A Comparative Study of Natural Gas Liquids Recovery Methods

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ABSTRACT

Today the main drive of oil and gas industry is to increase the production of all hydrocarbons in an economical and environmentally friendly practice, and reducing the hydrocarbon dew point of natural gas has been an issue for pipeline transportation since large intrastate, interstate, and international pipelines were developed. The problems surrounding the processing and transportation of large quantities of natural gas are many and interconnected. This research provides a review of major natural gas liquids recovery methods including refrigeration methods, chemical methods, physical methods, and combined heat and power (CHP) systems. The advantages and the disadvantages of each method will be discussed.

Keywords: Hydrocarbon dew point, natural gas liquids, pipeline transportation, refrigeration methods, chemical methods, physical methods, combined heat and power

INTRODUCTION

Reducing the hydrocarbon dew point (HCDP) of natural gas has been an issue for pipeline transportation since large intrastate, interstate, and international pipelines were developed. Dew point is defined as the temperature at which condensation begins when the gas is cooled at a constant pressure (Cengle and Boles 2002). As natural gas cools through processing and transportation, natural gas liquid (NGL) such as a combination of condensed propane, butane, and heavier hydrocarbons with different dew point temperatures at a given pressure will condense or evaporate back and forth from vapors to liquids based on pressure changes. Today the main drive of industry is to increase the production of all hydrocarbons in an economical and environmentally friendly practice.

The major problem for gas transportation is NGLs condensing or dropping out. That is why HCDP reduction is very important. Condensing NGLs can cause slugging in pipelines and result in flow measurement errors and register inaccurate energy content of the gas [4]. These NGLs also create dangerous situations at metering stations located throughout the pipeline network, typically located upstream of compressor stations. NGLs that accumulate in the pipeline can damage compressors, causing elevated maintenance and repair costs. The slugs formed from NGLs can also cause corrosion issues in older pipelines. Unless a pipeline is specifically designed to handle two-phase flow or wet gas, this situation should be avoided. Wet gas pipelines are typically used for transporting unprocessed gas from the well head to the processing station [5].

A driving factor in the early research done in NGL recovery was to improve the ethane economy and enhance its large scale recovery techniques [3]. Every gas-producing well is slightly different from every other well, which makes creating an "average" well difficult. There are many factors that make up a well's composition, everything from depth of the well to the type of rock being drilled through. A list of common composition issues has been compiled to show how natural gas starts on the way to the end user. This information is summarized in Table 1.

Once the gas has been found and brought to the surface, many conditions need to be met in order to allow the gas to be inserted into the transportation pipelines. These conditions, or tariffs, that producers of natural gas need to abide by are controlled primarily by the transportation company, and more loosely by the Federal Energy Regulatory

Table 1. Common Problems Associated with Natural Gas Wells

Item	Descriptions
1	Gas can be saturated with water.
2	Gas contains high quantities of grit, dirt, and other particulate matter.
3	Depending on location, gas can have high hydrogen sulfide content, on the order of 5-30%.
4	Many wells have very high levels of inert gas such as carbon dioxide and nitrogen.
5	Composition of hydrocarbons can vary widely, giving very high heating values.
6	Depending on depth of the well, gas can be very hot due to warming by the Earth.

Commission (FERC). However, most of the transportation companies use similar tariff conditions when purchasing gas from a producer. The general tariff conditions stated in Table 2 are from CenterPoint Energy Gas Transmission Company of Northern Louisiana [1]. CenterPoint has transmission pipelines in Northern Louisiana, Arkansas, and Oklahoma that connect to surrounding networks.

As stated above, these are the criteria of just one natural gas transportation company; however, these criteria were compared to Atmos Energy, another Gulf Coast transporter, and found to have no significant difference from CenterPoint [2]. This commonality shows that transporters want to maintain the *fungibility* of the natural gas for ease of sale between transporters. A commodity is said to be *fungible* when it can be traded or substituted for an equal amount of a like commodity, usually to satisfy a contract.

