Chapter 2

Gas Storage

2.1 Introduction

The storage acts as an inventory, supply backup and easy access to natural gas which in turn help in maintaining the balance of the transmission/distribution system. Advantages of gas storages are given below:-

- To meet load variations
- Maintaining contractual balance, avoid take or pay
- Leveling production over periods of fluctuating demand
- Market speculation
- Insuring against any unforeseen accidents
- Meeting regulatory requirement- reliability of gas at lowest cost
- Reducing price volatility
- Offsetting changes in demand

The storage facilities used in Natural Gas Distribution business all across the globe are as follows:

- Underground Storage Facilities (UGS)
- Gas Holders
- Gas Bullets/Tanks
- LNG Storage tanks
- Line pack

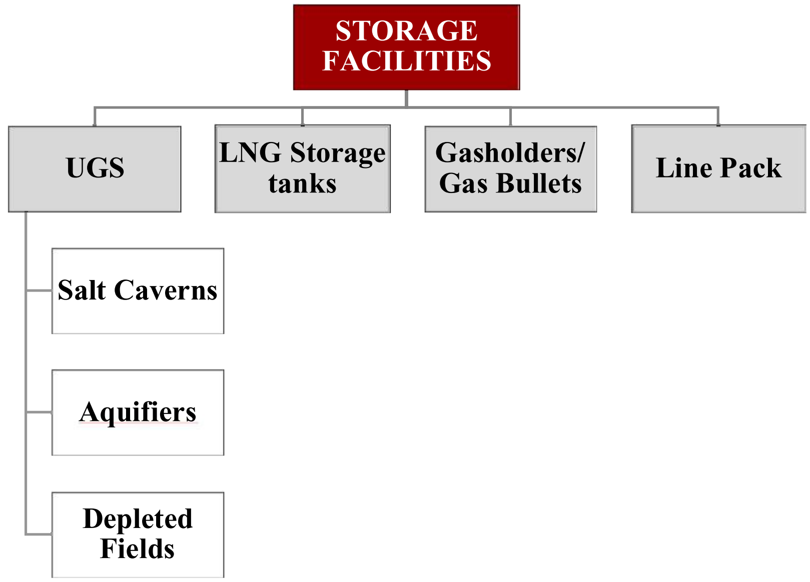

Fig 2.1 Type of Gas Storages, Source: EIA

2.2 Underground Storage Facilities

Underground storage facilities can be set up at the end, at the beginning or in between the main transmission/distribution system. Currently there are more than 606 underground gas storage facilities in the world with a working capacity of more than 300 bcm. Generally there are three principal types of underground gas storages. These are depleted reservoirs in oil/gas fields, aquifers and salt caverns

There are two main uses of underground gas storage. These are:

- Base load storage
- Peak load storage

Base load storages are used for meeting seasonal demand increase. These have the potential to store large volume of gas so as to satisfy long term seasonal demand requirements. Gas is injected into the storage during the summer months (non-heating season) and withdrawal of gas takes place during the winter months(heating seasons).The reservoirs used for this type of storage are large but their delivery rates are low. These are used for providing steady, prolonged supply for natural gas for longer period of time. The reservoirs generally used for base load storage are depleted gas reservoirs.

Peak load storage is used for meeting short term demand increase. They are designed to give high deliverability for short period of time. The injection and withdrawal rate of gas is higher than base load storage so it is more convenient for meeting short term increase in demand. The turnover rate for peak load storage can be as short as few days or weeks. The most common type of peak load storage facilities are salt caverns and aquifers.

2.2.1 Underground storage measures

In creating any underground storage facility firstly, the underground storage facility is reconditioned before injection to create a storage vessel. Then the gas is injected into the formation. As more and more gas is inserted into the formation more pressure starts building up in the formation. Hence, the underground storage becomes a type of pressurized natural gas container.

Measures used to quantify the fundamental characteristics of underground storage facilities are as followed:

- **Total gas storage capacity:** It is the maximum volume of gas that can be stored in an underground storage with respect to the storage design.
- **Base or cushion gas**: This is the volume of gas that needs to be maintained inside the storage facility so as to provide adequate pressure and deliverability rates.
- **Total gas in storage**: It is the total volume of gas stored in a storage facility at a particular period of time.
- **Unrecoverable gas:** This is the amount of gas that always remains in the storage and cannot be extracted out.
- **Working gas:** This is the volume of gas which is actually extracted out of the storage facility.
- **Working gas capacity** = Total gas storage capacity – Base gas.

