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# PETROLEUMENGINEERING

# COURSE CODE: PTE 316

**COURSE TITLE: FUNDAMENTALS OF NATURAL GAS ENGINEERING**

## **Discussion on the different methods of storing natural gas**

## **Storage of Natural Gas**



Natural gas, like most other commodities, can be stored for an indefinite period of time. The exploration, production, and transportation of natural gas takes time, and the natural gas that reaches its destination is not always needed right away, so it is injected into underground storage facilities. These storage facilities can be located near market centers that do not have a ready supply of locally produced natural gas.

Traditionally, natural gas has been a seasonal fuel. That is, demand for natural gas is usually higher during the winter, partly because it is used for heat in residential and commercial settings. Stored natural gas plays a vital role in ensuring that any excess supply delivered during the summer months is available to meet the increased demand of the winter months. However, with the recent trend towards natural gas fired electric generation, demand for natural gas during the summer months is now increasing (due to the demand for electricity to power air conditioners and the like). Natural gas in storage also serves as insurance against any unforeseen accidents, natural disasters, or other occurrences that may affect the production or delivery of natural gas.

Natural gas storage plays a vital role in maintaining the reliability of supply needed to meet the demands of consumers. Historically, when natural gas was a regulated commodity, storage was part of the bundled product sold by the pipelines to distribution utilities. This all changed in 1992 with the introduction of the [Federal Energy Regulatory Commission’s](http://www.ferc.gov/) (FERC) Order 636, which opened up the natural gas market to deregulation. Essentially, this meant that where natural gas storage was required prior to Order 636 for the operational requirements of the pipelines in meeting the needs of the utilities, it is now available to anyone seeking storage for commercial purposes or operational requirements. Storage used to serve only as a buffer between transportation and distribution, to ensure adequate supplies of natural gas were in place for seasonal demand shifts, and unexpected demand surges. Now, in addition to serving those purposes, natural gas storage is also used by industry participants for commercial reasons; storing gas when prices are low, and withdrawing and selling it when prices are high, for instance. The purpose and use of storage has been closely linked to the regulatory environment of the time.

**Base Load vs. Peak Load Storage**

There are basically two uses for natural gas in storage facilities: meeting base load requirements, and meeting peak load requirements. As mentioned, natural gas storage is required for two reasons: meeting seasonal demand requirements, and as insurance against unforeseen supply disruptions. Base load storage capacity is used to meet seasonal demand increases. Base load facilities are capable of holding enough natural gas to satisfy long term seasonal demand requirements. Typically, the turn-over rate for natural gas in these facilities is a year; natural gas is generally injected during the summer (non-heating season), which usually runs from April through October, and withdrawn during the winter (heating season), usually from November to March. These reservoirs are larger, but their delivery rates are relatively low, meaning the natural gas that can be extracted each day is limited. Instead, these facilities provide a prolonged, steady supply of natural gas. Depleted gas reservoirs are the most common type of base load storage facility.

Peak load storage facilities, on the other hand, are designed to have high-deliverability for short periods of time, meaning natural gas can be withdrawn from storage quickly should the need arise. Peak load facilities are intended to meet sudden, short-term demand increases. These facilities cannot hold as much natural gas as base load facilities; however, they can deliver smaller amounts of gas more quickly, and can also be replenished in a shorter amount of time than base load facilities. While base load facilities have long term injection and withdrawal seasons, turning over the natural gas in the facility about once per year, peak load facilities can have turn over rates as short as a few days or weeks. Salt caverns are the most common type of peak load storage facility, although aquifers may be used to meet these demands as well.

Natural gas is usually stored underground, in large storage reservoirs. There are three main types of underground storage: [depleted gas reservoirs](http://naturalgas.org/naturalgas/storage/#depleted), [aquifers](http://naturalgas.org/naturalgas/storage/#aquifers), and [salt caverns](http://naturalgas.org/naturalgas/storage/#saltcaverns). In addition to underground storage, however, natural gas can be stored as liquefied natural gas (LNG). LNG allows natural gas to be shipped and stored in liquid form, meaning it takes up much less space than gaseous natural gas.

**Types of Underground Storage**

Underground natural gas storage fields grew in popularity shortly after World War II. At the time, the natural gas industry noted that seasonal demand increases could not feasibly be met by pipeline delivery alone. In order to meet seasonal demand increases, the deliverability of pipelines (and thus their size), would have to increase dramatically. However, the technology required to construct such large pipelines to consuming regions was, at the time, unattainable and unfeasible. In order to be able to meet seasonal demand increases, underground storage fields were the only option.

