natural gas from gas wells and from condensate wells-in which there is little or no oil is termed, on the other hand non-associated or free gas. Gas wells differ from condensate wells, since the former type produces raw natural gas only, while the latter one produces natural gas along with very light liquid hydrocarbon known as natural gasoline. Basically, raw natural gas consists of methane along with varying amounts of:

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- Heavier gaseous hydrocarbons
- Acid gases that may include hydrogen sulfide, carbon dioxide and others
- Other gaseous components, such as nitrogen and helium
- Water that may be found in both liquid form and as water vapor
- Liquid hydrocarbons

The schematic diagram shown in Figure 1.3 illustrates how natural gas produced by gas-oil separation (associated natural gas), may contain heavier hydrocarbons.

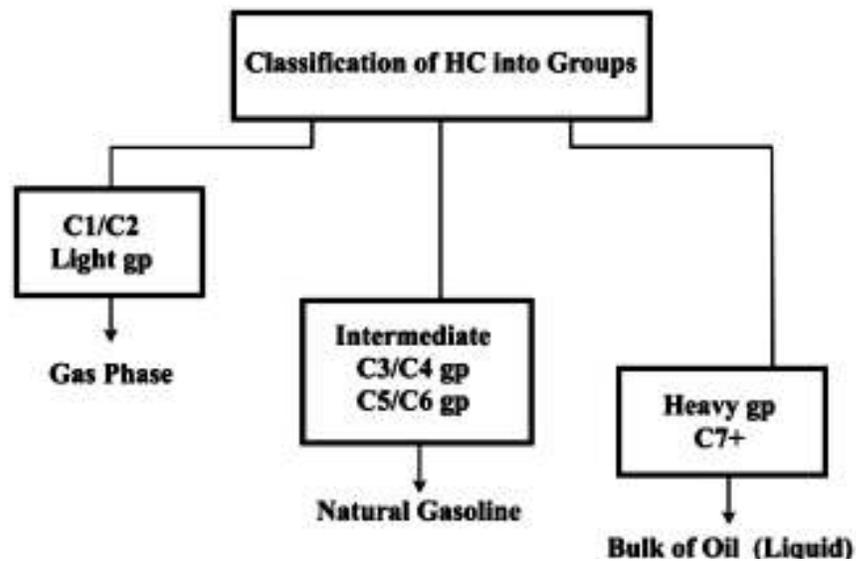


Figure 1.3: Classification of Hydrocarbons Found in Wellhead

Natural gas processing begins at the wellhead (Table 1.1). The composition of the raw natural gas extracted from producing wells depends on the type, depth, and location of the underground deposit and the geology of the area. Oil and natural gas are often found together in the same reservoir. The natural gas produced from oil wells is generally classified as “associated-dissolved,” meaning that the natural gas is associated with or

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dissolved in crude oil. Natural gas production absent any association with crude oil is classified as “non-associated.”

Table 1.1. The composition of the raw natural gas

Hydrocarbon components		Typical	Attributes and uses
Methane	CH ₄	70% to 98%	Commercial gas for residential, industrial and power generation use
Ethane	C ₂ H ₆	1% to 10%	Colorless, odorless, feedstock for ethylene
Propane	C ₃ H ₈	Trace to 50%	Burns hotter than methane, common liquid fuel; liquid petroleum gas (LPG)
Butane	C ₄ H ₁₀	Trace to 2%	Safe, volatile, used in pocket lighters; LPG
Pentane	C ₅ H ₁₂	Trace	Commonly used solvent
Non-hydrocarbon components			
Water vapor	H ₂ O	Inert	Occasionally used for reinjection
Carbon dioxide	CO ₂	Inert	Colorless, odorless, used for reinjection
Nitrogen	N ₂	Inert	Colorless, odorless, used for reinjection
Helium	HE	Inert	Colorless, odorless, light gas; specialty uses
Hydrogen sulfide	H ₂ S	Inert	Poisonous, lethal, foul odor, corrosive

The number of steps and the type of techniques used in the process of creating pipeline-quality natural gas most often depends upon the source and makeup of the wellhead production stream. In some cases, several of the steps shown in Figure 7 may be integrated into one unit or operation, performed in a different order or at alternative locations (lease/plant), or not required at all.

Natural gas collected at the well head must usually be processed to meet the pipeline-quality standards defined by each system (energy content, water content...) and to ensure safe and clean operation, both of the grid and of end-appliances. The type of gas processing required depends on the composition of the raw gas and on the pipeline system’s quality specifications. Although it is less complex than crude-oil refining, natural-gas processing is a crucial stage in the natural gas value chain. In addition to its primary purpose, cleaning, processing also performs the vital role of extracting the heavier hydrocarbons that raw natural gas contains, to varying degrees (these hydrocarbons are gaseous at underground pressure, but liquefy under ambient conditions into natural gas liquids).

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The processing layout can be configured in numerous ways. It can be sited, entirely or partially, at the field or at a compressor station close to the producing area. Processing facilities may be split up along these locations or grouped together in a dedicated processing plant.

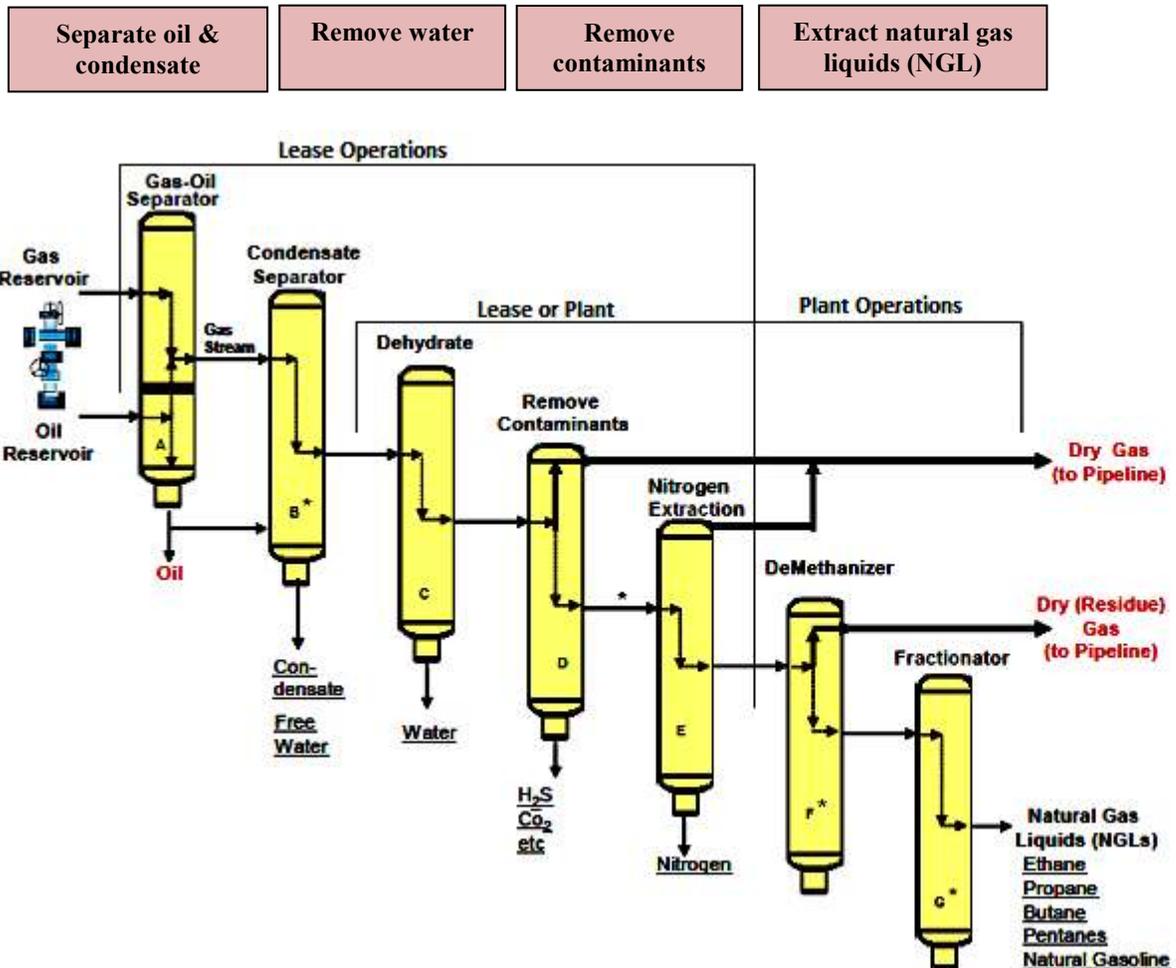


Figure 1.4: Schematic steps for natural gas processing

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The process above can be simplified in figure 1.5

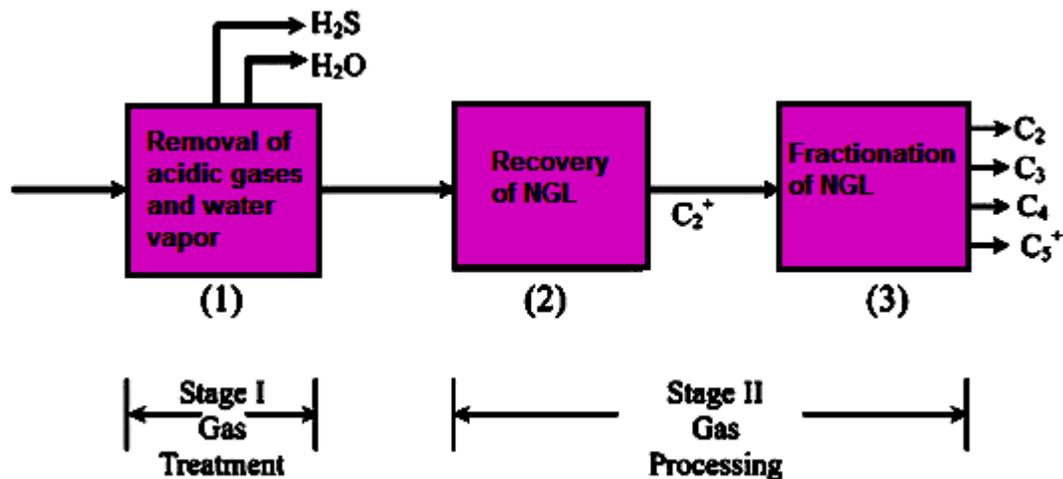


Figure 1.5: Natural Gas Processing System

- (a) Stage I and is known as gas treatment or gas conditioning
- (b) Stage II and is known as gas processing

The gas treatment operations carried out in stage I include the removal of gas contaminants, in particular H_2S (gas sweetening) followed by the separation of water vapor (dehydration). On the other hand, stage II, comprises two operations: NGL recovery and separation from the bulk of gas and its subsequent fractionation into the desired products. A sum up of these operations is given as follows.

