CHEMICAL ENGINEERING TRANSACTIONS
VOL. 31, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti
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ISBN 978-88-95608-22-8; **ISSN** 1974-9791
DOI: 10.3303/CET1331036

Prevention of Major Accidents of the Aboveground Parts of Natural Gas Storage Technologies and Shale Gas Production Facilities

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This article is intended to describe the most significant hazards associated with the operation of the aboveground parts of shale gas production technology and to compare them with possible hazard of the aboveground parts of natural gas storage technologies in underground storage reservoirs (in natural or artificial spaces in underground geological formations). In both cases, in addition to hazards of treatment of methane (natural gas and shale gas), there are used hazardous chemical substances that may threaten employees and surrounding population. These chemical substances are used for extraction or storage of gas.
The issue of prevention of serious accidents of aboveground part of technology for the extraction of shale gas has not yet been solved, but the information about safety and environmental aspects of extracting shale gas has already been described in the last two years, in the article (Pointet, 2011). Safety of chemical constituents used as propping agents is described in the study (Waxman at al., 2011).
At present there is no specific legislation of European Union regarding the management of risks of shale gas production, but the update of the European directive 96/82/EC includes storage of natural gas in underground storage. The new Directive 2012/18/EU is generally applicable to all such forms of storage, including the storage in natural gas fields (onshore underground gas storage in natural strata, aquifers, salt cavities and disused mines, and chemical and thermal processing operations and storage related to those operations which involve dangerous substances, as well as operational tailings disposal facilities, including tailing ponds or dams containing dangerous substances shall be included within the scope of the Directive).
Due to a larger volume of chemical substances stored in the aboveground part of the technology for extracting of shale gas (average amount about 230 m^3 in stage of hydraulic fracturing) compared with volumes of chemical substances used in the aboveground part of technology of underground storage of natural gas (about 50 m^3) the technology of shale gas extraction has significantly higher risk. However, in the case that the entire process of storage of chemical substances will be well managed and sufficient measures will be taken to minimize the risk, aboveground part of the technology for extracting of shale gas does not represent a significant difference from warehouses in chemical production plants.
From the comparison of hazards of the aboveground parts of natural gas storage technologies in underground storage reservoirs with hazards associated with the operation of the aboveground parts of shale gas production technology is obvious, that future legislation of European Union in the field of major accident prevention should include also the shale gas production facilities.
Although a research about hazards of the aboveground part of the shale gas extraction technology has been made to improve the knowledge on this risk source, more research would be required, especially with practical results of detailed risk analysis.

Please cite this article as: Kotek L. and Tabas M., 2013, Prevention of major accidents of the aboveground parts of natural gas storage technologies and shale gas production facilities, Chemical Engineering Transactions, 31, 211-216 DOI: 10.3303/CET1331036

1. Natural gas storage technologies

Storage of natural gas began in Nera Buffalo, New York in 1916 (Zoar storage field). During the 20th century, demand for new natural gas storage capacity increased. Worldwide, there are currently around 630 underground natural gas storage facilities comprising three main facility types: salt caverns, depleted gas fields, and aquifers. There is also a possibility of excavation of artificial cavern in a granite massif.
Over the period of almost 100 years, a lot of accidents or incidents during process of gas storage have been reported. Five of these incidents have led to 9 fatalities, with overall around 62 injured and circa 6700 having been evacuated during these incidents (Evans, 2008).
As for the aboveground part of storage facility of natural gas, it usually consists of the following parts:

- Compressor plant,
- Gas drying unit,
- Filtration and separation station,
- Measuring and reducing facility,
- Fire heater / heating boiler,
- Pressure safety reducing and flare technology,
- Storage facility.

Following hazardous substances are typically located in the aboveground part of storage facility of natural gas:

- Natural gas,
- Glycol or Triethylene glycol (for drying),
- Methanol (for prevention of natural gas hydrate),
- Oil (for lubrication),
- Water from formation (small amount especially from aquifers).

