OTC
Owner Team Consultation

Safe and Clean Storage of Natural Gas

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This is the third article in a series planned by OTC on natural gas (NG) and liquefied natural gas (LNG).

The originally planned series has grown to include two additional articles (nos. 3 & 4 below) and is scheduled for publication on the dates listed:

1. Overview of the LNG industry – September 2020
2. Traditional gas transport modes – November 2020
3. Safe and clean storage of natural gas – January 2021
4. Alternative modes of (gas) energy transport – March 2021
5. LNG technologies – May 2021
6. Comparison of inland gas and imported LNG – June 2021
7. Outlets for NG and LNG – August 2021
8. Gas for power generation – September 2021
9. Small scale versus large scale LNG – November 2021
10. Gas utilisation in transport – December 2021

These articles will be published over a period of 16 months (one month longer than originally planned) and will be interspersed with articles related to aspects of project management.

Introduction

Transportation of natural gas is intricately linked to its storage infrastructure. If produced NG is not immediately required, it can be stored for when it is needed. It is important that the storage method maintains the reliability of the natural gas supply. In addition, the handling and storage of gas needs to be done safely and in an environmentally acceptable manner.

In this article, we discuss the different natural gas storage methods and the safety and environmental considerations in both transport and storage of natural gas.

Underground gas storage

Background

Natural gas, like most other commodities, can be stored for an indefinite period. The exploration, production, and transportation of natural gas to markets cannot be completely synchronised with the off-take requirements, therefore requiring interim storage. These storage facilities can be located near market centres that do not have a ready supply of locally produced natural gas, or near the source of the gas. Natural gas in storage will also serve as insurance against any unforeseen accidents, maintenance requirements, equipment failures in the logistics chain, natural disasters, or other occurrences that may affect the production or delivery of natural gas.

Natural gas storage thus plays a vital role in maintaining the reliability of supply needed to meet the demands of consumers. Natural gas is often stored underground, in large storage reservoirs. There are three main types of underground storage, namely:

- Depleted gas and oil fields.
- Depleted aquifers.
- Salt formations.

These different types of underground gas storage are illustrated in Figure 1.

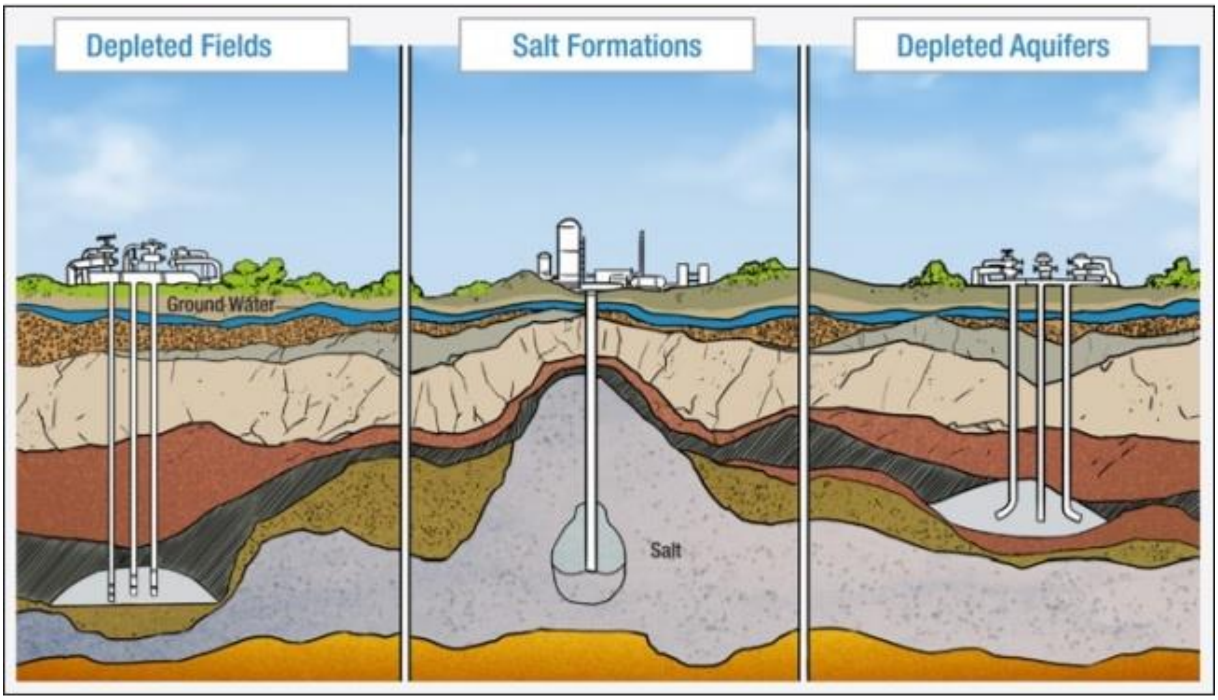

Figure 1: Underground natural gas storage (API, 2016)

