Part 1
Gas Sweetening$^{1,2}$

Contents

PROCESSING NATURAL GAS 1-1
ACID GAS CONSIDERATIONS 1-14
SWEETENING PROCESSES 1-17
SOLID BED PROCESSES 1-18
CHEMICAL SOLVENT PROCESSES 1-27
PHYSICAL SOLVENT PROCESSES 1-41
DIRECT CONVERSION PROCESSES 1-47
DISTILLATION PROCESS 1-56
GAS PERMEATION PROCESS 1-57
PROCESS SELECTION 1-87
DESIGN PROCEDURE 1-93
DESIGN EXAMPLES (OILFIELD UNITS) 1-115
DESIGN EXAMPLES (SI UNITS) 1-128
NOMENCLATURE 1-139
REFERENCES 1-140

PROCESSING NATURAL GAS

Introduction

Natural gas used by consumers is significantly different from the natural gas that is brought up from the wellhead.

The processing of natural gas, in many respects, is less complicated than the processing of crude oil but is equally important before it is used by the end users.

Natural gas used by consumers is composed almost entirely of methane.

Natural gas found at the wellhead, although composed primarily of methane, contains a number of impurities that need to be removed.

Raw natural gas comes from three types of wells:

Oil wells

DOI: 10.1016/B978-1-85617-982-9.00002-8
Gas wells, and
Condensate wells.

Natural gas from oil wells
Termed “associated gas”
Gas can exist
Separate from oil in the formation and is termed “free gas” or
Dissolved in the crude oil and is termed “dissolved gas.”

Natural gas from gas and condensate wells
Contain little or no crude oil
Termed “nonassociated gas”
Gas wells produce raw natural gas by itself
Condensate wells produce free natural gas along with a semiliquid hydrocarbon condensate

Whatever the source of raw natural gas
Exists in mixtures with
Other associated hydrocarbons such as
Ethane
Propane
Butane
i-Butane
Pentanes plus (natural gasoline)

Impurities
Water vapor
Hydrogen sulfide (H₂S)
Carbon dioxide (CO₂)
Helium
Nitrogen
Other compounds

Natural Gas Processing
Consists of separating all of the various hydrocarbons and impurities from the raw natural gas to produce what is termed “pipeline quality” dry natural gas.
Pipeline companies impose restrictions on the makeup of natural gas that is allowed into the pipeline. Requires natural gas to be purified by removing Impurities termed “waste products” and Associated hydrocarbons such as
- Ethane
- Propane
- Butane
- i-Butane
- Pentane plus (natural gasoline)

Associated hydrocarbons
Termed “natural gas liquids” (NGLs)
Can be very valuable by-products of natural gas processing
Sold separately and have a variety of different uses such as
- Enhancing oil recovery in oil wells
- Providing raw materials for oil refineries and/or petrochemical plants, and
- Sources of energy

Some of the needed processing can be accomplished at or near the wellhead (field processing).

Complete processing of natural gas takes place at a processing plant, usually located in a natural gas producing region.

Extracted natural gas is transported to processing plants through a network of gathering pipelines.
- Consists of small-diameter low pressure pipelines
- A complex gathering system can consist of thousands of miles of pipeline, interconnecting the processing plant to more than 100 wells.

In addition to processing done at the wellhead and centralized processing plants, some final processing is also done at “staddle extraction plants.”
- Plants are located on major pipeline systems.
- Removes small quantities of NGLs that may still exist in pipeline quality gas.
The processing of natural gas to meet pipeline quality gas involves the following four main processes to remove the various impurities:

- Oil and condensate removal
- Water removal
- Separation of NGLs
- Sulfur and carbon dioxide removal

In addition to the four processes above, heaters and scrubbers are installed, usually at or near the wellhead.

- scrubbers remove sand and other large-particle impurities.
- Heaters ensure that the temperature of the gas does not drop below the hydrate formation temperature.

Hydrates

- They have a tendency to form when the gas temperature drops.
- Hydrates are solid or semisolid compounds, resembling ice-like crystals.
- Should these hydrates accumulate, they can impede passage of natural gas through valves and gathering systems.