- Gas sweetening
- Gas dehydration
- Recovery and extraction of NGL (C_2 plus)
- Fractionation of NGL into individual products, which may include: ethane, propane, butane, isobutene, and natural gasoline.

Among the several stages (as lettered in figure 8) of gas processing/treatment are:

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Gas-Oil Separators:

In many instances pressure relief at the wellhead will cause a natural separation of gas from oil (using a conventional closed tank, where gravity separates the gas hydrocarbons from the heavier oil). In some cases, however, a multi-stage gas-oil separation process is needed to separate the gas stream from the crude oil. These gas-oil separators are commonly closed cylindrical shells, horizontally mounted with inlets at one end, an outlet at the top for removal of gas, and an outlet at the bottom for removal of oil. Separation is accomplished by alternately heating and cooling (by compression) the flow stream through multiple steps. Some water and condensate, if present, will also be extracted as the process proceeds.

Condensate Separator:

Condensates are most often removed from the gas stream at the wellhead through the use of mechanical separators. In most instances, the gas flow into the separator comes directly from the wellhead, since the gas-oil separation process is not needed. The gas stream enters the processing plant at high pressure (600 pounds per square inch gauge (psig) or greater) through an inlet slug catcher where free water is removed from the gas, after which it is directed to a condensate separator. Extracted condensate is routed to on-site storage tanks.

Dehydration:

A dehydration process is needed to eliminate water which may cause the formation of hydrates. Hydrates form when a gas or liquid containing free water experiences specific temperature/pressure conditions. Dehydration is the removal of this water from the produced natural gas and is accomplished by several methods. Among these is the use of ethylene glycol (glycol injection) systems as an absorption* mechanism to remove water and other solids from the gas stream. Alternatively, adsorption* dehydration may be used, utilizing dry-bed dehydrators towers, which contain desiccants such as silica gel and activated alumina, to perform the extraction.

Contaminant Removal:

Removal of contaminants includes the elimination of hydrogen sulfide, carbon dioxide, water vapor, helium, and oxygen. The most commonly used technique is to first direct the flow through a tower containing an amine solution. Amines absorb sulfur compounds from

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natural gas and can be reused repeatedly. After desulphurization, the gas flow is directed to the next section, which contains a series of filter tubes. As the velocity of the stream reduces in the unit, primary separation of remaining contaminants occurs due to gravity. Separation of smaller particles occurs as gas flows through the tubes, where they combine into larger particles which flow to the lower section of the unit. Further, as the gas stream continues through the series of tubes, a centrifugal force is generated which further removes any remaining water and small solid particulate matter.

Nitrogen Extraction:

Once the hydrogen sulfide and carbon dioxide are processed to acceptable levels, the stream is routed to a Nitrogen Rejection Unit (NRU), where it is further dehydrated using molecular sieve beds. In the NRU, the gas stream is routed through a series of passes through a column and a brazed aluminum plate fin heat exchanger. Using thermodynamics, the nitrogen is cryogenically separated and vented. Another type of NRU unit separates methane and heavier hydrocarbons from nitrogen using an absorbent* solvent. The absorbed methane and heavier hydrocarbons are flashed off from the solvent by reducing the pressure on the processing stream in multiple gas decompression steps. The liquid from the flash regeneration step is returned to the top of the methane absorber as lean solvent. Helium, if any, can be extracted from the gas stream in a Pressure Swing Adsorption (PSA) unit.

Methane Separation:

The process of demethanizing the gas stream can occur as a separate operation in the gas plant or as part of the NRU operation. Cryogenic processing and absorption methods are some of the ways to separate methane from NGLs. The cryogenic method is better at extraction of the lighter liquids, such as ethane, than is the alternative absorption method. Essentially, cryogenic processing consists of lowering the temperature of the gas stream to around -120 degrees Fahrenheit. While there are several ways to perform this function the turbo expander process is most effective, using external refrigerants to chill the gas stream. The quick drop in temperature that the expander is capable of producing condenses the hydrocarbons in the gas stream, but maintains methane in its gaseous form.

The absorption* method, on the other hand, uses a "lean" absorbing oil to separate the methane from the NGLs. While the gas stream is passed through an absorption tower, the absorption oil soaks up a large amount of the NGLs. The "enriched" absorption oil, now containing NGLs, exits the tower at the bottom. The enriched oil is fed into distillers

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where the blend is heated to above the boiling point of the NGLs, while the oil remains fluid. The oil is recycled while the NGLs are cooled and directed to a fractionator tower. Another absorption method that is often used is the refrigerated oil absorption method where the lean oil is chilled rather than heated, a feature that enhances recovery rates somewhat.

Fractionation:

Fractionation, the process of separating the various NGLs present in the remaining gas stream, uses the varying boiling points of the individual hydrocarbons in the stream, by now virtually all NGLs, to achieve the task. The process occurs in stages as the gas stream rises through several towers where heating units raise the temperature of the stream, causing the various liquids to separate and exit into specific holding tanks.

Natural gas processing and the removal of various components from it tend to involve the most complex and expensive processes. All of the H₂S and most of the water vapor, CO₂, and N₂ must be removed first. The separation of the hydrocarbons, known as NGL (C₂ plus) is carried out next producing methane as the sole product commercially marketed as natural gas.

The following are some of the most important parameters to be considered in the design of a system for natural gas processing:

1. Estimated gas reserve (both associated and free)
2. Gas flow rate and its composition
3. Market demand for both local export
4. Geographic locations and methods of shipping of finished products
5. Environmental factors
6. Risks imposed in implementing the project and evaluation of its economic feasibility

In general, the type of processing operations recommended for any specific plant, depend on the kind of gas under consideration along with the distribution of the hydrocarbons found in the gas. In particular the following factors are significant:

- The contents of heavier hydrocarbons
- The percentage of acid gases
- The presence of inert

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Refrigeration

Refrigeration is a very important unit operation. During the 1990's, it was estimated that annual investment in refrigeration machinery and equipment exceeded \$100 billion and the value of the products treated by refrigeration exceeded \$1 trillion.

Refrigeration is used as a method to cool a process stream to a lower temperature than water or air cooling will allow. Refrigeration can be described as the process of cooling materials where the heat transferred from a lower to a highertemperature by doing work such as mechanical Mans; The temperature may spans the range of -157°C to +4°C. Refrigeration is a very important unit operation.

Types of refrigeration may be categorized within five broad areas of application that touch most of our daily lives:

1. Daily devices, like household refrigerator / freezers.
2. Commercial equipment systems in example of supermarket display, restaurants, and cafeterias.
3. Food processing like refrigerated warehouse.
4. Industrial tools, in example of liquefaction of gases, chemical process cooling, and crystallization.
5. Public Transportation (refrigerated truck or trailer and marine containers).

A refrigeration system is a combination of components and equipment connected in a sequential order to produce the desired refrigeration effect (cooling or heating). Refrigeration maintains the temperature of the heat source below that of its surroundings while transferring the extracted heat, and any required energy input, to a heat sink, atmospheric air, or surface water.

Generally, refrigeration is used for temperature requirements from 80 – 85°F to as near absolute zero as the process demands. The petrochemical and chemical range does not go much below -200°F. Refrigeration process consists of five component equipments, they are:

1. Compressor.
2. Evaporator.
3. Condenser.
4. Expansion Valve.
5. And Refrigerant

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Cryogenic Heat Exchangers

Cryogenic is the science that addresses the production and effects of very low temperatures. The word cryogenics stems from Greek and means “the production of freezing cold”, however, the term is used today as a synonym for the low temperature state. It is not well defined at what point on the temperature scale refrigeration ends cryogenics begins, but most scientists assume it starts at or below -150°C (123 K; -238°F).

According to the laws of thermodynamics, there exists a limit to the lowest temperature that can be achieved, which is known as absolute zero. Molecules are in their lowest, but finite, energy state at absolute zero. Such a temperature is impossible to reach because the input power required approaches infinity. However, temperatures within a few billionths of a degree above absolute zero have been achieved. Absolute zero is the zero of the absolute or thermodynamic temperature scale. It is equal to -273.15°C or -459.67°F . The metric or SI (International System) absolute scale is known as the Kelvin scale whose unit is the kelvin (not Kelvin) which has the same magnitude as the degree Celsius. In terms of the Kelvin scale the cryogenic region is often considered to be that below approximately 120 K (-153°C).

The measurement of cryogenic temperatures requires methods that may not be so familiar to the general public. Normal mercury or alcohol thermometers freeze at such low temperatures and become useless. The platinum resistance thermometer has a well-defined behavior or electrical resistance versus temperature and is commonly used to measure temperatures accurately, including cryogenic temperatures down to about 20K. Liquefied gases, such as liquid nitrogen and liquid helium, are used in many cryogenic applications. Liquid nitrogen is the most commonly used element in cryogenics and is legally purchasable around the world. Liquid helium is also commonly used and allows for the lowest attainable temperatures to be reached.

The field of cryogenics advanced during World War II when scientists found that metals frozen to low temperatures showed more resistance to wear. Based on this theory of cryogenic hardening, the commercial cryogenic processing industry was founded in 1966 by ED Busch. With a background in the heat treating industry, Busch founded a company in Detroit called CryoTech in 1996 which merged with 300 below in 1999 to become the world’s largest and oldest commercial cryogenic processing company. Busch originally experimented with the possibility of increasing the life of metal tools to anywhere between

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200%-400% of the original life expectancy using cryogenic tempering instead of heat treating. This evolved in the late 1990s into the treatment of other parts.