2.2.2 Types of underground storages

2.2.2.1 Depleted gas/oil reservoirs

The most common type of underground gas reservoirs is depleted gas/oil reservoirs. These are the reservoirs from which gas has already been taken out thus leaving an underground formation geologically capable of holding natural gas. The two essential factors which help in determining whether the depleted reservoir will be suitable for storage or not are:

1. Geographic factors
2. Geological factors

Geographic factors means that the depleted gas or oil reservoir should be close to the market or the gas demanding/consuming regions. Further, it should also be close to the transportation network which includes pipelines and distribution system.

Geological factors includes two main components i.e. porosity and permeability. Porosity helps in determining the amount of gas the reservoir can hold, on the other hand, permeability helps in determining the rate of flow of natural gas. Permeability is the characteristic which affects the rate of injection and withdrawal of gas from the storage. So as to maintain the required pressure within the reservoir, around 50 percent of the gas in the storage is kept as cushion gas. There is no unrecoverable gas in this type of storage as the depleted fields in most of the cases contains some amount of gas, hence the gas injected in the storage is not wasted as unrecoverable gas.

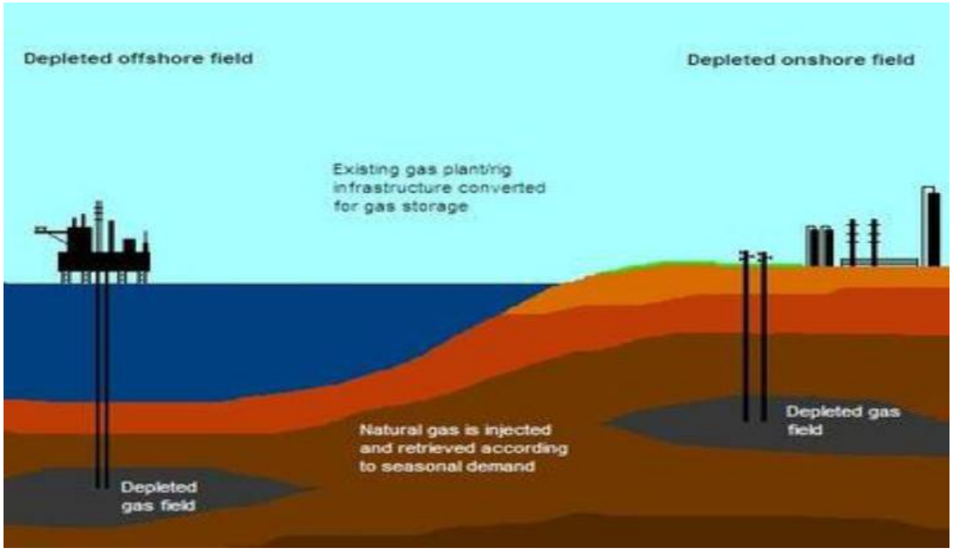

Fig 2.2 Depleted Gas Field, Source: EIA

Advantages

- Least damage to environment as most of the work can be carried out with the holes drilled earlier.
- Several access points to the reservoir and well known reservoir geological characteristics.
- Less expenditure as geological characteristics are well known so less work needs to be done in exploring the area through surveys like seismic survey etc. Further, already installed equipment can also be used which in turn help in reducing the infrastructure cost.
- Base gas requirement is lower than aquifers.
- No routine service disruption for periodic inspection.

Disadvantages

- Low porosity and permeability of reservoir can limit the injection and withdrawal rates.
- Half of the total storage capacity needs to be used as base gas for maintaining the desired pressure.
- Not all formations are suitable for building up storages.

Cost Analysis

The diagram shows the different types of cost involved in setting up a depleted gas reservoir. A depleted reservoir costs around $5million to $7million per Bcf of working gas capacity. The total investment cost can be calculated as follows:

- **Total investment cost** = Acquisition cost + Development cost + Gas gathering cost + Cost of cushion gas
- **The total storage cost** = initial investment cost + annual storage cost.