To reduce the occurrence of hydrates, the following equipment may be used:

- Indirect fired heater
- Hydrate inhibitors
- Dehydration
- Low temperature units

### Oil and Condensate Removal

In order to process and transport associated dissolved natural gas:

- Gas must be separated from the oil in which it is dissolved.
- Often accomplished by using equipment installed at or near the wellhead.

Actual processes used to separate oil from natural gas and the equipment used can vary widely.
Dry pipeline quality natural gas is basically identical across different geographic regions.

Raw natural gas from different regions may have different compositions and separation requirements.

In some instances, natural gas is dissolved in oil underground primarily due to the pressure that the formation is under.

When this natural gas and oil is produced, it is possible that it will separate on its own, simply due to decreased pressure (similar to opening a bottle of soda and allowing the release of dissolved carbon dioxide).

Separation of oil and gas is relatively easy, and the two hydrocarbons are separated and exit the separator for further processing.

Conventional separators are used which uses gravity separation to separate the heavy liquids (oil and water) and lighter fluid (natural gas).

In some instances, specialized process equipment, such as a low-temperature separator (LTX), is necessary to separate oil and natural gas.

LTX is used for wells producing high pressure gas along with light crude oil or condensate.

These separators use pressure differentials to cool the wet natural gas and separate the oil and condensate.

Wet gas enters the separator, being cooled slightly by a heat exchanger.

The gas then travels through a high pressure liquid “knockout” which serves to remove any liquids into a LTX.

Gas then flows into this LTX through a choke mechanism, which expands the gas as it enters the separator.

The rapid expansion of the gas allows for the lowering of the temperature in the separator.

After liquid removal, the dry gas then travels back through the heat exchanger and is warmed by the incoming wet gas.

By varying the pressure of the gas in various sections of the separator, it is possible to vary...
the temperature, which causes the oil and some water to be condensed out of the wet gas stream.

This basic pressure–temperature relationship can work in reverse as well, to extract gas from a liquid oil stream.

Water Removal

In addition to separating oil and some condensate from the wet gas stream, it is necessary to remove most of the associated water.

Most of the liquid, free water associated with extracted natural gas, is removed by simple separation methods at or near the wellhead.

The removal of the water vapor that exists in solution in natural gas requires a more complex treatment.

This treatment consists of “dehydrating” the natural gas, which usually involves one of the following two processes:

- Adsorption
- Absorption

Adsorption

Occurs when the water vapor is taken out by a dehydrating agent.

Occurs when the water vapor is condensed and collected on the surface.

Glycol Dehydration

An example of absorption dehydration is glycol dehydration.

A liquid desiccant dehydrator serves to absorb water vapor from the gas stream.

The principle agent in this process is glycol which has a chemical affinity for water.

When glycol comes in contact with a stream of natural gas that contains water, the glycol absorbs the water vapor out of the stream.

Glycol dehydration involves using a glycol solution, usually either diethylene glycol (DEG) or triethylene glycol.
(TEG), which is brought into contact with the wet gas stream in what is called a "contactor."

The glycol absorbs the water from the wet gas. Once absorbed, the glycol particles become heavier and sink to the bottom of the contactor where they are removed.

The natural gas, having been stripped of most of its water content, is then transported out of the dehydrator.

The glycol solution, bearing all of the water stripped from the natural gas, is put through a specialized boiler designed to vaporize only the water out of the solution.

While water has a boiling point of 212 °F (100 °C), glycol does not boil until 400 °F (204 °C).

This boiling point differential makes it relatively easy to remove water from the glycol solution, allowing it to be reused in the dehydration process.

A new innovation in this process has been the addition of flash tank separator–condensers.

As well as absorbing water from the wet gas stream, the glycol solution occasionally carries with it small amounts of methane and other compounds found in the wet gas.

In the past, methane was simply vented out of the reboiler.

In addition to losing a portion of the natural gas that was extracted, this venting contributes to air pollution and the greenhouse effect.

In order to decrease the amount of methane and other compounds that are lost, flash tank separator–condensers work to remove these compounds before the glycol solution reaches the boiler.