Cryogenics, such as liquid nitrogen, are further used for specialty chilling and freezing applications. Some chemical reactions, like those used to produce the active ingredients for the popular statin drugs, must occur at low temperatures of approximately -100°C (-148°F). Special cryogenic chemical reactors are used to remove reaction heat and provide a low temperature environment. The freezing of foods and biotechnology products, like vaccines, requires nitrogen in blast freezing or immersion freezing systems. Certain soft or elastic materials become hard and brittle at very low temperatures, which makes cryogenic milling (cryomilling) an option for some materials that cannot easily be milled at higher temperatures.

Cryogenic processing is not a substitute for heat treatment, but rather an extension of the heating – quenching – tempering cycle. Normally, when an item is quenched, the final temperature is ambient. The only reason for this is that most heat treaters do not have cooling equipment. There is nothing metallurgically significant about ambient temperature down to -320°F (140 °R; 78 K; -196°C).

In most instances the cryogenic cycle is followed by a heat tempering procedure. As all alloys do not have the same chemical constituents, the tempering procedure varies according to the material's chemical composition, thermal history and/or a tool's particular service application.

A heat exchanger for vaporizing a cryogenic fluid comprises a conduit through which the fluid is passed and a heat transfer sleeve surrounding the conduit. The sleeve is comprised of two heat transfer sections, each having a central arcuate portion in close partial circumferential contact with the conduit, a plurality of radially extending heat transfer fins, and a pair of interlocking members located on the fins at a predetermined distance from the central portion for assembling the two sections together around the conduit. In the assembled state, the resiliency of the fins on which the interlocking members are located provides a continuous clamping for which permits the two central portions to maintain intimate contact with the conduit as it undergoes thermal contraction, while also facilitating assembly and disassembly of the two sections. Each heat transfer fin is also provided with a corrugated or rippled surface near its tip to increase its surface area and the rate of heat transfer and vaporization.

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Gas Sweetening Systems

In some hydrocarbon processing plants acid gas such as Hydrogen sulfide (H₂S) and carbon dioxide (CO₂) are present in the gas streams. They can also be organic sulfur in the form of carbonyl sulfide (COS). The streams can be natural and associated gases such as propane and butane, and products from upgrading of heavy oils, bitumen or coal.

Gas sweetening technology using alkanolamines to remove acid components from hydrocarbon rich gases have been in operation for many years. The alkanolamine processes are particularly applicable where acid gas partial pressures are low or low levels of acid gas are needed in the sweet gas. Alkanolamines are used because they form basic solutions when mixed with water and chemically enhance the absorption of H₂S and CO₂ in the aqueous solution. Several alkanolamines solutions have been widely used in gas sweetening system.

1. Monoethanolamine (MEA)
2. Diethanolamine (DEA)
3. Diglycolamine (DGA)
4. Di-isopropanolamine (DIPA)
5. Methyl diethanolamine (MDEA)
6. Triethanolamine (TEA)
7. Glycol plus amine solution.

MEA and DGA react with H₂S, CO₂ and COS directly. DEA and DIPA react with H₂S, CO₂ and some COS directly. While MDEA and TEA are reacted with H₂S directly, CO₂ indirectly and a little COS. The following factors should be considered for evaluation and decision making as a general approach to all sour gas sweetening treatment installations:

1. Air pollution regulations regarding H₂S removal;
2. Type and concentration of impurities in sour gas;
3. Specification of treated gas (sweet gas);
4. Temperature and pressure at which the sour gas is available and at which the sweetened gas should be delivered;
5. Volume of the gas to be treated;

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6. Hydrocarbon composition of sour gas;
7. Selectivity required for acid gas removal;
8. Capital cost and operating cost;
9. Liquid product specifications (where application).

Good performance of a gas sweetening systems requires proper choice and control of process operating conditions.

The advantages of the amine process are:

1. It is a continuous circulating system of smaller rate than some other processes
2. Theoretically, it is a simple exothermic-endothermic reversible chemical reaction
3. It will remove all hydrogen sulphide from the gas to lead standards, below 0.05 grains, at contact pressure of about 100 psi and above. At lower pressure, complete removal of sulphide from the gas stream is not always achieved because of partial pressure equilibrium limitations

The disadvantages of amine process are:

1. The amine is subject to vaporization and other losses that can be expensive replenish.
2. Like any hydrogen sulphide removal plant, the amine process is subject to expensive corrosion problems. A well designed amine plant will have less corrosion than a poorly designed plant, but nevertheless, will have some corrosion.
3. Amine will remove carbon dioxide that might better be left in the gas.

Gas Dehydration

Natural Gas either from natural production or storage reservoirs contain water, which may condense and may also form solid gas hydrates to block pipeline flow and control systems. Natural Gas in transit to market should be dehydrated to a controlled water content to avoid hydrates, as well to minimize the corrosion problems.

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Dehydration of Natural Gas is the removal of the water that is associated with natural gases in vapor form. The natural gas industry has recognized that dehydration is necessary to ensure smooth operation of gas transmission lines. Dehydration prevents the formation of gas hydrates and reduces corrosion. Unless gases are dehydrated, liquid water may condense in pipelines and accumulate at low points along the line, reducing its flow capacity. Water is also removed to meet a water dew point requirement of a sales gas contract specification range from 32.8 to 117 kg/10⁶ std m³. Several methods have been developed to dehydrate gases on an industrial scale.

Absorption dehydration involves the use of a liquid desiccant to remove water vapor from the gas. The most frequently used desiccants in absorption processes are di-ethylene and tri-ethylene glycols. Usually, the absorption/stripping cycle is used for removing large amounts of water, and adsorption is used for cryogenic systems to reach low moisture contents. Although many liquids possess the ability to absorb water from gas, the liquid that is most desirable to use for commercial dehydration purposes should possess the following properties:

1. High absorption efficiency.
2. Easy and economic regeneration.
3. Non-corrosive and non-toxic.
4. No operational problems when used in high concentrations.
5. No interaction with the hydrocarbon portion of the gas, and no contamination by acid gases.

The glycols, particularly ethylene glycol (EG), di-ethylene glycol (DEG), tri-ethylene glycol (TEG), and tetra-ethylene glycol (TREG) come to closest to satisfying these criteria to varying degrees. Water and the glycols show complete mutual solubility in the liquid phase due to hydrogen-oxygen bonds, and their water vapor pressures are very low.

1. Tri-ethylene glycol (TEG) is the most commonly used dehydration liquid and is the assumed glycol type in this process description.
2. Di-ethylene glycol (DEG) is sometimes used for dehydration for uniformity when hydrate inhibition is required upstream of dehydration.
3. Tetra-ethylene glycol (TREG) is more viscous and more expensive than the other glycols. The only real advantage is its lower vapor pressure which reduces absorber

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vapor loss. It should only be considered for rare cases where glycol dehydration will be employed on a gas whose temperature exceeds about 50 °C, such as when extreme ambient conditions prevent cooling to a lower temperature.

Mole Sieve Dehydration

Adsorption (or solid bed) dehydration is the process where a solid desiccant is used for the removal of water vapor from a gas stream to meet water dew points less than -40 °F. The desiccant material becomes saturated as moisture is adsorbed onto its surface. A good desiccant should therefore have the greatest surface area available for adsorption.

The solid desiccants commonly used for gas dehydration are those that can be regenerated and, consequently, used over several adsorption-desorption cycles. The mechanisms of adsorption on a surface are of two types; physical and chemical. The latter process, involving a chemical reaction, is termed "chemisorption", a much stronger chemical bonding occurs between the surface and the adsorbed molecules. Chemical adsorbents find very limited application in gas processing. Adsorbents that allow physical adsorption hold the adsorbate on their surface by surface forces. For physical adsorbents used in gas dehydration, the following properties are desirable.

1. Large surface area for high capacity. Commercial adsorbents have a surface area of 500-800 m²/g.
2. Good "activity" for the components to be removed and good activity retention with time/use.
3. High mass transfer rate, i.e., a high rate of removal.
4. Easy, economic regeneration.
5. Small resistance to gas flow, so that the pressure drop through the dehydration system is small.
6. High mechanical strength to resist crushing and dust formation. The adsorbent also must retain strength when "wet".
7. Cheap, non-corrosive, non-toxic, chemically inert, high bulk density and small volume changes upon adsorption and desorption of water.

Adsorbents used for removing water from a fluid stream are known as "solid desiccant". The characteristics of solid desiccants vary significantly depending on their physical and

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chemical properties. Many known solids have some ability to adsorb, but relatively few are commercially important.

Some of the qualities that make a solid adsorbent commercially important are:

1. Available in large quantity;
2. High adsorption capacity: this reduces the adsorbent volume, requiring smaller vessels, resulting in lower capital and operating costs;
3. High selectivity, this permits removal of only the undesirable components and reduces operating expenses;
4. Easy regeneration: low regeneration temperature reduces the heating requirement for solid desiccant regeneration;
5. Ability to reduce the materials to be adsorbed to a low concentration;
6. Ability to be regenerated and used again;
7. Low-pressure-drop design: this makes more pressure available for the turboexpander operation in an NGL recovery process;
8. Good mechanical integrity: high crush strength, low attrition, low dust formation, and high stability against aging reduces the frequency of adsorbent change-out and downtime-related losses in production;
9. Environment-friendly properties: the materials should be noncorrosive, nontoxic, and chemically inert to permit safe handling;
10. Chemical inertness;
11. Reasonable adsorbent price.

Natural Gas Liquids

Hydrocarbon components of natural gas that are heavier than methane are called natural gas liquids (NGLs). Natural Gas Liquids (NGL) is those hydrocarbons in natural gas that are separated from the gas as liquids through the process of absorption, condensation, adsorption, cooling in gas separators, gas processing, or gas cycling plants. Generally, natural gas liquids include natural gas plant liquids and lease condensate. They can be extracted in a processing plant and commercialized as liquid fuels.