Many technologies have been developed with the goal of drawing out NGLs and water from natural gas streams. The main goal in dropping out the NGLs from the natural gas is to utilize them for feedstocks of other processes and other industries as well as blending agents in gasoline. Aside from transportation safety, another main reason for wanting to drop out these NGLs is to help supply the ever increasing demand for ethane, propane, butane, pentane, and heavier hydrocarbons as feedstocks for the petrochemical, plastics, and pharmaceutical industries. The economics of recovery, however, are much more unpredictable than is the demand for the NGLs as feedstock products.

Table 2. Transport Tariffs for Natural Gas in Gulf Coast Region

Item	Descriptions
1	The total heating value of the gas will be between 975 and 1100 Btu/ft^3.
2	Gas shall be free of objectionable odors, dust, impurities, and solid, gaseous, or liquid matter.
3	Gas shall contain less than ¼ grain of hydrogen sulfide per 100 ft^3 of gas volume.
4	Gas shall not contain more than 5 grains in total of sulphur compounds per 100 ft^3 of gas volume.
5	Gas shall be between 40 ºF and 120 ºF.
6	Gas shall not contain more than 7 pounds of water vapor per 1 MMScf at a pressure of 14.73 psia and 60 ºF.
7	Gas shall not contain more than 0.002% by volume of oxygen.
8	Gas shall not contain more than 2% by volume of carbon dioxide.
9	Gas shall not contain more than 3% by volume of nitrogen.
10	Gas shall not have a hydrocarbon dew point over 20 ºF at 800 psig.
11	Gas shall not contain any toxic, hazardous, or deleterious materials or substances.

Since the development of the initial recovery techniques, the economics of NGL recovery have driven the supply of ethane and heavier hydrocarbons rather than the demand [3]. Many technologies were being improved upon and introduced to the gas processing industry. The objective of this research is to provide a review of major natural gas liquids recovery methods including refrigeration methods, chemical methods, physical methods, and combined heat and power (CHP) systems. The advantages and the disadvantages of each method will be discussed.

REFRIGERATION METHODS

Refrigeration was the first method used to process gas in the early 1930's and has come a long way since then. The basis of refrigeration is to use a circulating cooling liquid or vapor that picks up heat from a cold space and transports the heat to a warm space where it is rejected to a thermal sink. Typical modern systems use ammonia, propane, lithium bromide or Freon as the circulating working fluid. The goal of refrigeration systems today is to maximize their NGL recovery levels while reducing the amount of energy and equipment needed to recover the NGLs. One optimization method is to use cold residue reflux and recycle split vapor process, essentially reusing cold fluids in multiple stages, giving the edge needed to gas processors to use refrigeration [9, 10]. However, with the large number of refrigeration and optimization methods in development and being used throughout the industry, they cannot all be addressed here. Furthermore, typical refrigeration cycles cannot reach the C_2+ level of NGL recovery, which other methods can, due to the physical limitations of the circulating fluid. Yet by utilizing multiple refrigeration cycles in a cascading effect, it is possible to liquefy a significant portion of the ethane in the natural gas. The most popular refrigeration methods are Joule-Thompson cooling and cryogenics.

Joule-Thompson Cooling

The simplest of all of the possibilities for NGL recovery, which has been used for many years, is Joule-Thompson, or JT, cooling [6]. JT cooling is the process of a high pressure gas expanding through a small orifice to drop the pressure and increase its velocity, resulting in a temperature drop. Most gases cool when they expand. JT cooling has been used as a primary source of recovery for NGLs but has fallen out of favor with managers due to the increasing cost of fuel gas and the inefficient nature of pressure recovery [7]. JT cooling is often a detrimental side effect of processing and transportation and is perceived as a problem by industry.