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| storage_graph1 |
| **Working Gas Capacity by Type of Storage** |
| Source: EIA – ‘Natural Gas Storage in the United States in 2001’ |

As mentioned, there are three main types of underground natural gas storage facilities. Specific characteristics of depleted reservoirs, aquifers, and salt caverns may be found below. Essentially, any underground storage facility is reconditioned before injection, to create a sort of storage vessel underground. Natural gas is injected into the formation, building up pressure as more natural gas is added. In this sense, the underground formation becomes a sort of pressurized natural gas container. As with newly drilled wells, the higher the pressure in the storage facility, the more readily gas may be extracted. Once the pressure drops to below that of the wellhead, there is no pressure differential left to push the natural gas out of the storage facility. This means that, in any underground storage facility, there is a certain amount of gas that may never be extracted. This is known as physically unrecoverable gas; it is permanently embedded in the formation.

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| storage_graph2 |
| **Daily Deliverability by Type of Storage** |
| Source: EIA – ‘Natural Gas Storage in the United States in 2001’ |

In addition to this physically unrecoverable gas, underground storage facilities contain what is known as ‘base gas’ or ‘cushion gas’. This is the volume of gas that must remain in the storage facility to provide the required pressurization to extract the remaining gas. In the normal operation of the storage facility, this cushion gas remains underground; however a portion of it may be extracted using specialized compression equipment at the wellhead.

‘Working gas’ is the volume of natural gas in the storage reservoir that can be extracted during the normal operation of the storage facility. This is the natural gas that is being stored and withdrawn; the capacity of storage facilities normally refers to their working gas capacity.

 At the beginning of a withdrawal cycle, the pressure inside the storage facility is at its highest; meaning working gas can be withdrawn at a high rate. As the volume of gas inside the storage facility drops, pressure (and thus deliverability) in the storage facility also decreases. Periodically, underground storage facility operators may reclassify portions of working gas as base gas after evaluating the operation of their facilities.

The graphs shown indicate the working gas capacity and deliverability of natural gas storage facilities in the U.S. as of 2001. It can be seen that depleted reservoirs constitute the majority of working gas capacity and deliverability. However, the high deliverability of salt caverns is shown by the high daily deliverability relative to working gas capacity.

* **Depleted Gas Reservoirs**

The first instance of natural gas successfully being stored underground occurred in Weland County, Ontario, Canada, in 1915. This storage facility used a depleted natural gas well that had been reconditioned into a storage field. In the United States, the first storage facility was developed just south of Buffalo, New York. By 1930, there were nine storage facilities in six different states. Prior to 1950, virtually all natural gas storage facilities were in depleted reservoirs.

Q most prominent and common form of underground storage consists of depleted gas reservoirs. Depleted reservoirs are those formations that have already been tapped of all their recoverable natural gas. This leaves an underground formation, geologically capable of holding natural gas. In addition, using an already developed reservoir for storage purposes allows the use of the extraction and distribution equipment left over from when the field was productive. Having this extraction network in place reduces the cost of converting a depleted reservoir into a storage facility. Depleted reservoirs are also attractive because their geological characteristics are already well known. Of the three types of underground storage, depleted reservoirs, on average, are the cheapest and easiest to develop, operate, and maintain.

The factors that determine whether or not a depleted reservoir will make a suitable storage facility are both geographic and geologic. Geographically, depleted reservoirs must be relatively close to consuming regions. They must also be close to transportation infrastructure, including trunk pipelines and distribution systems. While depleted reservoirs are numerous in the U.S., they are more abundantly available in producing regions. In regions without depleted reservoirs, like the upper Midwest, one of the other two storage options is required.

Geologically, depleted reservoir formations must have high permeability and porosity. The porosity of the formation determines the amount of natural gas that it may hold, while its permeability determines the rate at which natural gas flows through the formation, which in turn determines the rate of injection and withdrawal of working gas. In certain instances, the formation may be stimulated to increase permeability.

In order to maintain pressure in depleted reservoirs, about 50 percent of the natural gas in the formation must be kept as cushion gas. However, depleted reservoirs, having already been filled with natural gas and hydrocarbons, do not require the injection of what will become physically unrecoverable gas; that gas already exists in the formation.

* **Aquifers**

Aquifers are underground porous, permeable rock formations that act as natural water reservoirs. However, in certain situations, these water containing formations may be reconditioned and used as natural gas storage facilities. As they are more expensive to develop than depleted reservoirs, these types of storage facilities are usually used only in areas where there are no nearby depleted reservoirs. Traditionally, these facilities are operated with a single winter withdrawal period, although they may be used to meet peak load requirements as well.