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In NGLs as most hydrocarbons have a wide range of labels and at times different definitions. The very flexibility of NGL uses leads to much uncertainty. To avoid confusion, it is important to define the terms used:

- **Natural Gas Liquids (NGLs):** Liquid hydrocarbons suspended as particles in gas, under conditions of subterranean pressure and temperature, are called NGLs. True gas consists of methane (one carbon molecule – C1); ethane (C2) is considered both an NGL in many regions (N. America, Europe and the Mideast), but a part of natural gas in most of Asia. Other NGLs consist of LPG (C3/C4, propane, butane and iso-butane) and condensate, C5 and heavier. While LPG is produced in substantial volumes in refining and ethane in limited volume, most NGLs originate from gas production. When NGL is contained within a gas stream, it is called “in a vapor phase.”
- When separated into respective NGL components from ethane to iso-butane, at least 90% of the NGL stream has only one type of carbon molecule, which NGLs are known as “purity products.” The term “Heavy NGLs” in the US refers to natural gasoline and butane/iso-butane, but this is somewhat misleading. The only heavy NGL that can be separated, stored and transported without special containment is condensate.
- “Mixed” NGLs: In the US market NGLs are often sold in a mixed stream, particularly in petrochemicals. The most common is ethane/propane called E/P Mix, consisting of 80% ethane/20% propane.
- **Natural Gasoline:** This refers to heavy NGL, taken out of gas in plant processing, and the term, though widely used in the US market, generally is considered not used in the rest of the world.

Natural gas that is rich in NGLs is usually called wet gas or rich gas, as opposed to dry gas or lean gas. Liquefied petroleum gas (LPG), to make a further distinction, is a subset of NGLs, comprising propane and butane. LPG can be liquefied through pressurization (i.e. without requiring cryogenic refrigeration), and used as a liquid fuel.

In 2012, supply of NGLs amounted to 9 million barrels a day, representing about 10% of world liquid hydrocarbon production. While total liquid supply has increased at a 1% compound average annual growth rate (CAGR) since 1980, NGLs production has more than doubled with a CAGR of 3.1%.

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NGLs all have their own prices and pricing mechanisms. It may become commercially attractive to produce NGLs, depending on the composition of NGLs in a given natural gas stream and on average price spreads with methane. For instance, natural gasoline (the pentanes-plus fraction of NGLs) sells in the U.S. at prices that are 4 to 5 times higher than natural gas on a comparable energy basis. Conversely, ethane was in 2013 cheaper than natural gas in the U.S.

The mix of hydrocarbon fractions and contaminants in natural gas is specific to each field¹. In some fields, natural gas liquids (NGL) account for significant share of the natural gas mix, leading to important volumes of liquid hydrocarbons produced.

NGLs produced by gas processing are separated from the overall gas stream at a processing plant, which separates the raw NGL mix from dry gas. The dry gas is then sent through pipeline to consumers, while the raw mix is sent to a fractionation facility, which processes and separates the mix into different NGLs (ethane, propane, butane, iso-butane, and natural gasoline), also known as “purity products.”

As shale natural gas production continues to expand, it has a direct impact on supply of NGLs. Whether the infrastructure and market for NGLs can absorb these increasing volumes and how the new supplies will impact demand for NGLs and related products are key questions facing producers and consumers of these important petrochemical products.

The impact of increasing natural gas production on NGL supplies is a function of three factors:

- (1) the amount of natural gas that is processed to remove the NGLs;
- (2) the amount of NGLs that are contained in the natural gas that is processed;
- (3) the processing technique used to remove the NGLs.

Increases in the first factor are primarily being driven by the shale revolution. The second factor is associated with the physical composition of natural gas as it is produced at the wellhead.

Natural gas production at the wellhead is typically composed of a number of hydrocarbon and other compounds. The largest hydrocarbon component of most natural gas is methane. But wellhead gas, also known as “wet gas” or “gross gas production,” contains NGLs. NGLs are generally in gaseous form at the wellhead and are extracted from natural gas by chilling to very low temperatures to produce liquid hydrocarbons—hence

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the name “natural gas liquids”. In some situations, NGL extraction is required to produce a natural gas stream that can meet pipeline or industrial specifications. In other cases, when the price of NGLs is higher than that of natural gas, NGLs are extracted for economic reasons.

Figure 1.6 is a simplified representation of the NGL supply chain. NGLs are produced by both natural gas processing plants and petroleum refineries. Natural gas processing plants separate dry gas (i.e., methane) from wellhead gas production, or wet gas (natural gas containing quantities of NGLs—i.e., ethane, propane, normal butane isobutane, natural gasoline), while refineries produce NGLs as a byproduct of refinery distillation and cracking processes.

Each successive NGL has an additional carbon molecule and different chemical properties. For example, ethane is C_2H_6 , propane is C_3H_8 , butane is C_4H_{10} , and natural gasoline is C_5H_{12} . NGLs are used by the petrochemical industry as feedstock to produce a variety of plastic products, for heating in the case of propane, as components in the motor gasoline pool (“motor gasoline”), and are exported in some cases.

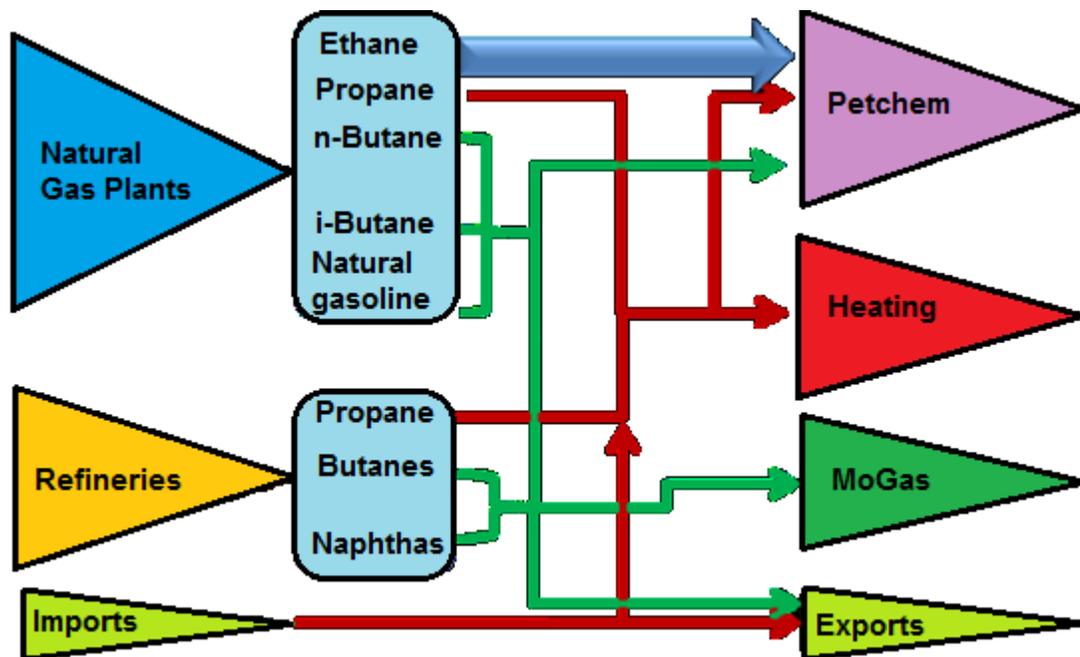


Figure 1.6: the NGL supply chain

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Fundamentals of the NGL Market pricing is cyclical. As the primary consumer of NGLs, the petrochemical industry is an integral factor in determining prices, particularly in the case of ethane, which represents roughly 40% of the NGL stream. Industrial consumers bid for NGLs depending on the difference between the price of NGLs and the price of gas, also known as the “spread.”

During periods of strong industrial-sector demand, the spread increases and gas processors continue to pull ethane out of the natural gas stream. As NGL production increases, prices for NGLs come down and it is more economic for gas processors to leave ethane in the gas stream, a process known as “ethane rejection.”

Leaving ethane in the gas stream increases the physical volume of natural gas, putting downward pressure on prices and reducing gas—and NGL—production. Declines in NGL production leads to an increase in prices, and the trend repeats itself (see Figure 1.7).

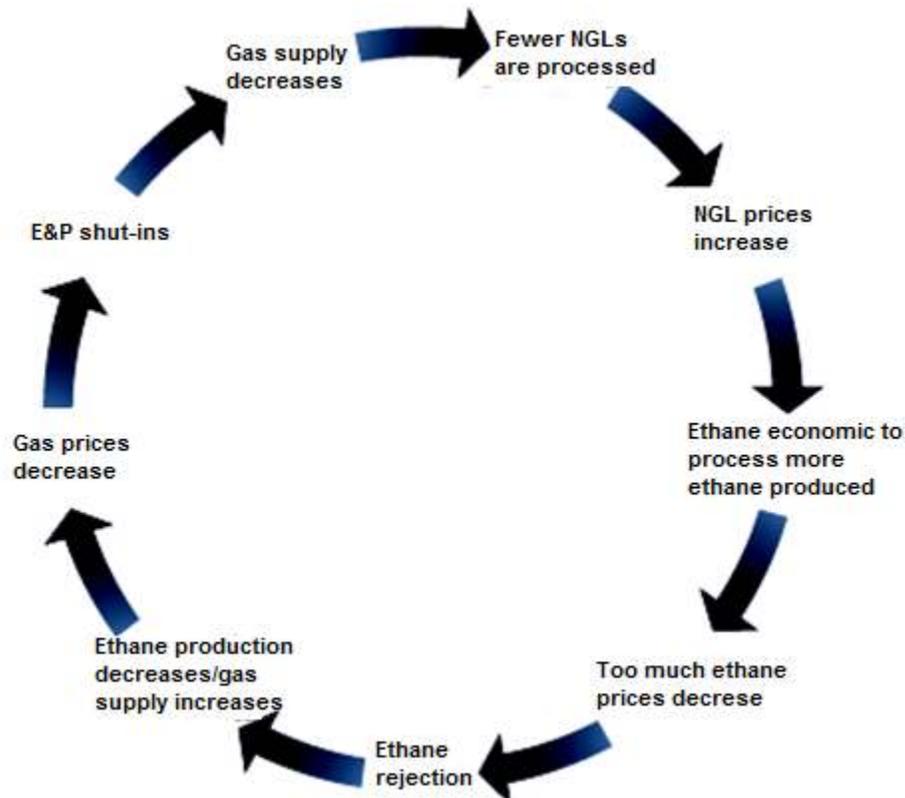


Figure 1.7: cycles of NGL production effect to prices

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By studying the natural gas and NGL outlook country by country, four global trends in natural gas production can be identified that impact NGL supply. The importance of each trend varies by country or region, while multiple trends blur the picture in some regions. Trends 1 to 3 have a positive impact on the supply outlook for NGLs and the liquids ratio, while trend 4 has a negative impact.