A flash tank separator consists of a device that reduces the pressure of the glycol solution stream, allowing the methane and other hydrocarbons to vaporize or “flash.”

The glycol solution then travels to the reboiler, which may also be fitted with air or water cooled condensers, which serve to capture any remaining organic compounds that may remain in the glycol solution.

In practice, these systems recover 90–99% of methane that would otherwise be flared into the atmosphere.
Solid-Desiccant Dehydration

Solid-desiccant dehydration is the primary form of dehydrating natural gas using adsorption and usually consists of two or more adsorption towers, which are filled with a solid desiccant.

Typical desiccants include

- Activated alumina
- Silica gel
- Molecular sieve

Wet natural gas is passed through these towers from top to bottom.

As the wet gas passes around the particles of desiccant material, water is retained on the surface of these desiccant particles.

Passing through the entire desiccant bed, almost all of the water is adsorbed onto the desiccant material, leaving the dry gas to exit the bottom of the tower.

Solid-desiccant dehydrators are typically more effective than glycol dehydrators and are usually installed.

Where very dry gas is required, such as upstream of a cryogenic expander, LPG, and LNG plants

As a type of straddle system along natural gas pipelines.

These types of dehydration systems are best suited for large volumes of gas under very high pressure and are thus usually located on a pipeline downstream of a compressor station.

Two or more towers are required due to the fact that after a certain period of use (typically 8 h), the desiccant in a particular tower becomes saturated with water.

To “regenerate” the desiccant, a high-temperature heater is used to heat gas to a very high temperature.

Passing this heated gas through a saturated desiccant bed vaporizes the water in the desiccant tower, leaving it dry and allowing for further natural gas dehydration.

Separation of NGLs

Natural gas coming directly from a well contains many NGLs that are commonly removed.
In most instances, NGLs have a higher value as separate products, and it is thus economical to remove them from the gas stream.

The removal of NGLs usually takes place in a relatively centralized processing plant and uses techniques similar to those used to dehydrate natural gas.

There are two basic steps to the treatment of NGLs in the natural gas stream:

First, the liquids must be extracted from the natural gas.

Second, these NGLs must be separated themselves, down to their base components.

**NGL Extraction**

The two principle techniques for removing NGLs from the natural gas stream are

- Absorption method
- Cryogenic expander process.

These two processes account for around 90% of total NGLs production.

**Absorption Method**

The absorption method of NGL extraction is very similar to using absorption for dehydration.

The main difference is that, in NGL absorption, an absorbing oil is used as opposed to glycol.

The absorbing oil has an “affinity” for NGLs in much the same manner as glycol has an affinity for water.

Before the oil has picked up any NGLs, it is brought into contact with the absorption oil.

As the natural gas is passed through an absorption tower, it is brought into contact with the absorption oil which soaks up a high proportion of the NGLs.

The “rich” absorption oil, now containing NGLs, exists the absorption tower through the bottom.

It is now a mixture of

- Absorption oil
- Propane
Butanes
Pentanes, and
Heavier hydrocarbons.

The rich oil is fed into lean oil stills, where the mixture is heated to a temperature above the boiling point of the NGLs, but below that of the oil.

This process allows recovery of around
75% of butanes
85–90% pentanes and heavier molecules from the natural gas stream.

This basic absorption process can be modified to improve its effectiveness, or to target the extraction of specific NGLs.

In the refrigerated oil absorption method
Lean oil is cooled through refrigeration
Propane recovery can be upward of 90%, and
40% of ethane can be extracted from the natural gas stream.

Extraction of the other heavier NGLs can be close to 100% using this process.

Cryogenic Expansion Process

Cryogenic processes are also used to extract NGLs from natural gas.

Absorption methods can extract almost all of the heavier NGLs.

Lighter hydrocarbons, such as ethane, are often more difficult to recover from natural gas stream.

In certain instances, it is economic to simply leave the lighter NGLs in the natural gas stream.

If it is economic to extract ethane and other lighter hydrocarbons, cryogenic processes are required for high recovery rates.

Cryogenic processes consist of dropping the temperature of the gas stream to around minus 120 °F.

There are a number of different ways of chilling the gas to these temperatures.