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. To meet the seasonal demand increases, the deliverability of pipelines (and thus their size), would have had to increase dramatically. However, the technology required to construct such large pipelines to consuming regions was, at the time, unattainable and infeasible. The only solution to meet the seasonal demand increases was to use underground gas storage fields. According to the U.S. Energy Information Administration (EIA, 2020), as of 2019 there was 4,261 trillion cubic feet (tcf) of working underground gas storage capacity in the USA.

The following sections describe the three different types of underground natural gas storage in more detail.

Depleted gas and oil fields

Depleted gas reservoirs are conventional and unconventional gas reservoirs that have large pore space available, after the natural gas production has been completed. The gas is stored inside a sealed reservoir within impermeable cap rocks. 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 repurposed 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 underground natural gas storage was done in depleted reservoirs. Currently, about 79% of the approximately 400 active underground storage facilities in the USA are depleted natural gas or oil fields.

Depleted aquifers

Natural aquifers are underground porous, permeable rock formations that act as natural water reservoirs. Aquifers may be suitable for natural gas storage if the water-bearing sedimentary rock formation is overlaid with an impermeable cap rock. They are not part of drinking water aquifers and make up only about 10% of storage facilities.

In certain situations, these water-containing formations may be repurposed and used as natural gas storage facilities. As they are more expensive to develop than depleted oil or gas reservoirs, these types of storage facilities are usually used 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.

Salt formations

Underground salt formations offer another option for natural gas storage. Salt formation storage facilities (also known as caverns and beds) make up about 11% of all underground gas storage facilities. 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 have the structural strength of steel, which makes it very resilient against reservoir degradation over the life of the storage facility.

Salt cavern leaching is used to create caverns and can be quite expensive. However, once created, a salt cavern offers an underground natural gas storage vessel with extremely high deliverability. Salt cavern storage facilities are primarily located along the Gulf Coast, as well as in the northern states of the U.S. and in Europe.

Storage of Liquefied Natural Gas

In addition to underground storage, natural gas is also stored as liquefied natural gas (LNG). LNG is cryogenically cooled natural gas which is liquefied to reduce the volume for shipping and storage. LNG enables natural gas to be shipped and stored in liquid form, meaning it takes up much less space than gaseous natural gas. Figure 2 illustrates large capacity LNG storage tanks.

Figure 2: Cryogenic LNG storage (Reuters, 2020)

In the USA, LNG storage capacity has increased as new LNG plants have been commissioned, as indicated in Figure 3, reaching 56 million barrels of LNG capacity in 2019.