1. Large scale natural gas developments characterized by

- Participation by International Oil Companies (IOC) that tend to have a high NGL awareness compared to prevailing host country awareness.
- The development of large gas condensate fields. The IOCs often see a larger potential in such fields than in standalone gas projects.
- The development of LNG projects for which it is important to strip liquids out of the gas to make the sales gas match the spec of the target market and to optimize the value of the project by monetizing valuable associated liquids. Integrated LNG and NGL infrastructure reduce the costs in the NGL value chain.

2. Increased utilization of associated gas

- Higher awareness of the value of associated gas, both as marketed gas and for reinjection to support oil production.
- Initiatives to reduce flaring of associated gas.
- Better infrastructure to gather and process associated gas.

3. Higher liquids content in traditional dry non-associated gas

- When traditional shallow gas reservoirs are depleted, oil companies drill deeper down and find structures with higher pressure, generally containing more condensate and other NGLs.
- Technology improvement, higher energy prices and experience make oil companies less reluctant to develop complex reservoirs.
- The NGL awareness is higher, and therefore the value of gas condensate fields is rated higher.

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4. Wet associated gas is being replaced by dry non-associated gas

- As oil production declines in many countries compared to gas production, traditional associated gas with a high liquids content declines too.
- Countries must replace associated gas with non-associated gas to meet domestic needs. This non-associated gas tends to be drier.
- Growth in non-conventional gas production may result in lower liquids ratios.

Liquefied Petroleum Gas

In natural gas processing plants, several stages of separation and fractionation are used to purify the natural gas from the liquid heavier hydrocarbons. This separated liquid is named as natural gas liquids (NGL). The source of Natural Gas Liquids is a natural occurring mixture of gaseous hydrocarbons found in the ground or obtained from specially wells. The composition of natural gas varies in different parts of the world. Its chief component, methane, usually makes up from 80% to 95% of its composition. The balance is composed of varying amounts of ethane, propane, butane, and other hydrocarbon compounds approximately as follows:

1. Ethane (35-55%)
2. Propane (20-30%)
3. Normal Butane (10-15%)
4. Isobutane (4-8%)
5. Pentanes Plus (also called natural gasoline, debutanized natural gasoline) (10-15%)

The raw NGL is sent to LPG recovery plant to separate LPG (i-C₃ and i-C₄) from stabilized NGL (C₅+). Both products are very valuable and expensive in the market. Liquefied Petroleum Gas (LPG) is a mixture of hydrocarbon gases, primary propane and butane. The exact composition of LPG varies according to its source, processing principles and depends on the season.

LPG is odorless, colorless and non-toxic. To reduce the danger of an explosion from undetected leaks, commercial LPG usually contains an odorizing agent, such as

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ethanethiol, which gives it a distinctive pungent odor. LPG has a higher calorific value (94 MJ/m³ equivalents to 26.1 kWh) than natural gas (38 MJ/m³ equivalents to 10.6 kWh).

Table 1.2 - Properties of LPG

Name of the property	Value for LPG
Freezing point	-187°C
Specific gravity	0.588
Vapor pressure at 38°C	1212 kPa
Heat content	50221 kJ/kg

There are several technologies which have been developed in order to extract LPG from natural gas liquids (NGL). Some research and simulations have also been done to find the most optimum and economic technology.

Liquefied Natural Gas

LNG is a mixture of hydrocarbons composed predominantly of methane and which can contain minor quantities of ethane, propane, butane, nitrogen or other components normally found in natural gas. LNG shall have a methane content of more than 75 % and a nitrogen content of less than 5 %. Although the major constituent of LNG is methane, it should not be assumed that LNG is pure methane

The density of LNG depends on the composition and usually ranges from 420 kg/m³ to 470 kg/m³, but in some cases can be as high as 520 kg/m³. Density is also a function of the liquid temperature with a gradient of about 1,4 kg/m³/K. Density can be measured directly but is generally calculated from composition determined by gas chromatographic analysis.

LNG has a boiling temperature depending on composition and usually ranging from -166 °C to -57 °C at atmospheric pressure. The variation of the boiling temperature with the vapour pressure is about 1,25 x 10⁻⁴ °C/Pa. The temperature of LNG is commonly measured using copper/copper nickel thermocouples or using platinum resistance thermometers. The viscosity of LNG depends of the composition and is usually from 1,0 x 10⁻⁴ Pa·s to 2,0 x 10⁻⁴ Pa·s at -160 °C, which is nearly 1/10 to 1/5 of the water. Viscosity is also a function of the liquid temperature.

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Feed to LNG plants is composed primarily of methane, together with ethane, propane, butane and heavier components. Non-hydrocarbon components such as nitrogen, carbon dioxide, hydrogen sulphide and mercury are also usually present. A typical range of feed composition is shown in the table below.

Table 1.3: Typical LNG feed gas composition

Methane	CH ₄	70 – 90%
Ethane	C ₂ H ₆	0 – 20%
Propane	C ₃ H ₈	
Butane+	C ₄ H ₁₀ +	
Carbon dioxide	CO ₂	0 – 8%
Nitrogen	N ₂	0 – 9%

The primary drivers for the capital cost of an LNG liquefaction facility are site specific in nature. Surprisingly, less than 50% of the LNG plant cost is capacity related. As a result, most of the cost of an LNG liquefaction project is beyond the influence of the design engineer and is a function of site related conditions, project development and project execution efforts.

Although there is no typical or standard LNG plant, the major elements that are found in most LNG plants include:

1. a feed gas handling and treating section
2. a liquefaction section
3. a refrigerant section
4. a fractionation section
5. an LNG storage section
6. a marine and LNG loading section
7. a utility and offsite section

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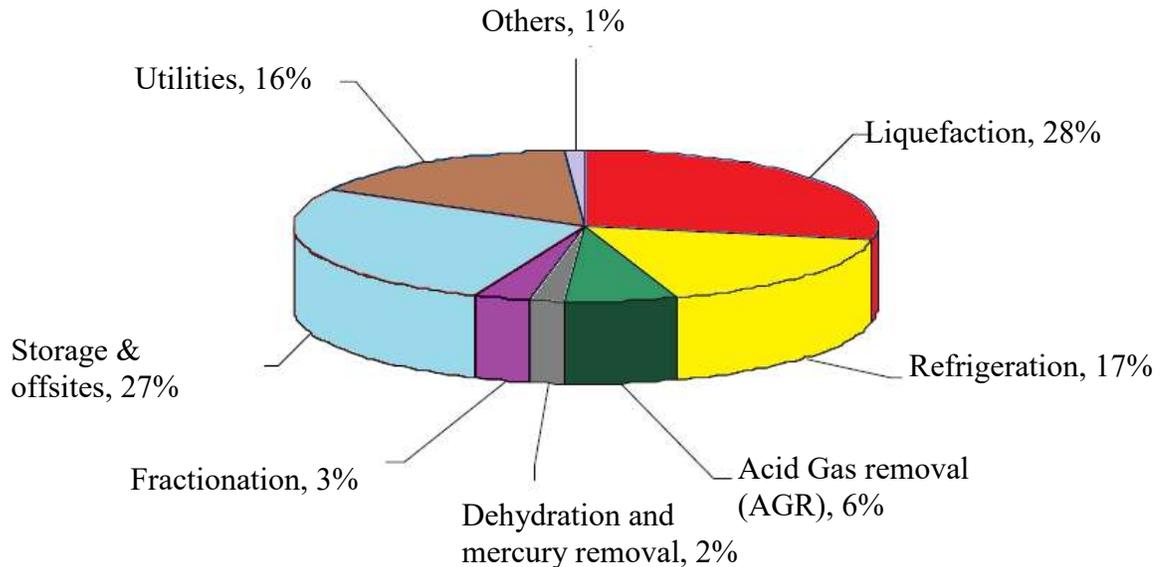


Figure 1.8: A typical cost distribution for an LNG plant

Gas Plant Slug Catcher

A multi-phase flow pipeline is intended for transporting the gas and liquid phases simultaneously from a production field to a processing unit. A gas plant slug catcher may be situated at the end of the pipeline to separate the phases and to provide temporary storage for the liquid received. There are different modes under which liquid can be produced from the pipeline. These include: the continuous liquid flow production mode under normal steady flow conditions; the intermittent or transient liquid production mode occurring when flow rates are varied; and the pigging or sphering mode when liquid is displaced from the pipeline into the slug catcher in a relatively short time.

These occasionally very large volumes of liquids encountered must be handled and stored as they emerge from the pipeline, preferably without any reduction in velocity, which would be reflected in the gas production. For this reason, a liquid-receiving facility known as a slug catcher is connected to a two phase pipeline.

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The initial gas-liquid separation occurs in a slug catcher. Slug catchers are critical because downstream gas processing units rely on a continuous gas stream free of liquids, even when surges of liquid enter the plant. A slug catcher is a gas-liquid separator sized to hold the biggest slug a plant will experience. Depending upon slug catcher design, inlet receiving handles just slugs or combines slug catching with liquid storage. The slug catcher is mainly made up of two different compartments: the first one includes the multiphase separator under steady flow conditions while the second consists of the storage where the received liquid is accumulated under operating conditions.

The slug catcher is a separator, where separation typically occurs between the heavy liquid hydrocarbons and the gaseous lighter ends i.e. the gas or vapor is separated from the liquids. The appropriate design of the slug catcher avoids problems at the receiving terminals. In order to prevent the acceleration of the gas/liquid mixture, the inlet diameter of the pipes entering the slug catcher should be the same as that of the pipeline. Normally the slug catcher is made up of a series of pipes that are parallel and inclined in order to give the hold-up volume for the liquid.