However, JT cooling is not a better process over other NGL recovery methods, because there is no way to recover the pressure loss. The lack of a pressure recovery process for JT cooling requires that the cooling occur close to the end user, or installation of a booster compressor to recover the lost pressure. Conversely, using JT cooling near the end user does not address the problem of transporting a wet gas efficiently. JT cooling has no method for recovering the energy lost during the pressure drop to yield a higher efficiency and often is viewed as a problem in transport pipelines. When gas goes through a metering station or distribution points, there is an increase in the likelihood of JT cooling. This needs to be countered to avoid two-phase flow which affects metering accuracy and creates potentially damaging liquid slugs. Classically, this is done by heating the gas either directly up stream or downstream of the JT cooling spot to prevent dramatic cooling and NGL drop out at these locations. The down side is that at this point in the system there should be little to no liquids left in the gas and the JT cooling is used more for its pressure reduction than cooling effects [8]. The advantages and disadvantages of Joule-Thompson cooling method is summarized in Table 3.

Cryogenics

Cryogenics is used to obtain ultra-low temperatures and extremely high levels of ethane recovery by utilizing both propane and ethane as working fluids in a cascading refrigeration plant. Cryogenic plants

Table 3. Advantages and Disadvantages of Joule-Thompson Cooling Method

Advantage	Disadvantage
1. Simple	1. Inefficient
	2. Increasing cost of fuel due to pressure drop
	3. Detriment side effect of processing and transportation
	4. Need to install near the end user
	5. Need to install a booster compressor to recover the lost pressure
	6. Need to heat up gas to prevent dramatically cooling

require a significant capital expenditure over other systems due to the complexity of the controls and the need for special materials handling procedures to handle the extreme cold. For cryogenic plants to be fully utilized, nearly all of the impurities in the natural gas need to be removed prior to NGL recovery. This includes nitrogen, carbon dioxide, and all water. All water must be removed in order to keep ice and hydrate formation from occurring in the lines, and the removal of nitrogen and carbon dioxide increases the efficiency of the plant by not having to cool these highly energetic gases [11, 12]. The advantages and disadvantages of cryogenic method are summarized in Table 4.

CHEMICAL METHODS

Lean Oil Absorption

The lean oil absorption is considered as a chemical method has been in use since the early 1910's when the process was invented. The basic principal of the lean oil absorption is to pass a wet natural gas stream over or through lean oil, allowing the oil to absorb the NGLs. Typically the lean oil has a molecular weight of 100 to 150, with the 100 molecular weight being more efficient at removing the lighter NGLs [13]. After the NGLs have been absorbed, the now rich oil is sent to a distillation tower where the components are separated. The NGLs are separated and sent out of the system for further processing, while the now lean oil, methane and some ethane are recovered and sent back through the process to maintain continuity.

Over the life time of the lean oil process, better techniques have been developed to remove other gases from the natural gas, such as nitrogen [14]. However, lean oil absorption requires large equipment

Table 4. Advantages and Disadvantages of Cryogenics method

Advantage	Disadvantage
1. Provide ultra low temperature and high levels of ethane recovery	1. Cryogenics plant requires significant capital expenditure
	2. Cryogenics system needs special material handling procedures to handle the extreme cold
	3. Complexity of control system
	4. All water must be removed in order to keep ice and hydrate formation from occurring
	5. For typical refrigeration method, it cannot reach C_2 level or higher of NGL recovery

and physical space in which to operate along with large heaters to power the distillation tower. Many other NGL recovery methods are capable of achieving greater efficiencies with lower costs and smaller physical footprints [15]. Incidentally, many of the lean oil absorption NGL recovery plants have been converted over to more modern refrigeration or other types of recovery methods. These other methods are more economical and will generate more NGLs for the same amount of energy and capital input [13, 16]. The advantages and disadvantages of lean oil absorption method is shown in Table 5.

PHYSICAL METHODS

Membrane Technology

Membrane technology is a relatively new development in gas processing because of the advancements in materials, manufacturing, and technology. In early membrane technology large molecules, typically organic compounds, were being removed from air via membranes. As technology progressed in materials manufacturing and creation of ever more exotic membranes became possible, smaller and smaller molecules could be removed from process gas. In the twenty year history of membranes, an ever increasing number of applications and ever higher operating pressures, and thus throughputs, have become possible with membranes. Even as membranes come to the forefront of state of the art, they still remain one of the simplest, easiest, and often times cheapest of the conventional processes. Currently membrane technology is capable of removing NGLs, hydrogen sulfide, carbon dioxide, nitrogen, and water from natural gas streams [17, 18]. The advantages and disadvantages of membrane technology method are summarized in Table 6.