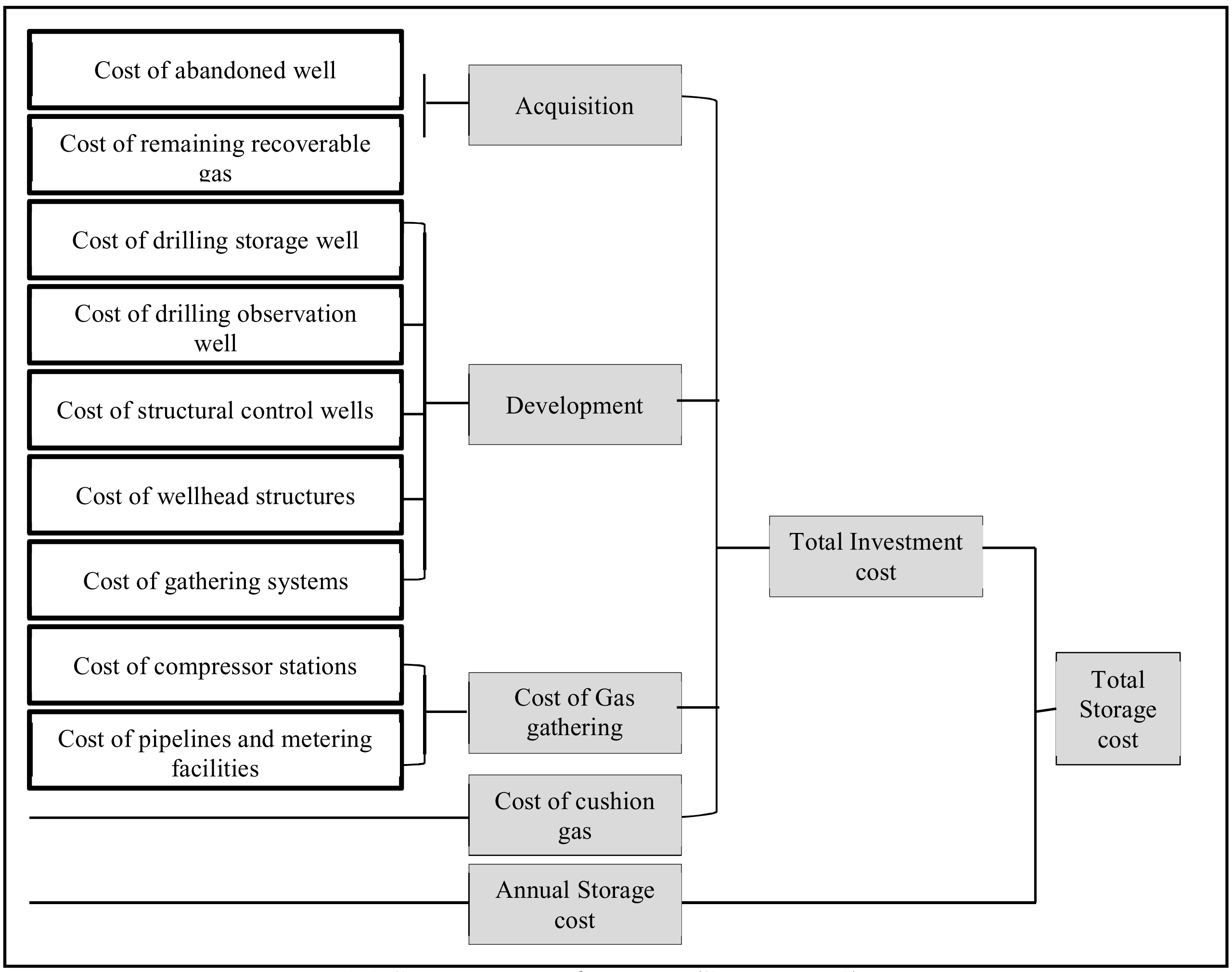

Fig 2.3 Storage cost schematic, (Source: EIA)