Aquifers are the least desirable and most expensive type of natural gas storage facility for a number of reasons. First, the geological characteristics of aquifer formations are not as thoroughly known, as with depleted reservoirs. A significant amount of time and money goes into discovering the geological characteristics of an aquifer, and determining its suitability as a natural gas storage facility. Seismic testing must be performed, much like is done for the exploration of potential natural gas formations. The area of the formation, the composition and porosity of the formation itself, and the existing formation pressure must all be discovered prior to development of the formation. In addition, the capacity of the reservoir is unknown, and may only be determined once the formation is further developed.

In order to develop a natural aquifer into an effective natural gas storage facility, all of the associated infrastructure must also be developed. This includes installation of wells, extraction equipment, pipelines, dehydration facilities, and possibly compression equipment. Since aquifers are naturally full of water, in some instances powerful injection equipment must be used, to allow sufficient injection pressure to push down the resident water and replace it with natural gas. While natural gas being stored in aquifers has already undergone all of its processing, upon extraction from a water bearing aquifer formation the gas typically requires further dehydration prior to transportation, which requires specialized equipment near the wellhead. Aquifer formations do not have the same natural gas retention capabilities as depleted reservoirs. This means that some of the natural gas that is injected escapes from the formation, and must be gathered and extracted by ‘collector’ wells, specifically designed to pick up gas that may escape from the primary aquifer formation.

In addition to these considerations, aquifer formations typically require a great deal more ‘cushion gas’ than do depleted reservoirs. Since there is no naturally occurring gas in the formation to begin with, a certain amount of natural gas that is injected will ultimately prove physically unrecoverable. In aquifer formations, cushion gas requirements can be as high as 80 percent of the total gas volume. While it is possible to extract cushion gas from depleted reservoirs, doing so from aquifer formations could have negative effects, including formation damage. As such, most of the cushion gas that is injected into any one aquifer formation may remain unrecoverable, even after the storage facility is shut down. Most aquifer storage facilities were developed when the price of natural gas was low, meaning this cushion gas was not very expensive to give up. However, with higher prices, aquifer formations are increasingly expensive to develop.

All of these factors mean that developing an aquifer formation as a storage facility can be time consuming and expensive. In some instances, aquifer development can take 4 years, which is more than twice the time it takes to develop depleted reservoirs as storage facilities. In addition to the increased time and cost of aquifer storage, there are also environmental restrictions to using aquifers as natural gas storage. In the early 1980’s the [Environmental Protection Agency](http://www.epa.gov/) (EPA) set certain rules and restrictions on the use of aquifers as natural gas storage facilities. These restrictions are intended to reduce the possibility of fresh water contamination.

* **Salt Caverns**

Underground salt formations offer another option for natural gas storage. These formations are well suited to natural gas storage in that salt caverns, once formed, allow little injected natural gas to escape from the formation unless specifically extracted. The walls of a salt cavern also have the structural strength of steel, which makes it very resilient against reservoir degradation over the life of the storage facility.

Essentially, salt caverns are formed out of existing salt deposits. These underground salt deposits may exist in two possible forms: salt domes, and salt beds. Salt domes are thick formations created from natural salt deposits that, over time, leach up through overlying sedimentary layers to form large dome-type structures. They can be as large as a mile in diameter, and 30,000 feet in height. Typically, salt domes used for natural gas storage are between 6,000 and 1,500 feet beneath the surface, although in certain circumstances they can come much closer to the surface. Salt beds are shallower, thinner formations. These formations are usually no more than 1,000 feet in height. Because salt beds are wide, thin formations, once a salt cavern is introduced, they are more prone to deterioration, and may also be more expensive to develop than salt domes.

Once a suitable salt dome or salt bed deposit is discovered, and deemed suitable for natural gas storage, it is necessary to develop a ‘salt cavern’ within the formation. Essentially, this consists of using water to dissolve and extract a certain amount of salt from the deposit, leaving a large empty space in the formation. This is done by drilling a well down into the formation, and cycling large amounts of water through the completed well. This water will dissolve some of the salt in the deposit, and be cycled back up the well, leaving a large empty space that the salt used to occupy. This process is known as ‘salt cavern leaching’.

Salt cavern leaching is used to create caverns in both types of salt deposits, and can be quite expensive. However, once created, a salt cavern offers an underground natural gas storage vessel with very high deliverability. In addition, cushion gas requirements are the lowest of all three storage types, with salt caverns only requiring about 33 percent of total gas capacity to be used as cushion gas.