2. Hazards of natural gas storage technologies

The hazards associated with the aboveground part of technology for underground storage of natural gas relate to the system integrity, with leakage of the natural gas or another chemical substance from the storage facility.
The following table provides a list of chemical substances and their locations within the aboveground part of technology for underground storage of natural gas.

Table 1: Chemical substances in aboveground part of technology for storage of natural gas

	Natural gas	Glycol	Methanol	Oil	Water from formation
Compressor plant	x			x	
Gas drying unit	x	x		x	x
Filtration and separation station	x	x	x		x
Measuring and reducing facility	x		x	x	x
Fire heater / heating boiler	x			x	
Pressure safety reducing and flare technology	x		x		
Storage facility		x	x		x

There is usually stored about 20 m^3 of glycol (or tryethylene glycol) and 20 m^3 of methanol in storage tanks in aboveground part of technology. Additional methanol is stored near each of extraction probes (in case of underground storage - type aquifer) in containers with a volume of about 0.5 m^3.
The amount of stored natural gas varies depending on the size and pressure inside the reservoir; maximum stored amounts of natural gas are usually at least hundreds of millions of Nm^3 of natural gas.

3. Shale gas production facilities

Gas shales are formations of organic-rich shale, a sedimentary rock formed from deposits of mud, silt, clay and organic matter. A combination of two advanced techniques is used for the extraction of shale gas - horizontal drilling and hydraulic fracturing. The latter is used to release the gas for production from impermeable shale formations; this technique consists of pumping a fluid and a propping agent down the wellbore under high pressure to create fractures in the hydrocarbon bearing rock. Geologic pressure within the shale rock forces these fracturing fluids back to the surface where they are referred to as "produced water" (Wood, 2011).

A mixture which is injected into the borehole, is composed of 98 to 99.5% water and sand and further it contains small amounts of propping agent (various chemical additives). Additional chemicals perform many different functions. Shale gas wastewater contains high concentrations of totally dissolved solids (salts). Shale gas wastewaters also contain various organic chemicals, inorganic chemicals and metals. Currently, wastewaters associated with shale gas extraction are prohibited from being directly discharged to waterways and other waters.

As for the aboveground part of shale gas production facility, it usually consists of the following parts:

- Hydraulic fracturing pumping plant,
- Gas drying unit,
- Filtration and separation station,
- Measuring and reducing facility,
- Fire heater / heating boiler,
- Pressure safety reducing and flare technology,
- Storage facility.

Following hazardous substances are typically located in the aboveground part of shale gas production facilities:

- Natural gas,
- Glycol or Triethylene glycol (for drying),
- Oil (for lubrication),
- Propping agents,
- Shale gas wastewater (a large amount).

4. Hazards of shale gas production facilities

Safety concerning the aboveground part of the technology for the extraction of shale gas raised from the possibility of dangers of propping agents (chemical substances used for hydraulic fracturing). Because of the focus of this paper, environmental aspects of extraction are not taken into account.

The following table provides a list of chemical substances and their locations within the technology for the extraction of shale gas.

Table 2: Chemical substances in aboveground part of technology for the extraction of shale gas

	Natural gas	Glycol	Oil	Propping agents	Shale gas wastewater
Hydraulic fracturing pumping plant	x			x	
Gas drying unit	x	x		x	x
Filtration and separation station	x	x	x	x	x
Measuring and reducing facility	x		x		x
Fire heater / heating boiler	x				
Pressure safety reducing and flare technology	x		x		
Storage facility		x	x	x	x

The composition of the propping agents varies depending on the characteristics of the target formation and operational objectives. The identity and toxicity profile of chemical constituents used as propping agents is not well publicized, but from the available sources, the entire multi-stage fracturing operation for a single well requires around 9.000÷29.000 m^3 of water and with chemical additives of up to 2% by volume, around 180÷580 m^3 of chemical additives (Frimmel, 2012). Therefore, a large amount of chemical constituents used as propping agents must be stored on site.