2.2.2.2 Aquifers

Aquifers are generally natural water reservoirs. These are underground porous, permeable rock formations which need to be reconditioned so as to be used as natural gas storage facilities. One important parameter for developing an aquifer is that water bearing sedimentary rock formation should be overlaid with an impermeable cap rock. To develop an aquifer all associated infrastructure needs to be developed which includes installation wells, extraction equipment, pipelines, dehydration facilities etc. Due to this reason the establishment cost of aquifers becomes higher. In some situations powerful injection equipment is also required to replace water inside the reservoir with gas. The gas which is stored in aquifers also needs to be processed after withdrawal since there are chances that water vapors might get mixed with gas inside the storage, hence making the gas not suitable for transportation. Further cushion gas requirement is more in aquifers since there is no naturally occurring gas present in the reservoir like in a depleted reservoirs. The cushion gas requirements generally around 80 percent of the total gas volume.

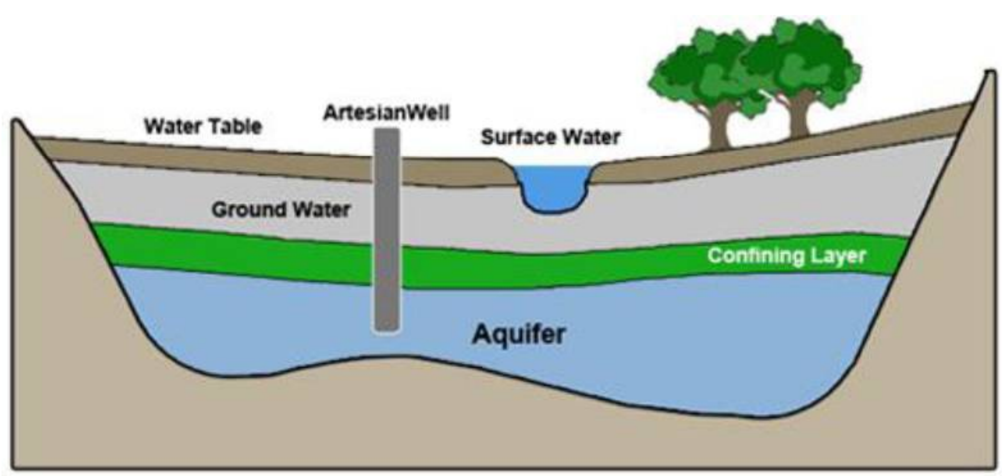

Fig 2.4 Aquifers, (Source: EIA)

Advantages:

- Gas storage can be developed in locations where hydrocarbon reserves are not readily available or not suitable for storage.

Disadvantages:

- Higher cost involved for establishment as compared to other types of storage.
- Additional equipment for Dehydration of gas after extraction.
- Water containment.
- Large base load gas requirements as compared to other types of storages.

Cost Analysis

Apart from the cost involved in depleted reservoirs storage aquifers also consists of two more type of costs:

- Explicit Recharge cost
- Implicit cost

2.2.2.3 Salt Caverns

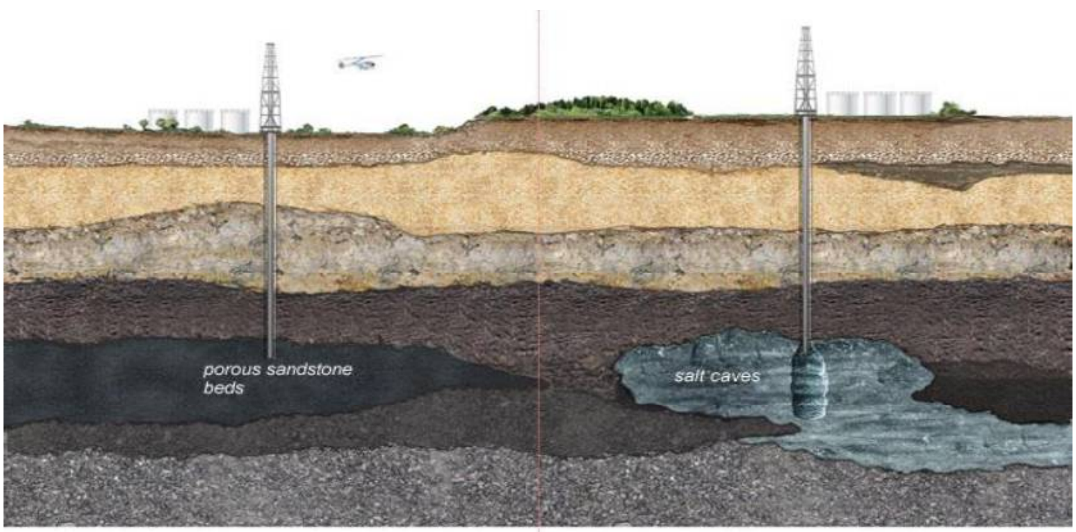

Fig 2.5 Salt Caverns, (Source: EIA)