Salt cavern storage facilities are primarily located along the Gulf Coast, as well as in the northern states, and are best suited for peak load storage. Salt caverns are typically much smaller than depleted gas reservoirs and aquifers, in fact underground salt caverns usually take up only one one-hundredth of the acreage taken up by a depleted gas reservoir. As such, salt caverns cannot hold the volume of gas necessary to meet base load storage requirements. However, deliverability from salt caverns is typically much higher than for either aquifers or depleted reservoirs. Therefore natural gas stored in a salt cavern may be more readily (and quickly) withdrawn, and caverns may be replenished with natural gas more quickly than in either of the other types of storage facilities. Moreover, salt caverns can readily begin flowing gas on as little as one hour’s notice, which is useful in emergency situations or during unexpected short term demand surges. Salt caverns may also be replenished more quickly than other types of underground storage facilities.

**QUESTION 2**

1. **REASON WHY COMPRESSOR STATIONS NECESSARY IN OIL AND GAS INDUSTRY**

## Compressor Stations: What They Do, How They Work, and Why They Are Important



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One of the most important components of the natural gas transport system is the compressor station. These stations perform the essential task of compressing natural gas as it travels through pipelines. It is this compression which allows the gas to continue flowing through the pipe and eventually to its final destination for distribution to refineries and other end users.

### **What Are Compressor Stations?**

Compressor stations are facilities located along a natural gas pipeline which compress the gas to a specified pressure, thereby allowing it to continue traveling along the pipeline to the intended recipient.

**Frequency of Compressor Stations –** The total number of compressor station facilities required to move product varies depending on the region and conditions. Generally compressor stations are located about every 40-70 miles along the pipeline.

**Operating Pressure of the Pipeline –** There is a wide variation in the pressure within a given section of pipeline compared to other pipelines in other areas. The typical pressure may range anywhere from 200 psi (pounds per square inch) to 1,500 psi. This wide variation is also due to the type of area in which the pipeline is operating, its elevation, and the diameter of the pipeline. Because of the change in the environment, compressor stations may compress natural gas at different levels. Supply and demand can also be a factor at times in the level of compression required for the flow of the natural gas.

**Liquid Separation and Filtering at Compressor Stations –** Compressor stations typically include scrubbers, strainers or filter separators which remove liquids, dirt, particles, and other impurities from the natural gas. Though natural gas is considered “dry” as it passes through the pipeline, water and other hydrocarbons may condense out of the gas as it travels. Thus compressor stations will also remove these impurities from the gas so that they can be disposed of or sold as desired.

**Personnel at Compressor Stations –** Depending on the particular compressor station, its size, sophistication, and other factors, it may or may not be staffed with live, on-site personnel. Many modern compressor stations can be completely monitored and operated remotely.

### How Do Compressor Stations Work?

Compressor stations include several key component parts, the primary being the actual compressor unit. The main parts include:

**Compressor Unit –** The compressor unit is the piece of equipment which actually compresses the gas. Some compressor stations may have multiple compressor units depending on the needs of the pipeline. The compressor unit is a large engine which typically works in one of three ways:

**Turbines with Centrifugal Compressors –** This type of compressor is powered by a turbine to turn a centrifugal compressor and is powered by natural gas from the pipeline itself.

**Electric Motors with Centrifugal Compressors –** This type of compressor also utilizes centrifugal compressors to compress the gas; however, instead of being powered by a natural gas fueled turbine, they instead rely on high voltage electric motors.

**Reciprocating Engine with Reciprocating Compressor –** This type of compressor uses large piston engines to crank reciprocating pistons located within cylindrical cases on the side of the unit. These reciprocating pistons compress the gas. These engines are also fueled by natural gas.

**Filters and Scrubbers –** As mentioned above another component of compressor stations are filters and scrubbers which remove water, hydrocarbons, and other impurities from the natural gas.

**Gas Cooling Systems –** When the natural gas is compressed its temperature rises. This is usually offset by having the gas travel through cooling systems which return it to temperatures that will not damage the pipeline.

**Mufflers –** Mufflers are typically present to help reduce the noise level at compressor stations. These are especially important if the compressor station is located near residential or other inhabited areas.

### Why Are Compressor Stations Important?

Compressor stations enable the natural gas itself to travel through the pipelines which is crucial to the natural gas transport system. They also allow the gas to be rerouted into storage areas during periods of low demand. In addition, compressor stations are often accompanied by PIG launchers and PIG receivers which are vital for the maintenance and efficiency of the pipeline. They even include many safety features allowing the pipeline and station to function safely.