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DEFINITIONS

Absorber (Contactor) - A vertical pressure vessel where gas and glycol are intermingled counter-currently to remove water vapor from the gas. The contactor usually contains bubble cap trays, valve trays or structured packing.

Absorption - A separation process involving the transfer of a substance from a gaseous phase to liquid phase through the phase boundary.

Absorption-refrigeration—One refrigeration process that uses heat-transfer (thermal) driving force to utilize the refrigerant.

Accumulator: a storage vessel for liquid refrigerant; also known as surge drum.

Acid Gas - Natural Gas containing Carbon Dioxide or Hydrogen Sulphide which forms an acid compound when combined with water.

Acid gas loading - The amount of acid gas, on a molar or volumetric basis, which will be picked up by a solvent.

Activated Alumina – An adsorbent made of aluminium oxide (Al₂O₃). It is used as a desiccant for drying gases and air and as a fluoride filter for drinking water

Actual trays - The number of trays installed in a column or the equivalent number of actual trays for a packed column.

Adsorbent – Chemicals or materials that can capture liquids or gases.

Adsorption - A separation process involving the removal of a substance from a gas stream by physical binding on the surface of a solid material.

Alkanolamine - Organic amine which contains at least one alcohol group and one amine group, e.g. MEA, DEA DGA.

Amine Treating - Process in which an aqueous alkanolamine solution is used to remove components mostly H₂S and CO₂ from hydrocarbons.

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Anti Foam - Surface active agents used to suppress foaming of a solution. Usually used in small concentrations (typically 10 wppm or less).

Blowing - Condition in a tower in which a fine dispersion or fog of liquid is entrained from one tray to tray above. It is caused by excessive vapor velocities through tray openings at relatively low liquid rates. Blowing causes poor vapor/liquid contacting which reduces tower efficiency.

Boiling point - the temperature corresponding to equilibrium between the liquid and vapor phases at 101.325 kPa (or 14.696 psia).

Boil-off gas - gas generated during the storage or handling of volatile liquefied gases

Bottoms - The liquid or residual matter which is withdrawn from the bottom of a fractionator or other vessel during processing or while in storage

British Thermal Units (BTU) - A unit of heat widely used in the gas industry. Defined as the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. Also described as a fixed 1055.056 Joules. Commonly used in multiples of one million Btu, abbreviated as MMBtu.

Bubble cap tray - Horizontal plate holding bubble caps and downcomers in the contactor.

Bubble Point - Temperature (for a given pressure) or pressure (or a given temperature) at which the first bubble of vapor appears from a liquid.

Bulge Temperature - Maximum amine solution temperature in an absorber tower. The temperature of amine solution increases as it flows down due to heat released by acid gas absorption.

Capacity, refrigerating system: the cooling effect produced by the total enthalpy change between the refrigerant entering the evaporator and the refrigerant leaving the evaporator.

Chiller, Evaporator: a heat exchanger in which the liquid refrigerant is vaporized by a process stream which is in turn cooled.

Coadsorption - The adsorption of multiple substances at the same time

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Coefficient of Performance (COP) – the ratio of desired output divided by the required input. It is the rate of how well the heat pump or refrigerator is performing. –A component that determine a system’s overall efficiency.

Coking - the solid product resulting from the destructive distillation of coal in an oven or closed chamber or by imperfect combustion, consisting principally of carbon.

Compressibility factor -A factor, usually expressed as "Z," which gives the ratio of the actual volume of gas at a given temperature and pressure to the volume of gas when calculated by the ideal gas law.

Compression ratio: ratio of outlet to inlet absolute pressures for a compressor.

Compressor–A device that compressing the fluid to raise its pressure.

Condensate -The liquid formed by the condensation of a vapor or gas; specifically, the hydrocarbon liquid separated from natural gas because of changes in temperature and pressure when the gas from the reservoir was delivered to the surface separators. In a steam system it may be water that is condensed and returned to the boilers.

Condensation – is the change of the physical state of matter from gas phase into liquid phase, and is the reverse of evaporation.

Condenser: a heat exchanger in which the refrigerant, compressed to a suitable pressure, is condensed by rejection of heat to a cooling medium.

Contaminant (Impurity) - The presence of an unwanted constituent

Coolant – is a fluid which flows through or around a device to prevent it’s overheating, transferring the heat produced by the device to other devices that use or dissipate it. An ideal coolant has high thermal capacity, low viscosity, is low cost, nontoxic, and chemically inert, neither causing nor promoting corrosion of the cooling system.

Cooling down – is an easy exercise that will allow the body to gradually transition to a resting or near-resting state.

Cooling medium: any substance whose temperature is such that it is used, with or without change of state, to lower the temperature of refrigerant either during condensing or subcooling.

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Cryobiology – The branch of biology involving the study of the effects of low temperatures on organisms (most often for the purpose of achieving cryopreservation).

Cryogenics – The branches of physics and engineering that involve the study of very low temperatures, how to produce them, and how materials behave at those temperatures.

Cryonics – The emerging medical technology of cryopreserving humans and animals with the intention of future revival. Researchers in the field seek to apply the results of many sciences, including cryobiology, cryogenics, rheology, emergency medicine, etc. "Cryogenics" is sometimes erroneously used to mean "Cryonics" in popular culture and the press.

Cryosurgery – The branch of surgery applying very low temperatures (down to -196 °C) to destroy malignant tissue, e.g. cancer cells.

Cyclic Refrigeration – A cycle that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through refrigerator.

Cyclone tube - A high capacity cyclone type contacting device. A number of tubes may be assembled on a deck or tray for gas/liquid separation (de-misting) or glycol contacting.

DeButanizer -A fractionator designed to separate butane (and more volatile components if present) from a hydrocarbon mixture.

Degradation - Loss of desirable alkanolamine properties which occurs during usage. Alkanolamines degrade by reacting with CO₂, COS, CS₂, O₂, etc. to form undesirable products.

Degradation products - Impurities in a treating solution which are formed both reversible and irreversible side reactions.

Dehydration - Removal of water vapor from a gas.

DeMethanizer -A fractionator designed to separate methane (and more volatile components if present) from a hydrocarbon mixture.

DePropanizer -A fractionator designed to separate propane (and more volatile components if present) from a hydrocarbon mixture.

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Desiccant - An adsorbent that shows primary selectivity for the removal of water

Desiccant Fouling Material adsorbed from the carrier stream may not be desorbed satisfactorily on regeneration. Some reaction may also occur on the adsorbent leading to products that are not desorbed. These reaction products may inhibit efficient adsorption and obstruct or "foul" capacity of the active surface.

Design pressure - The pressure used in the design of a vessel for the purpose of determining the minimum permissible wall thickness or physical characteristics of the different parts of the vessel.

Dewpoint - The temperature at which vapor begins to condense into a liquid at a particular system pressure. A natural gas stream exhibits both hydrocarbon and water dewpoints. Sometimes the dewpoint is only a meta-stable condition – in the stable condition the condensed material is a solid (ice/hydrate) occurring at a higher temperature.

Dewpoint depression - The difference in water dewpoint temperature between the gas entering and leaving the contactor.

Distillation -The process of separating materials by successively heating to vaporize a portion and then cooling to liquefy a part of the vapor. Materials to be separated must differ in boiling point and/or relative volatility.

Downcomer - The vertical conduit between trays which allows liquid to pass from tray to tray.

Downstream - A term used to describe activities along the gas value chain. Downstream typically refers to liquefaction, shipping and regasification.

Dry Gas - An alternative name for lean gas. It does not always mean free of water.

Effect, refrigerating: the rate of heat removal by a refrigerant in a refrigeration system. It is equal to the difference in specific enthalpies of the refrigerant at two designated thermodynamic states.

Entrainment - Small droplets or particles of one phase carried in a stream of another phase, usually liquid droplets in a gas stream, due to incomplete phase separation.

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Entropy – is a measure of the number of specific ways in which a thermodynamic system may be arranged, commonly understood as a measure of disorder.

Evaporator– A device used to turn the liquid into gaseous form. Heat exchanger used to absorb heat energy.

Exergy - The maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used.

Expansion valve – A device that used to control an expansion of liquid refrigerant. Controls the flow of refrigerant and allows for phase change from a liquid to vapor.

Extraction -The process of transferring one or more components from one liquid phase to another by virtue of different solubility in the two liquids. It is also used to indicate removal of one or more constituents from a stream.

Field production of crude oil: Represents crude oil production on leases, including lease condensate. Excludes plant condensate and other processed liquids.

Flash chamber – mixing chamber where both liquid and vapor are stored.

Flash gas: the gas resulting from the instantaneous evaporation of refrigerant by a pressure reducing device, such as a control valve.

Flood - The condition wherein excess liquid hold-up occurs and normal counterflow action is prevented in the glycol contactor, regeneration still or stripping column. It is a design limit which when reached in operation causes an excessive loss of liquid from the top of the column.

Foaming - Condition in which amine solution froth is formed and does not collapse. Usually caused by contaminants, such as heavy hydrocarbons, in solution. Foaming decreases tower throughput capacity or efficiency.

Fouling - the accumulation of unwanted material on solid surfaces to the detriment of function

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Fractionation - Generally used to describe separation of a mixture of hydrocarbons into individual products based on difference in boiling point and/or relative volatility.

Free water - Liquid water which is not dissolved in any other substance.

Frost Plug: small diameter closed nozzle protruding from the side of an insulated vessel which indicates liquid level in the vessel by accumulation of frost.

Gas constant (R) - The constant multiplier in the Ideal Gas Law. Numerically, $R = PV/T$, if V is the volume of one mole of an ideal gas at temperature T and pressure P .

Gas plant operator: Any firm, including a natural gas processing plant owner that operates a gas plant and keeps the gas plant records.

Gas processing - The separation of constituents from natural gas for the purpose of making salable products and also for treating the residue gas to meet required specifications.

Gas/glycol heat exchanger - A heat exchanger employed to cool the lean glycol by the gas leaving the contactor before the glycol enters the contactor

Glycol - A hygroscopic liquid. Mono-ethylene Glycol (MEG) and Di-ethylene Glycol (DEG) are commonly used in hydrate inhibition service and Tri-ethylene Glycol (TEG) is most common in gas dehydration service.