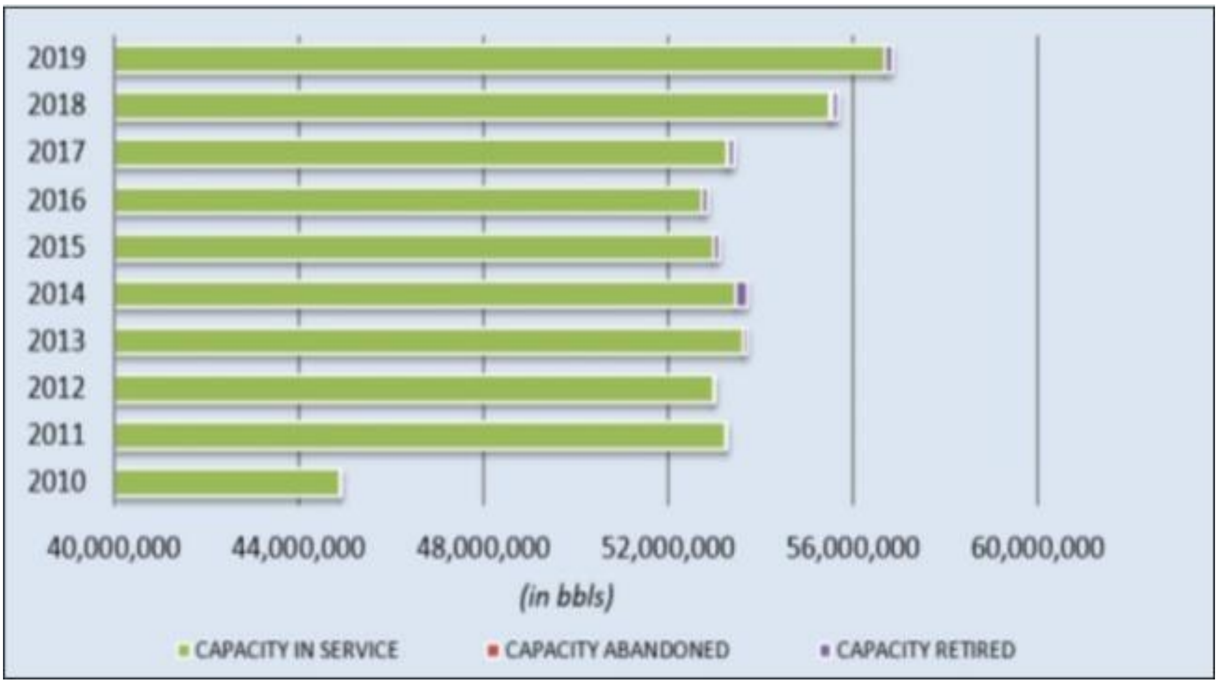

Figure 3: Total US LNG Storage capacity (PHMSA, 2020)

Globally, Japan has the world's largest LNG storage tank capacity as of February 2020, with a capacity of 18,2 million m^3. South Korea and China had the second and third largest LNG storage tank capacity, with 12,4 million and 10,17 million m^3, respectively. Spain, with the fourth largest LNG storage capacity, at 3,17 million m^3 has only a third of China's capacity. Figure 4 shows the LNG storage capacities of the countries most active in this field.

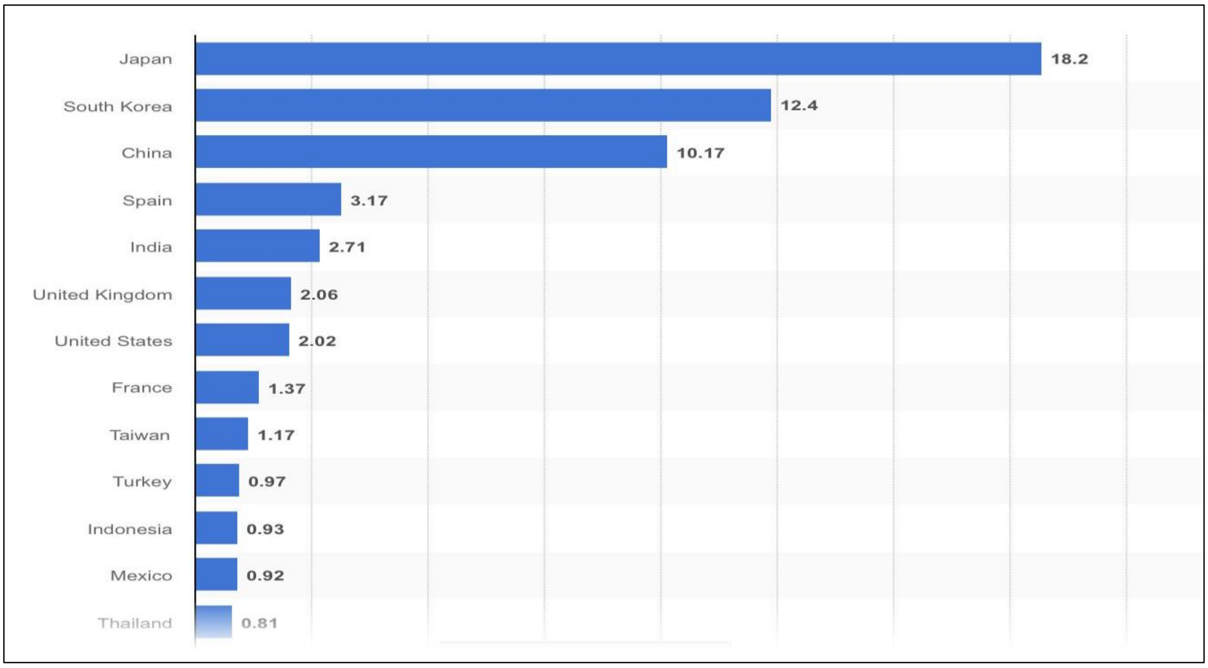

Figure 4: Global LNG storage tank capacity (million m^3) (Statista, 2021)

Current investments in improved LNG infrastructure are expected to fuel greater demand for LNG in the coming years. Demand is set to see greater year-on-year growth from 2021 onwards, with the Middle East expected to become an LNG consumer. Total annual demand is projected to reach around 450 million metric tons, of which 326 million tons is driven by markets in Asia Pacific.