Turbo Expander

One of the most innovative NGL recovery methods developed in the 1960s was that of the turbo expander. The turbo expander uses

Table 5. Advantages and Disadvantages of Lean Oil Absorption Method

Advantage	Disadvantage
1. Able to remove light and heavy NGL	1. Lean Oil Absorption requires large equipments and physical spaces
2. Able to remove other gaseous such as nitrogen	2. Distillation process requires large heaters to power distillation tower

Table 6. Advantages and Disadvantages of Membrane Technology method

Advantage	Disadvantage
1. Simplest method	1. Membrane fouling at high driving force
2. Cheapest conventional process	2. Concentration polarization

the same principals of a steam turbine used for power generation. A high energy gas, in this case high pressure natural gas, is injected into a turbine and as the gas expands through the turbine it pushes on the blades and turns the shaft while being reduced in pressure and temperature. This is essentially pressure recovery from previous compression or "free" energy from a high pressure well head. The resultant shaft power created from this expansion of natural gas is used to run a similar turbine in reverse to compress gas later in the process. The advantage of the turbo expander is that it also has a dramatic cooling effect, similar to the JT expansion method, which cools the gas as it expands. Typical turbo expander processes can operate at –10°F for HCDP and –40°F for propane recovery. However, turbo expanders have a large amount of equipment associated with the process in order to further cool the gas and separate the NGLs from one and other for separate shipment. Turbo expanders are very efficient at recovering high levels of C_3+ and even C_2+ from gas. When used with a refrigeration system, the turbo expander can be used to recover high amounts of ethane more economically than refrigeration or cryogenics alone. Turbo expanders have one of the highest capital investments, close to that of cryogenics, of all types of projects. The turbines used in the process have very tight tolerances and require extensive regular and preventative maintenance in order to keep the blades from becoming damaged during normal operations [12, 19, 20]. The advantages and disadvantages of turbo expander method are summarized in Table 7.

Table 7. Advantages and Disadvantages of Turbo Expanders

Advantage	Disadvantage
1. Dramatic cooling effect	1. Large amount of equipment associated With the process
2. Use free energy from high pressure well head	2.Turbo expanders require significant capital expenditure
3. Turbo expanders are very efficient at recovering high levels of C_3 or higher	3. The turbines used in the process requires extensive regular and preventative maintenance

Supersonic Nozzle

In the late 1990s a new technology that harnessed the same principals of JT cooling and turbo expanders came on the scene. By moving a high pressure gas over a stationary curved blade, a vortex is formed by the deflected motion of the gas. Coupled then with a nozzle, similar to JT cooling, a supersonic vortex can be formed inside a non-moving piece of equipment. In reality, the principals that drive the vortex tube have been known for centuries. The vortex tube was conceived to improve the separation of natural gas and the NGLs over that of the Joule-Thompson system, while reducing the cost and complexity as compared to a turbo expander plant. The vortex tube can accomplish this while still maintaining a majority of the pressure of the gas, negating the need for a booster compressor [21]. This new separation device has been shown to have a pressure drop of only 25-35% of the inlet pressure of the gas. Significant improvement of the vortex tube concept was made by the Shell Oil Research group with the Twister™.

The Twister™ is a vortex tube utilizing a supersonic flow with veins at the inlet to create a swirling motion in the gas. As the high pressure gas enters the unit, it passes over the veins creating a vortex with very high angular momentum. The gas then enters the nozzle section, which brings the gas to a supersonic velocity downstream of the throat of the nozzle. The velocity increase and pressure decrease cause a dramatic drop in gas temperature causing water and NGLs to condense into a fog cloud. With the small droplets of condensate moving with a very high angular velocity, they are caused to move to the outside of the primary gas flow. These droplets are then collected and taken out of the system. The now "dry" gas then leaves the nozzle and expands at constant heat and entropy, recovering 75% of its original pressure.