STI Group offers full turnkey construction and fabrication services for compressor stations. These services include the various components such as scrubbers, reciprocating and centrifugal compressors, compressor skid modularization, associated piping and housing. In addition we handle pumping stations, gas treatment facilities, launcher and receiver fabrication and installation, and even the assembly, dismantling, and reassembly of the stations themselves.

**QUESTION 3**

1. **KEY COMPONENT PARTS OF COMPRESSOR STATION AND THEIR FUNCTIONS**
2. a suction scrubber.
3. a gas manifold or a distribution header.
4. gas compressor “single or multiples stages” according to the required discharge pressure.
5. gas cooler fan.
6. discharge scrubber.
7. condensate gathering system.
8. corrosion inhibitor skid.
9. a dehydration unit.
10. metering station.
11. blow down flares.
12. Utilities:

### Gas Compressor Station components:

**1.  suction scrubber**:

it is the first component of the gas compressor station, its is a 3-phase separator used to separate liquids and condensate from natural gas, the existence of any liquid in the natural gas stream will cause a compressor vibration.
the liquids will be disposed to the burn bit to be burned, while the condensate will go to the condensate gathering header.

**2. gas manifold or a distribution header**.

after leaving the scrubber, natural gas will enter a manifold or a distribution header, it is used to distribute the gas to the compressor station trains ” in large compressor station and if there is a big amount of gas is compressed”, before entering the compressing train it goes through a strainer to eliminate any liquid droplets.

**3. gas compressor**
single or multiples stages according to the required pressure.  its is either driven by a gas turbine or an electric motor, single stage or multiple stages “2 or 3” according to the required discharge pressure.

centrifugal compressors are the most preferred in gas compressor station, and it is equipped with an [anti-surge system](https://www.arab-oil-naturalgas.com/surge-control-centrifugal-compressors/amp/).

compressors are equipped with seal oil system that seals the sour gas from the lubricating oil, which in turn lubricates the bearings, it is also equipped with vibration, speed and temperature sensors.

**4. cooler fan:**

after being compressed, the temperature of natural gas is greatly increased, sometimes reach to 170 – 180 ºC , this requires cooling the gas, it is done by air cooler fans, which draw air beneath, and cools the gas.

**5. discharge scrubber**:

after being compressed and cooled, vapors in natural gas will condense to liquids, these liquids can be separated and disposed in the discharge scrubber, as mentioned in suction scrubber; liquids will be disposed to the burn bit to be burned, while the condensate will go to the condensate gathering header, each compressing train is supplied with a suction and discharge scrubber.

**6. condensate gathering system**:

the condensates are gathered from all the scrubbers in the compressor station, there are many options to make use of this amount, but the most common one is to inject this condensate in the gas discharge pipeline, there is a special technology to do this, it is injected by a sparger to guarantee the homogeneous propagation in the pipeline.

**7. corrosion inhibitor skid**:

because of compression and cooling for the natural gas, water vapor will be converted to liquid water, it may react with hydrogen sulfide to form sulfuric acid, this will lead to serious corrosion problems to the pipelines and equipment, so corrosion inhibitor is injected before the air cooler to prevent corrosion. this is done by special type injectors which receive the chemical from a chemical injection skid consists of a dosing pump and a tank, injection pressure must be higher than the gas pipeline pressure, otherwise there will be no chemical injection.

**8. dehydration unit:**

each gas compressor station is equipped with a [gas dehydration unit](https://www.arab-oil-naturalgas.com/natural-gas-dehydration-p1/amp/),  it is used to remove the water vapor from natural gas.

**9. metering station:**

it is used to measure the quantity of natural gas, gas volumes are expressed in Standard Cubic Foot and the Standard Cubic Meter.



**10. blow down flares:**

it is a kind of [flare](https://www.arab-oil-naturalgas.com/flare-types-and-components/amp/) used to dispose the gas from the compressor station when shut down happens, Emergency Shut-Down Valves “ESDVs” that are equipped in each scrubber will do this.

**11. Utilities**:

such as: instrument air system and fire-fighting system.

**Purging & Pressurizing**

this process is done before starting the compressor station, purging will expel oxygen from pipelines and equipment, while pressuring means raising the pressure in the compressor train to be prepared to receive gas to get stable operation conditions, pressuring will also protect compressor blades from sudden increase in gas pressure.

purging and pressurizing can be made automatically or manually.