Figures quoted thus far focus primarily on large LNG producers, bulk movement of LNG in ships, as well as storage and regasification facilities at ports, and gas reticulation via pipelines for power generation and large industrial use. However, there is a strong movement towards localised LNG production using distributed small and micro LNG plants. Examples include small gas fields and biogas facilities (green LNG) with local use of the LNG for either vehicles, distributed power generation or general industrial use. This implies LNG being stored in much smaller quantities in vacuum insulated bullets or spheres ranging from 50 to 1000 m^3 per bullet. These small LNG tanks can provide significant additional distributed LNG storage capacity. Figure 5 illustrates LNG storage bullets.

Figure 5: LNG bullets (Marksan Global, 2020)

Safety considerations

Natural gas is typically 90+% methane and is generally much safer to transport and handle than other fuels. The primary characteristics that make natural gas safer than other fuels are as follows:

- Methane vapour is lighter than air and dissipates quickly, unlike other fuels that pool on the ground and create a greater fire hazard.
- Methane is non-toxic, whereas most other common fuels are highly toxic.
- Methane is not explosive in open air and is less flammable than other fuels.

- Methane does not leave behind slicks, sludges, and other residues.

Natural gas burns with a visible flame and has narrow flammability limits, combusting only in air-to-fuel proportions of 5 to 15%. Below 5% the mix is too lean to burn and above 15% the mix is too rich to burn. Pools of liquefied natural gas do not ignite as readily as pools of gasoline or diesel fuel. The auto-ignition temperature of methane is 540°C, significantly higher than gasoline (260°C) or diesel (315°C). So, while open flames and sparks can ignite natural gas, many hot surfaces such as a car silencer will not. Methane vapours in open air exhibit a slow flame speed of about 8 km/h.

Natural gas is primarily transported by pipeline. Pipeline companies take active preventative measures to ensure that safety, security, health, and environmental concerns are addressed and conduct ongoing integrity management. Pipelines are also more economical and environmentally friendly than other modes of transport like rail or truck with less greenhouse gas emissions and have proven to have fewer spills.

The perception of LNG is often that it is an extremely dangerous liquid because of its energy content and low temperature (LNG is maintained at -160°C). LNG tankers are regarded as particularly dangerous and toxic, with LNG container ships being called floating bombs (Dodge, 2014). However, the reality based on proven historical data is that LNG has the best safety record of all common fuel types and is completely non-toxic. Natural gas vapours are flammable and present safety hazards and that must be managed, but these hazards are substantially less than for gasoline, diesel, and other liquid fuels.

LNG can be hazardous if spilled, as it will boil rapidly and create a vapour cloud. Initially the methane vapour will condense water vapour out of the air making the cloud visible and causing it to hang close to the ground until it warms up. If an ignition source is present the cloud can ignite, and it will burn back to the source. If the cloud does not ignite it can potentially travel some distance under the right conditions, but typically it will quickly warm up, rise, and dissipate. The most dangerous and likely hazard is if LNG is spilled inside a contained area where the vapours cannot dissipate, in this scenario there is great danger of fire if ignition sources are present. LNG spills on water do not harm aquatic life or damage waterways in any way.

Boiling liquid expanding vapour explosions (BLEVEs) are possible, but highly unlikely. BLEVEs result from rapid vaporization due to container failure, but failures are prevented by modern design standards which mandate double-walled containers and durable insulation.

The only major LNG accident in the USA occurred in the early days of the industry during WWII in Cleveland, Ohio in 1944. Due to wartime material shortages, a tank constructed with substandard materials ruptured from embrittlement and spilled ~4000 m^3 of LNG. The LNG overflowed the containment dikes and spilled into a nearby sewer drain. The vapours contained in the sewer pipes ignited and burned down a residential neighbourhood, killing 128 people and injuring over 200.

While this tragedy is often referenced by opponents of LNG, it was an important learning lesson for the industry who adopted stringent safety codes afterwards to prevent this type of accident from ever occurring again. Containment dikes are designed better and are engineered to hold the entire volume that is stored in tanks. Material choices are much more stringent. And most importantly, LNG storage tanks are not located in areas where spills will threaten local communities. Storage tanks leaking into sewers presents a worst-case scenario where the vapour is contained and not allowed to dissipate.