Salt caverns are formed from existing salt deposits. The salt deposits are generally in two forms i.e. salt domes and salt beds. Salt domes are thick formations and are leached up through overlying sedimentary layers so as to form large dome type structures. On the other hand salt beds are thinner formations. Due to thinner formations they are more prone to deterioration. To develop a salt cavern a process called salt cavern leaching is used. First water needs to be introduced into the formation through a hole drilled into the formation. The water dissolves the salt from the deposit, then the water with dissolved salt is recycled back which in turn leave an empty space in the formation. Once a salt cavern is formed it offers very high deliverability. Further, the cushion gas requirement is around 33 percent of total volume of gas stored which is the least among all the underground storage available.

Advantages

- Injection and withdrawal rate is the highest among all underground gas storages available
- Injection and withdrawal can be carried out in multiple cycle

Disadvantages

- Environmental issues related to brine disposal
- Practical and geological limitations
- Corrosive environment

Cost Analysis:

The salt cavern storage is more costly to develop than the depleted gas reservoirs. The cost elements in salt cavern include:

- The Survey's cost, (cost to locate a suitable salt bed)
- Water handling cost
- Water injection cost
- Water extraction cost
- Cost of unrecoverable gas
- Cost of cushion gas
- Managing the site

2.2.3 Comparison of different types of underground storages

Table 2.1Comparison of different types of underground storages

	Depleted Reservoirs	**Aquifers**	**Salt Caverns**
Working Volume	Medium to Large	Large	Small
Withdrawal Flow Rate	Medium (Depending upon porosity and permeability)	Medium (Depending upon porosity and permeability)	High
Injection Period	150 to 250 days	150 to 250 days	20 to 40 days
Withdrawal Period	100 to 150 days	100 to 150 days	10 to 20 days
Development Duration	5 to 8 years	10 to 12 years	5 to 10 years

(Source: EIA)

Combined diagram of different types of underground gas storages is shown below:

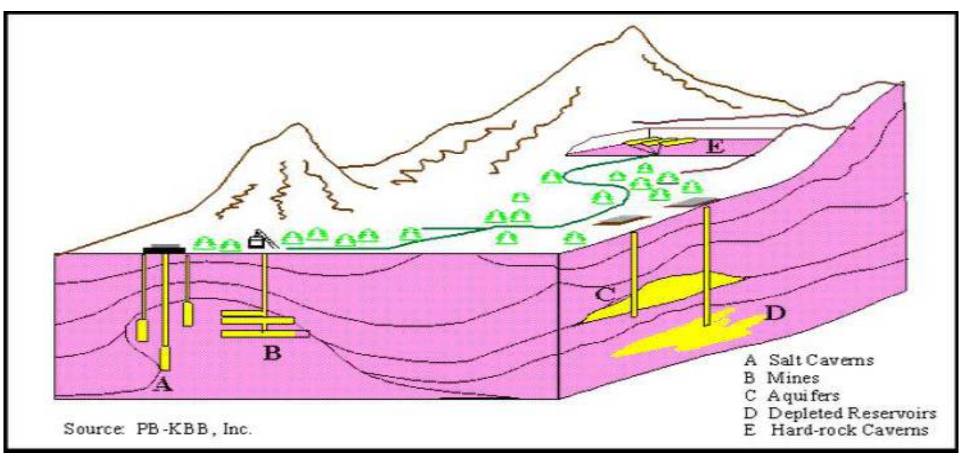

Fig 2.6 Combined diagram of different type of underground gas storage,

Source: PB-KBB,inc.