The Twister™ uses a Laval nozzle to create supersonic flow forcing water and heavy HC to form a condensed fog with particles that are only microns in diameter. These particles can then be flung to the walls of the Twister™ body by the vortex forces operating at 300,000 to 500,000 G's (1 G = 32.2 ft/sec^2). The main purpose of the Twister™ is to reduce the dew point of both the water and hydrocarbon content of a natural gas stream quickly with no moving parts or chemicals. The most appealing aspects of the Twister™ are its complete lack of moving parts and chemicals, coupled to the low maintenance and unmanned operations making it a very cost competitive piece of equipment [22, 23, 24]. The advantages and disadvantages of supersonic nozzle method are shown in Table 8.

Table 8. Advantages and Disadvantages of Supersonic Nozzle Method

Advantage	Disadvantage
1. Maintaining a majority of the pressure of the gas, negating the need for a booster compressor	1. Capable of processing medium and small volume scales of gas
2. Pressure drop is only 25%-35%	
3. Low maintenance	
4. Unmanned operations	
5. Very cost competitive piece of equipment	

COMBINED HEAT AND POWER SYSTEMS

Combined heat and power (CHP) or cogeneration is based on using a single fuel source to produce two kinds of power, thereby reducing the production loses of the system. This principle has been utilized as a method of power production since the Industrial Revolution. However, its use has dwindled in the past century due to the advent of widespread electrical power distribution and economies of scale. With the new world-wide concern about global warming and greenhouse gas emissions, as well as ever increasing fuel prices, CHP has come back into popular use by industry and even in the residential sector. For HCDP reduction purposes, CHP can be used to supply the needed thermal input to run a refrigeration system. The input heat evaporates a refrigerant mixture that is then distilled and used in an evaporator to remove heat from the cold space [25, 26, 27].

CHP is used to utilize waste heat from a compressor engine commonly found in industry to power a refrigeration unit to cool the low pressure gas. By capturing the waste heat from a compressor engine, instead of merely dumping it into the atmosphere, the precious Btus produced as a by-product of combustion can be put to good use. For a typical gas compressor in the field there are three major sources of heat from which to draw, the lubrication oil cooler, the water jacket cooler, and the main exhaust stack. These are given from lowest to highest Btu recovery possibilities. Capturing this heat increases the fuel efficiency used to run the engine which increases the overall efficiency of the system.

Many of the processes currently in use today are for large scale volumes of gas being run through a gas processing facility, including lean oil absorption, turbo expander, and cryogenic refrigeration. They all require large amounts of equipment and support facilities or large quantities of chemicals. The medium and small scale projects for NGL recovery and hydrocarbon dew pointing are the Twister™ and other supersonic devices, Joule-Thomson, and ammonia refrigeration processes. These processes require much less in the way of equipment and support facilities, making them more desirable as NGL recovery and hydrocarbon dew pointing methods. The advantages and disadvantages of CHP are summarized in Table 9.

Table 9. Advantages and Disadvantages of Combined Heat and Power

Advantage	Disadvantage
1. Utilize waste heat to supply refrigerant system	1. Capable of processing medium and small volume scales of gas
2. Require small amounts of equipment and support facilities	
3. Low maintenance cost	
4. Long history of success	
5. Capable of generating distributed power	

CONCLUSION

Natural gas must be purified until it meets pipeline condition before transporting. The major reason is that condensed NGLs can cause slugging in pipelines and result in flow measurement errors and register inaccurate energy content of the gas. These NGLs also create dangerous situations at metering stations located throughout the pipeline network, typically located upstream of compressor stations.

There are many NGLs recovery methods available in the market. Each of the NGLs recovery methods has differences in the advantages and disadvantages. NGLs recovery methods such as lean oil absorption, turbo expander, and cryogenic refrigeration require large amounts of equipment and support facilities or large quantities of chemicals. On the other hand, Twister™ and other supersonic devices, Joule-Thomson, and ammonia refrigeration processes combined with CHP require much less equipment and support facilities, making them more desirable as NGL recovery and hydrocarbon dew pointing methods.

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