LNG storage tanks for maritime shipping and road transport, as well as tanks for use in rail and trucks, are built to stringent standards and are inherently more robust than crude, fuel, and chemical tanks. LNG tanks are always double walled with extensive pressure relief systems. They are robust and have survived many highway accidents without rupturing. The real-world safety record speaks for itself, whether on the roads or on the open seas, LNG is much safer to transport and use than comparable liquid fuels.

Insurance companies support the claim that LNG shipping is safer than comparable crude oil shipping. Insurance rates are typically 25% less for LNG container shipping than for crude oil shipping. Crude oil spills are well documented for the long-term damage they cause, but comparable environmental threats do not exist for LNG. Insurance rates for natural gas fuelled vehicles are also lower than for gasoline or diesel vehicles.

Environmental considerations

The safety record for natural gas transport and storage is exemplary because of the inherent properties of methane as well as the strict adherence to specific regulations and standards. There is limited impact of spillages into the environment due to the absence of liquid or heavy residues to potentially contaminate ground and water sources.

There is one issue that needs further exploration. If methane leaks into the air before being used, it absorbs infrared radiation from the sun and contributes to warming the atmosphere. For this reason, it is considered a greenhouse gas (GHG), like carbon dioxide (CO_2). A GHG is any gas that prevents infrared radiation from escaping the Earth's atmosphere into space.

Every GHG has its own global warming potential (GWP), which is a measure of how much heat the GHG can trap within the atmosphere and how much of an impact it is expected to have. Whereas CO_2 has a GWP of 1, methane is estimated to have a GWP of between 28 and 36 (EPA, 2020). Emitted methane remains in the atmosphere for about a decade on average, which is much less time than for CO_2. However, methane also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP. The methane GWP also accounts for some indirect effects, such as the fact that methane is a precursor to ozone, and ozone is itself a GHG. Methane emissions to atmosphere are typically expressed as CO_2 equivalents (CO_2e). CO_2e is the weight of CO_2 released to atmosphere having the same estimated GWP as a given weight of another GHG, in this case methane.

It is estimated that even though methane combustion results in less CO_2 being produced directly, if more than about 4% of the methane being used escapes directly into the atmosphere it offsets the advantages for the lower direct CO_2 production.

Therefore, it is imperative that the monitoring and maintenance of equipment, especially flares, are to an extremely high standard. Issues such as special high efficiency flares, minimising flanges, high integrity gasketing and flange joints, valve glands and bellow valves will need to be considered in the future. Mechanical seals on compressors could also be a source of methane leaks requiring for example double mechanical seals with barrier fluids. Regular checks are required using sniffer devices to check for leaks at flanges, valves, and seals.

It is important to realise that the regulations to limit methane leaks will become more and more stringent with methane being second to CO_2 in causing global warming. Authorities in some countries are already visiting methane processing facilities taking measurements of methane leakage rates and then charging the facility an equivalent carbon tax on these emissions.

Implementing more stringent gas leak testing and prevention is not new and has been implemented in various industries where very toxic or carcinogenic substances are being handled. These methodologies even include gas chromatographs taking air samples and analysing these every few minutes at potential leaks points or in the atmosphere in general. These analyses are typically reporting contaminants in the parts per million ranges. This is a way that these industries can very quickly pick up and repair any leaks or emissions. Although the measures as described sound prohibitive, they have led to much safer and cleaner facilities in the other industries. If implemented in a practical way, these measures rapidly become business as usual in the longer-term.

Methane is a substance that naturally occurs, is formed in nature in numerous ways, and is being released continuously from coal beds, water treatment facilities, waste disposal facilities, animal feedlots, abattoirs, and other biomass. This naturally occurring methane can be captured in various ways as biomethane. For those who are opposed to fossil fuels, natural gas (methane), compressed natural gas (CNG) and liquified natural gas (LNG) are readily produced from biomethane. Biomass is renewable and not from fossil fuels. Bio-LNG is perhaps the greenest and safest fuel we have available nowadays. Any natural biomethane removed from the environment in this way will contribute to reducing global warming.

Closing remarks

In this article we have shown that natural gas can be handled, stored, and transported very safely and that over a period of more than 70 years there have been minimal safety or environmental impacts. With the rise in the awareness of global warming and the contribution of methane, there will be more scrutiny from regulators and carbon taxes will most probably be levied on actual measured rates of leakage. It is believed that with more rigorous leak detection and improved equipment, fugitive methane emissions can be kept to a minimum.

It is important to state that by utilising biomethane from crop and food waste, animal manure and water treatment facilities as a source of energy, we can prevent the natural escape of these into the environment. This can significantly reduce the contribution of biomass to global warming.

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