2.3 Gas Holders

Underground gas storage is more feasible than the above ground storage but it is highly dependent on the location as for the storage to develop in depleted reservoirs one basic condition is required that is the availability of reservoir. The same goes with the salt caverns and aquifers as well. In the city like Delhi, these geography dependent storage options will not be available and thus developing underground storage facilities is not going to be a cakewalk. However, Gas storage in 'Gas Holders' might prove helpful in this scenario.

A gas holder or gasometer is a large container in which natural gas is stored near atmospheric pressure at ambient temperature. The volume of the container follows the quantity of stored gas, with pressure coming from the weight of a movable cap. Typical volumes for large gasholders are about 50,000 cubic meters. Though more technological advancement, more capacity tanks can be constructed. Gas holders can be constructed that can hold large quantity of gas at high pressure, and it depends on the parameters of the tank such as -

- Design pressure and temperature of the tank
- Material used for construction of the tank
- Corrosion allowance

To store 5 mmscmd of gas in gas holders, 10 storage tanks will be required and to store 3 mmscmd (which is approximately the daily demand for PNG and CNG in Delhi) of gas 6 such storage tanks will be required.

Following are the details of some of the designs for gas holders:

2.3.1 Leffer Waterless Gas holder

It has a polygonal hollow shell stiffened at the upper end by the roof and at the lower end by the foundation. It has a sealing element i.e. the piston whose position varies according to the content and at the same time controls the pressure. The piston is not affected by the weather conditions and permits a virtually constant pressure throughout its travel. It is a dry storage of gas as no sealing water is present. To prevent the inner surface of the shell from corrosion sealing fluid is used.

Fig 2.7 Leffer Waterless Gas holder

The structural elements of the gas holders are:

- **Bottom:** with bottom sumps and gas connections
- **Shell:** with galleries, staircase, shell windows, indicators and safety went pipes
- **Roof:** with central ventilation, air inlets, saddle skylights and roof hand railing.

- **Piston:** with piston trough, seal, guide, rollers, and tangential guides.

The normal construction specifications of this type of gas holder for storing 150000 cubic meters are:

- Diameter = 51.2 meters
- Height = 87.35 meters for the side walls and 99.46 meters to the top.

The capacity can further be expanded by altering the dimensions mentioned.

The piston is designed without dead space and hence there are no chances of accumulation of any substantial explosive gas air mixture during starting up or shutting down. The piston is guided vertically by two rings of rollers located in a vertical spacing of approx. 1/10 of the holder diameter at the piston assembly. The rollers run on fixed column bars and horizontal rotation of the piston is prevented by 2 tangential guide movable in radial directions.

Steps of construction:

- First the side walls of the holder are constructed followed by assembly of the roof structure. Then the roof plates are laid and welded, as well as the vents and roof railing.
- Below this section the marginal bottom plates are laid, the piston structure with piston roof, sealing trough and guides for erection. After this the roof is lowered onto the piston with special support.
- The piston and the roof are then progressively raised by air pressure and at the same time the erection of shell, stairs and galleries is carried out.
- When the desired height is reached the roof is finally connected to the shell after completing the welding of the bottom inside area. The piston is then lowered.

2.3.2 Horton sphere pressure vessels

Horton sphere can be used to store large volume of gases (or liquids) under a wide range of pressure and temperature. Some of the advantages of using Horton sphere are -

- It offers uniform stress
- Requires less land area
- Lower associated costs for piping, foundations, accessories and painting
- The spheres are oxygen free which reduces corrosion
- Large quantities of compressed gases can be stored

Fig 2.8 M/s China gas NG Horton spheres

(Source: www.chinagasholding.com.hk)

2.3.3 Concrete Gas Holder tank

The Gasholder tank can be below the ground level, partially below or entirely above the ground level, depending on the conditions.

The materials required in constructing the concrete gas holder tanks are:

- Stone
- Brick
- Concrete
- Cast or Wrought Iron
- Steel
- Hewn from the bedrock
- A combination of the above (Composite)

Concrete gas holder can also prove to be a viable option for storing natural gas.

2.3.4 Floating Roof Holders

Floating roof holders are a type of atmospheric storage tank. It can be applied if a desired pressure is in the range of 0.5 psia to 11.1 psia, 11.1 psia means 0.76 bar.It is less than the atmospheric pressure, thus large quantity of gas is not stored in floating roof holders and it might take huge space and large number of tanks to store natural gas for one day supply. (15 mmscm in our case).