Glycol flash separator - A two or three phase separator which is used in the rich glycol stream to remove entrained gas and hydrocarbon liquids.

Glycol/glycol exchanger - A heat exchanger employed to recover heat from the outgoing hot lean glycol from the reboiler and for preheating the incoming cool rich glycol from the contactor.

Halocarbons: a family of refrigerants consisting of fluorinated and/or chlorinated hydrocarbons.

Heat duty - The rate of heat absorption by the process.

Heat flux - The average heat transfer rate through the heat exchanger tube, to the fluid.

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Heat of Reaction - Heat released by reactions during absorption of acid gases amine solution or heat required by reactions during desorption of acid gases from amine solution.

Heat Pump – A device that provides heat energy from a source of heat to another destination.

Heat Stable Salts (HSS) - Salts of alkanolamine are not regenerable, i.e. do not decompose in the regenerator. HSS are formed by reaction of alkanolamines with acids stronger than H₂S or CO₂, such as SO₂, SO₃, chlorides, thiosulfates, ferrocyanates, thiocyanic, acids etc.

Heavy ends -The portion of a hydrocarbon mixture having the highest boiling point. Usually hexanes or heptanes and all heavier hydrocarbons are the heavy ends in a natural gas stream.

Height of a transfer unit (HTU) - The height of packing required to give one mass transfer unit.

Hot gas bypass: warm discharge gas recycled to chiller for maintaining system's operating integrity at minimum load conditions.

Hydrate - A clathrate compound formed by a combination of methane, ethane, propane, iso-butane, H₂S or CO₂ and water at elevated pressure and low temperature.

Hydrocarbon - An organic compound containing only elements hydrogen and carbon. Hydrocarbons exist as gases, liquids and solids. For example Methane, Ethane, Propane, Butane, Pentane, Hexane & Heptanes.

Hydrocarbon Flash/Skimming Drums - Drum(s) designed to reduce hydrocarbon concentration in rich amine solution from the absorber bottom. Pressure is reduced in the drum(s) to flash off light hydrocarbon vapors. The skimming drum is designed to separate out a liquid hydrocarbon phase from amine solution.

Hydrocarbon gas liquids (HGL): A group of hydrocarbons including ethane, propane, butane, isobutane, and pentanes plus, and their associated olefins, ethylene, propylene, butylene, and isobutylene. Equivalent to sum of natural gas plant liquids and liquefied refinery gases on the supply side, and the sum of natural gas liquids and olefins on the

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market side. Includes propane and normal butane produced at gas-to-liquids plants. Excludes liquefied natural gas (LNG).

Inlet gas separator (Scrubber) - A separator which removes free liquids from the inlet gas stream. The separator may be separate from or integral with the contactor.

Isotherm - A line on a map connecting points having the same temperature at a given time or on average over a given period.

Knockout (K.O) Drum - Drum for disengaging entrained liquid droplets from a stream of a different phase, usually a gas stream.

Lean End Pinch - Condition in the top of an absorber where the actual vapor pressure (or concentration) of acid gas over lean amine solution is very close to the equilibrium partial pressure (or concentration) of acid gas in the absorber overhead product, thus limiting absorption of additional acid gas into the amine solution.

Lean glycol (or Dry glycol) - Glycol which has been regenerated and has a low water content.

Lean Solution - Regenerated amine solution, i.e. regenerator bottoms, which has low acid gas concentrations.

Lean Solution Cooler - Exchanger used to cool lean amine solution from the rich/lean exchanger before the lean solution is fed to top of the absorber tower.

Lease condensate: Light liquid hydrocarbons recovered from lease separators or field facilities at associated and non-associated natural gas wells. Mostly pentanes and heavier hydrocarbons. Normally enters the crude oil stream after production

Light hydrocarbons -The low molecular weight hydrocarbons such as methane, ethane, propane and butanes.

Liquefaction – is a term used in materials sciences to refer to any process which either generates a non-liquid from a solid or a gas, or generates a non-liquid phase which behaves in accordance with fluid dynamics.

Liquefied natural gas LNG - a colourless and odourless cryogenic fluid in the liquid state at normal pressure composed predominantly of methane and which may contain minor

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quantities of ethane, propane, butane, nitrogen or other components normally found in natural gas

Liquefied natural gas plant or LNG plant - a plant the components of which are used to store liquefied natural gas and may also include a plant that conditions, liquefies, transfers or vaporizes liquefied natural gas.

liquefied petroleum gases (LPG): A group of hydrocarbon gases, primarily propane, normal butane, and isobutane, derived from crude oil refining or natural gas fractionation. These gases may be marketed individually or mixed. They can be liquefied through pressurization without refrigeration for convenience of transportation or storage.

Liquefied refinery gases (LRG): Hydrocarbon gas liquids produced in refineries from processing of crude oil and unfinished oils. They are retained in the liquid state through compression and/or refrigeration. The reported categories include ethane, ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene.

Liquid Absorbents. A solution known as liquid absorbent is often used to absorb the vaporized refrigerant (water vapor) after its evaporation in an absorption refrigeration system. This solution, containing the absorbed vapor, is then heated at high pressure. The refrigerant vaporizes, and the solution is restored to its original concentration for reuse.

Liquid refrigerant receiver: a vessel in a refrigeration system designed to ensure the availability of adequate liquid refrigerant for proper functioning of the system and to store the liquid refrigerant when the system is pumped down.

Liquid seal - A liquid column in the downcomer that forces the gas to pass up through the trays rather than up the downcomer.

LNG Train - An independent gas liquefaction unit within a processing facility. A liquefaction facility may contain one or more trains each producing a designed output measured in million tons per annum (Mtpa) .

LNG value chain - The commercial development of LNG which means LNG suppliers first confirm sales to the downstream buyers and then sign 20–25 year contracts with strict terms and structures for gas pricing.

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Mercaptan - A hydrocarbon group (usually a methane, ethane, or propane) with a sulfur group (-SH) substituted on a terminal carbon atom.

Minimum Heat Duty or Steam Rate/Requirement - Reboiler heat duty or steam rate sufficient to satisfy regenerator tower heat balance plus a small excess necessary for regenerator control.

Molecular sieves – Naturally occurring adsorbents with uniform pore size that can be tuned to be highly selective.

Natural gas - gaseous forms of hydrocarbons, principally methane, with minor amounts of ethane, butanes, pentanes, and hexanes along with nonhydrocarbon impurities such as nitrogen, carbon dioxide and hydrogen sulfide.

Natural gas liquids (NGL): A group of hydrocarbons including ethane, propane, normal butane, isobutane, and pentanes plus. Generally include natural gas plant liquids, and all liquefied refinery gases, except olefins.

Natural gas plant liquids (NGPL) Production: The reduction in volume of natural gas due to the removal of natural gas plant liquids constituents such as ethane, propane, butane, and pentanes plus.

Natural gas plant liquids (NGPL): Those hydrocarbons in natural gas that are separated as liquids at natural gas processing plants, fractionating and cycling plants. Products obtained include ethane, liquefied petroleum gases (propane and butanes), and pentanes plus. Component products may be fractionated or mixed. Lease condensate is excluded

Natural gasoline: A commodity product commonly traded in NGL markets, which comprises liquid hydrocarbons (mostly pentanes and hexanes) that generally remain liquid at ambient temperatures and atmospheric pressure. A subset of pentanes plus.

Olefinic hydrocarbons (olefins): Unsaturated hydrocarbon compounds with the general formula C_nH_{2n} containing at least one carbon-to-carbon double-bond. Olefins are produced at crude oil refineries or petrochemical plants and are not naturally occurring constituents of oil and natural gas. Sometimes referred to as “alkenes” or “unsaturated hydrocarbons.” Excludes aromatics.

Organic Acid - Carboxylic acid, with molecular formula $RCOOH$ where R is a hydrogen atom or alkyl group, e.g. formic, acetic, oxalic or naphthenic acid.

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Overhead - Stream exiting from top of a vessel, usually a tower or knockout drum.

Overhead Condensate - Water, saturated with H₂S and CO₂, which is condensed out of regenerator overhead vapors by cooling. Recycle of this condensate helps maintain water material balance in the amine treating unit.

Packing - Material installed in the contactor, still column or stripping column that provides a large surface area for intermingling liquid and vapor to facilitate mass transfer during absorption, distillation or stripping.

Paraffinic hydrocarbons (paraffins): Saturated hydrocarbon compounds with the general formula C_nH_{2n+2} containing only single-bonds. Sometimes referred to as alkanes or natural gas liquids

Pentanes plus: A mixture of liquid hydrocarbons, mostly pentanes and heavier, extracted from natural gas in a gas processing plant (i.e., plant condensate) or from crude oil in a refinery. Natural gasoline is the largest component of pentanes plus.

pH - Measure of the acidity of a liquid on a scale of 0 to 14 with 7 being neutral. 0 to 7 is acidic and 7 to 14 is alkaline.

Pinch - Condition in a tower where there is close approach to equilibrium, i.e. there is a small difference between the actual vapor pressure (or concentration) of acid gas over amine solution and the equilibrium acid gas partial pressure (or concentration) over amine solution.

Plant condensate: Liquid hydrocarbons recovered at inlet separators or scrubbers in natural gas processing plants at atmospheric pressure and ambient temperatures. Mostly pentanes and heavier hydrocarbons, equivalent to pentanes plus

Polarity - a separation of electric charge leading to a molecule or its chemical groups having an electric dipole or multipole moment. Polar molecules interact through dipole–dipole intermolecular forces and hydrogen bonds.

Pressure drop - The difference in pressure between two points of a fluid carrying network

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Random packing consists of shaped pieces (e.g. rings, saddles) that have been dumped, not stacked, in the column. Structured packing is essentially a series of parallel formed metal sheets.

Random packing consists of shaped pieces (e.g. rings, saddles) that have been dumped, not stacked, in the column. Structured packing is essentially a series of parallel formed metal sheets.