2.3.5 Cubic Doughnut Tank System (CDTS)

For offshore storage and transportation of CNG, CDTS tanks are used, CDTS tanks are formed with intersecting cylinders that forms twelve edges of the cube. This results in significant volumetric efficiency than the spherical tank. For CNG, it can sustain pressure up to 125 bar.

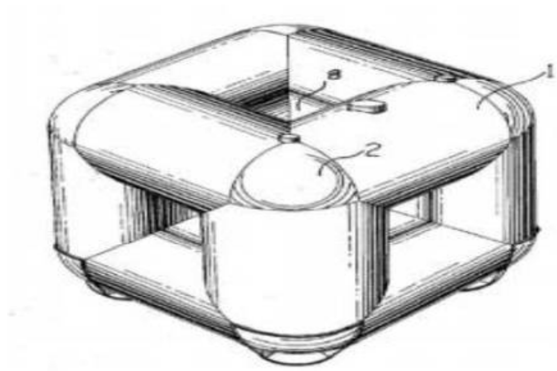

Fig 2.9 Cubic Doughnut Tank System

(Source: www.altairproductdesign.com/)

Table2.2 Cubic Doughnut Tank System dimensions

Tank size in m	Volume in m3	Quantity in SCM
5	102	32886
10	813	263088
15	2742	887920
20	6500	2104700

The operating temperature is between 0 to -30 degree centigrade.

In 20 m CDTS tank, 2.1047 MMSCM of gas can be stored. These are used for transportation of CNG for small distances, usually less than 1000 km, when converting to LNG is not feasible.

If implemented in onshore, the 20 m CDTS tank can store 2.1 MMSCM of gas. Hence 8 CDTS tanks will be required to store 15 MMSCM of gas.

The limitations are:

- It has not been implemented by any country for the onshore purposes
- In onshore, environmental concerns will be there, as there is a risk involved in storing large quantity of gas at 125 bar. If there is any calamity, then the flora, fauna, and human life will be in danger.

- As it has not been implemented by any country, it will be difficult to calculate its payback period, and other hidden risks that might be involved.
- Land acquisition.

2.4 LNG storage tanks

Creation of LNG storage facility largely depends upon the degree of containment chosen. For building a LNG tank concrete posttensioning steel is used since these are suitable at cryogenic conditions. At cryogenic temperatures, concrete compressive strength and posttensioning steel tensile strength increases instead of decreasing. Generally there are three degree of containments which are as follows:-

- Single containment
- Double containment
- Full containment

A typical diagram of storage tanks at Petronet LNG plant are shown in the following figure:

Fig 2.10 LNG Storage Tanks at PLL Plant (www.petronetlng.com)

2.4.1 World largest full containment LNG storage tank

The world's largest LNG tank is developed by Korea Gas Corporation. The tank is an above ground tank and consists of an inner tank and an outer tank. The inner tank is made up with 9 percent nickel steel and the outer tank is made up of reinforced concrete and pre stressed concrete.

Cost analysis

Taking 1 cubic meter of gas = 0.00171 cubic meter of LNG.

As per given information the LNG tank capacity is 200000 cubic meter.

Hence 200000 cubic meter of LNG = 116959064.3274854 cubic meter or 116 MMSCM.

Now as per the data available the cost of 200000 cubic meter is 115.8 m USD. This cost include engineering, procurement and construction cost.

Safety Considerations

- There are chances of leak and accidents while storing, transferring and transportation of LNG.
- There are chances of fire also if LNG is stored, transferred under pressure.
- If the boil off gas is not properly monitored there are chances of explosion.
- The LNG storage tank structural design and operational performance should meet international standards.
- Periodic inspection and maintenance is a must for corrosion and structural integrity for storage tanks. Cathodic protection can be used so as to keep a control on corrosion.
- Proper procedures by trained people need to be followed for loading and unloading of LNG in LNG tanks.