Raw gas - a mixture containing methane, other paraffinic hydrocarbons, nitrogen, carbon dioxide, hydrogen sulfide, helium and minor impurities, or some of them, that is recovered or is recoverable at a well from an underground reservoir and that is gaseous at the conditions under which its volume is measured or estimated.

Raw NGL Mix. Raw NGL mix or “y” grade refers to the heavier NGL components that are extracted via natural gas processing. The resulting NGL mix is commingled product consisting of ethane (depending on whether ethane rejection took place), propane, butane, isobutane, and natural gasoline. It is not until fractionation, the next step in the NGL value chain, that the raw NGL mix is further separated into individual NGL components.

Reboiler - Heat exchanger (usually kettle type) which takes amine solution from bottom of regenerator and boils it to supply vapors for acid gas stripping from and heating of the amine solution. Vapors from reboiler return to bottom of regenerator and liquid from reboiler is lean solution. Steam usually supplies energy to reboiler.

Reclaimer - Vessel for separating alkanolamine from degradation products, heat stable salts, and solids by batch distillation. Alkanilamine and water distilled from the reclaimer are returned to the amine treating unit.

Recovery -That percent or fraction of a given component in the plant feed which is recovered as plant product.

Recycle -Return of part of a process stream to a point upstream from where it was removed to enhance recovery or control.

Refinery gas: Still gas consumed as refinery fuel

Reflux -In fractionation, the portion of condensed overhead returned to the column to enhance achievable purity of the overhead product.

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Reflux Ratio - Molar ratio of condensed water to acid gas vapors leaving the regenerator over head condenser.

Reflux ratio -A way of giving a relative measurement to the volume of reflux. Usually referred either to the feed or overhead product.

Refrigerant – A substance that used as a medium to cool the process in refrigeration system.the fluid used for heat transfer in a refrigeration system, which absorbs heat at a low temperature and low pressure and rejects heat at a higher temperature and a higher pressure.

Refrigeration – A process in which work is done to move heat from one circumstances to the other environment.the heat transfer of heat from a lower temperature region to a higher temperature one. A device called a refrigerator or heat pump accomplishes refrigeration.

Refrigerator – A common devices that consists of a thermal insulated and a heat pump that transfers heat from inside compartment (for cooling process) to its environment.

Re-gasification - The reconversion (warming) of LNG to a gas for pipeline distribution.

Regenerator - A unit including reboiler, still column and other related facilities to regenerate (or re-concentrate) rich glycol to lean glycol.

Relative humidity - the amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature.

Relative volatility –the ratio of the concentration of one component in the vapor over the concentration of that component in the liquid divided by the ratio of the concentration of a second component in the vapor over the concentration of that second component in the liquid. For an ideal system, relative volatility is the ratio of vapor pressures i.e. $\alpha = P_2/P_1$

Rich End Pinch - Condition in the absorber bottom where the actual acid gas partial pressure (or concentration) above rich amine solution is very close (or equal) to the equilibrium acid gas partial pressure (or concentration) in the feed to the absorber, thus limiting absorption of more acid gas into amine solution.

Rich glycol (or Wet glycol) - Glycol which has absorbed water and thus has a high water content.

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Rich Solution - Amine solution which has passed through the absorber, i.e. absorber bottoms, and has high concentration of acid gas.

Rich/Lean (Temperature) Approach - Difference between the temperatures of rich solution leaving and lean solution entering the rich/lean exchanger(s).

Rich/Lean Exchanger - Heat exchanger which utilizes heat from hot lean amine solution, leaving the regenerator reboiler, to preheat rich solution feed to the regenerator.

Saturated gas (with respect to water) - A gas stream which contains the maximum amount of water vapor at a given temperature and pressure without condensing the water.

Sour gas - Any gas stream which containing acid gas components H_2S and/or NH_3 , e.g. absorber feed, regenerator overhead condensate, wash water etc.

Sparging tube - Internal pipe in the reboiler used to distribute stripping gas.

Specific gravity -The ratio of the mass of a given volume of a substance to that of another equal volume of another substance used as standard. Unless otherwise stated, air is used as the standard for gases and water for liquids, with the volumes measured at 60°F and standard atmospheric pressure.

Splitter -A name applied to fractionators, particularly those separating isomers (e.g., butane splitter refers to a tower producing most of the isobutane in the feed as overhead and most of the normal butane in the feed as bottoms).

Standard (pressure and temperature) - Unit of ideal gas volume at reference conditions of 101.325 kPa and 15 °C. Abbreviated: $m^3(st)$.

Steam Ratio - Ratio of regenerator reboiler steam rate to circulating lean solution rate. The reboiler steam rate is frequently converted to the equivalent rate of 60psig saturated steam (905 Btu/Lb).

Steam-Jet refrigeration – One of the kind of refrigeration process that used high-pressure jet of steam driving force to utilize the refrigerant.

Still gas: Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. The principal constituents are methane and ethane. May

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contain hydrogen and small/trace amounts of ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene. Still gas is typically consumed as refinery fuel or used as petrochemical feedstock.

Still reflux column - Vertically mounted distillation (fractionation) column on top of the reboiler.

Stripper -A column wherein absorbed constituents are stripped from the absorption oil. The term is applicable to columns using a stripping medium, such as steam or gas.

Stripping column - A packed column where glycol from the reboiler flows downward to the surge drum while gas flows upward stripping the glycol of water.

Stripping column - A packed column where glycol from the reboiler flows downward to the surge drum while gas flows upward stripping the glycol of water.

Stripping gas - Gas that is contacted with glycol to help remove water from the glycol.

Stripping Steam - Steam, due to amine solution vaporization in the reboiler, entering the regenerator bottom from the reboiler. Stripping steam rate is set by the reboiler steam rate.

Surge drum - Reservoir for regenerated glycol which may be integral with, or separate from, the reboiler.

Surge/Storage Drum or Tank - Vessel which provides amine solution holdup capacity for the amine treating unit.

Sweet gas - Gas which has no more than the maximum sulfur and/or CO₂ content defined by (1) the specifications for the sales gas from a plant; (2) the definition by a legal body. Also, the treated gas leaving a sweetening unit.

Sweet service - Where the partial pressure of H₂S is less than 0.34 kPa.

The coefficient of performance or COP - The efficiency of a refrigerator or the ratio of the heating or cooling provided over the electrical energy consumed

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Theoretical tray - One in which the vapor and liquid leaving the stage are in equilibrium. The number of actual trays is equal to the number of theoretical trays divided by the overall tray efficiency.

Thermocouple – Temperature sensor consisting of the junction of two dissimilar metals. The output voltage produced is a function of the difference in the temperature between the hot and cold junction.

Traded - column A vessel wherein gas and liquid, or two essentially immiscible liquids, are contacted, usually counter-currently on trays. Also refer to packed column.

Transfer unit - The dimensionless distance within which every solute molecule has "unit opportunity" to transfer to the gas phase. A transfer unit can be calculated for a theoretical stage.

Tray efficiency - The ratio between the number of theoretical and actual trays.

T-s diagram – schematic or graphical representation of the temperature versus entropy for refrigeration cycles.

Turbine – device used to extract heat energy to produce mechanical energy.

Unit circulation rate (UCR) - Volumetric or mass flowrate of lean glycol per mass flowrate of water removed

Valve tray - Horizontal plate holding valves and downcomers in the contactor. A valve consists of a liftable metal plate which covers a hole in the tray, providing a variable area for gas flow.

Van der Waals forces - the sum of the attractive or repulsive forces between molecules (or between parts of the same molecule) other than those due to covalent bonds, or the electrostatic interaction of ions with one another, with neutral molecules, or with charged molecules.

Vapor-compression – One of the kind of refrigeration process that used mechanical driving force to utilize the refrigerant.

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Water balance - Maintenance of desired inventory of water in amine treating unit. It requires controlling net flow of water into or out of unit to give desired concentration of water in amine solution circulating through unit.

Weeping - Condition in a tower in which liquid continuously leaks through tray openings to the tray below. It is caused by vapor velocities through tray opening which are too low to support the liquid level on the tray. Excessive weeping reduces vapor/liquid contacting and therefore tower efficiency.

Accumulators- These are storage tanks following distillation column condensers. For partial condensers, this flow may be a mixture of vapor and liquid. The outlet flow may be regulated by a level controller in order to avoid the tank either flooding (liquid out the top) or going dry (vapor out the bottom).

Coalescer- A mechanical process vessel with wettable, high-surface area packing on which liquid droplets consolidate for gravity separation from a second phase (for example gas or immiscible liquid).

Demister Mist Extractor- A device installed in the top of scrubbers, separators, tray or packed vessels, etc. to remove liquid droplets entrained in a flowing gas stream.

Disengaging Height- The height provided between bottom of the wire-mesh pad and liquid level of a vapor-liquid separator.

Hold-Up Time- A time period during which the amount of liquid separated in a gas-liquid separator is actually in the vessel for the purpose of control or vapor separation.

Knock-Out- A separator used for a bulk separation of gas and liquid.

Line Drip- A device typically used in pipelines with very high gas-to-liquid ratios to remove only free liquid from a gas stream, and not necessarily all the liquid.

Manifold - A pipe with one or more inlets and two or more outlets, or vice versa.

Mesh- The "mesh count" (usually called "mesh"), is effectively the number of openings of a woven wire filter per 25 mm, measured linearly from the center of one wire to another 25 mm from it.

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Pigging - Procedure of forcing a solid object through a pipeline for cleaning or other purposes.

Residence time - The time period for which a fluid will be contained within a specified volume.

Slug catcher - Separator that is designed to separate intermittent large volumes of liquids from a gas stream.

Surge time- The time it takes for the liquid level to rise from normal (NLL) to maximum (HLL) while maintaining a normal feed without any outlet flow.

Terminal Velocity or Drop-Out Velocity- The velocity at which a particle or droplet will fall under the action of gravity, when drag force just balances gravitational force and the particle (or droplet) continues to fall at constant velocity.

Underflow- The stream containing the remaining liquid and the coarser solids, which is discharged through a circular opening at the apex of the core of a hydrocyclone is referred to as "underflow".

Vapor Space- The volume of a vapor liquid separator above the liquid level.

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