- At cryogenic temperature LNG is in liquid form. As LNG is warmed boil off gas i.e. methane is formed. If this boil off gas is released in uncontrolled form there are chances of fire if an ignition source is present.
- It is necessary to develop a spill prevention and control plan covering almost all the significant scenarios of spills.
- An emergency shutdown and detection system needs to be installed.
- Proper material for storage tank construction, piping etc. must meet international standards and the materials should be able to sustain cryogenic temperatures.
- Conservation of water should be carried out for LNG facility cooling wherever possible by alternatives like air cooling.
- Proper flare and vent system is essential.

2.5 LNG Vehicles

The LNG is stored in the tank specifically designed to accumulate LNG which is at -161 degree centigrade. It then goes to heat exchanger where it is re-gasified and then electronic control unit of the engine sends the appropriate amount of gas to the engine, where the combustion takes place and power is generated. The LNG tank is double insulated and it is generally made up of stainless steel. The pressure inside the tank depends upon the system that ranges from atmospheric pressure to 18 bar.

LNG is a good option for heavy duty and long driving range vehicles (> 300 miles per fill i.e. 480 kms), with engine capacity of 8.9 L to 12 L. LNG is a good option if the vehicle is in constant operation and needs to be refilled quickly. The effective size in gallons for LNG tanks is typically in the range of 102 – 128.

Fig 2.11 Vehicle for LNG transport

(Source: www.petronetlng.com)

Following properties of LNG makes it the fuel for future:

- LNG is not flammable, only the vapor ignites when the LCL is 5% and UCL is 15% by volume in air.
- LNG is non-toxic and non-corrosive and it does not contaminate soil or ground water.
- When spilled, LNG vaporizes.

Some of the manufacturers of LNG vehicles are:

- Iveco (Stralis LNG)
- Mercedes (Econic LNG)
- Scania (P310 LNG)
- Volva (FM methane Diesel)

In U.S also there is an increase in number of vehicles running on LNG, mostly heavy vehicles. In U.S. there are 150 LNG fueling stations out of which 42 are public. In North America, Shell will invest 640 crores in LNG and CNG refueling stations. In China there are 350 LNG fuelling stations and also has the most number of LNG vehicles in the world.

Cost

New LNG truck cost $ 100,000 (64 lacs approx.), more than a new diesel truck. An average cost of LNG truck is $ 211,000 (1.34 crore).

LNG Re- gasification facilities in India

Following LNG re-gasification facilities exist in India. Total installed capacity is 25 MMTPA, which can supply around 100MMSCMD of natural gas. The existing terminals are:

- Petronet LNG Ltd Dehej Gujrat- 10 MMPTA
- Shell Ltd Hazira Gujrat – 5 MMTPA
- RGPPL Terminal Maharastra – 5 MMTPA
- Petronet LNG, Kochi Kerala- 5 MMTPA

2.6 Line Pack

For storage purpose the line pack can be used as well. Line pack can be defined as the amount of gas available in a pipeline. The gas can be stored in large quantities and at high pressure in the pipeline.

Fig 2.12 Line Pack Gas Storage

The formula to calculate the line pack is given below:

V = 7.855 * 10 ^-4 {T (base) / P (base)} * {P (average) / Z (average) * T (average)} * D^2 *L

Where,

V = Line pack

T (base) = Base temperature

P (base) = Base pressure

P (average) = Average of inlet and outlet pressure

Z (average) = Compressibility factor

T (average) = Average temperature

D = Inner Diameter (in mm)

L= Length of a pipeline

Cost analysis:

- The line pipe is priced in U.S. at 1200 $ (77000 INR approx.) for 908 kg of a line pipe.
- For coating, there is an increment of about 15% above this cost, i.e. it will be around 88550 INR for 908 kg of pipeline.
- The total installation cost will be about 2.5 times higher than this cost.
- Compressors and other equipment like coolers are priced in U.S at $ 1500 (98000 INR) per demand horsepower.

2.7 Concluding Remark

Importance of gas storages has been discussed in this chapter. There are various types of gas storage facilities across the globe. Some gas storages are developed under ground and have very large storage capacities. These are safe in operations but have large construction cost. The other type of gas facilities are installed above ground. Capacities of such storages are limited however the cost of construction of such facilities in generally low. Location of gas storages are generally decided depending upon distance from consumption center, availability of land, connectivity and safety considerations.