Liquid chemicals are usually stored in the containers and in the 1 m^3 high-density polyethylene steel caged containers. Water and additives are usually blended in the on-site blending unit (part of the hydraulic fracturing pumping plant).

More than 2,500 substances used as propping agents between 2005 and 2009 containing 750 chemicals and other components (Waxman at al., 2011), 58 of these chemical substances have one or more properties that may give rise to concern (toxic, flammable or toxic to aquatic organisms). The level of risk associated with the use of propping agents is related to the quantity and concentration of these substances.

The amount of shale gas varies depending on the size of the reservoir; maximum extracted amounts of shale gas are usually at least millions of Nm^3.

5. Comparison of hazards and threats

Underground storage of natural gas requires the transportation of dangerous chemical substances to the site, storage and use of these substances and generation of water from formation (Badri, 2010).

The operation of technology for extraction of shale gas requires the transportation of large amount of dangerous chemical substances to the site, storage and use of these substances and generation of shale gas wastewater.

Table 3: Chemical substances in aboveground part of technologies

	Shale gas extraction facility	Natural gas storage facility
Natural gas	10^8 Nm^3	10^6 Nm^3
Glycol	20 m^3	20 m^3
Oil	1 m^3	1 m^3
Propping agents	230 m^3	-
Shale gas wastewater	15 000 m^3	-
Methanol	-	35 m^3 (tank and containers)
Water from formation	-	20 m^3

The key operational hazards in these processes include the following:

- Spillage or overflow of dangerous chemical substance during the transportation or storage,
- Release of dangerous chemical substance or natural gas during the operation (rupture of tank or pipeline),
- Misuse of chemical substances.

These hazards and ways of exposure are well known from the process industry and the action can be taken to reduce the likelihood of occurrence of such events.

Due to the similarities between the aboveground part of natural gas storage technologies and shale gas production facilities, safety recommendations concerning the aboveground part of natural gas storage technology can be used in shale gas production facility; however it is necessary to take into account a much larger amount of chemical substances (flammable, toxic).

The most relevant factors should be taken into account when assessing the risks associated with the operation of the aboveground parts of shale gas production technology; these include:

- Properties of the substances, including waste water being stored,
- Information provided by the supplier of the chemical substance,
- Quantities being stored,
- Type of storage (tanks or containers),
- Temperature and pressure of the stored chemical substances,
- Location of the storage area in relation to object boundaries, surrounding buildings, permanent sources of ignition, or transport routes,

- Possibility of corrosion or erosion (sand),
- Training and supervision of operators,
- Frequency of hydraulic fracturing,
- Inspection and maintenance, incidents and security.

If the risks of operation of shale gas production facility are unacceptable, the following measures (from risk assessment of aboveground part of natural gas storage technology) can be used to reduce these risks:

- Reduction of the amount of dangerous substances to a minimum or substitution of hazardous chemical substances with safe ones (if it is possible),
- Avoidance of or minimising the release of a dangerous chemical substance;
- Control of level / pressure of a dangerous substance with alarm,
- Prevention of formation of explosive atmosphere including the measuring of concentration of hazardous substances (especially natural gas) and use of appropriate ventilation,
- Avoidance of ignition sources including electrostatic discharges,
- Control of the object with a fire protection sensor and cameras,
- Provision of explosion suppression on the technology / building,
- Provision of automatic safety control system with appropriate Safety Integrity Level.

6. Conclusion

The present article was focused on hazard identification of the aboveground part of the shale gas extraction technology (during operation) and the possibility of using the experience gained in the storage of natural gas in underground reservoirs.

Due to a larger volume of chemical substances stored in the aboveground part of the technology for extracting of shale gas (average amount about 230 m^3 in stage of hydraulic fracturing) compared with volumes of chemical substances used in the aboveground part of technology of underground storage of natural gas (about 50 m^3) the technology of shale gas extraction has significantly higher risk. However, in the case that the entire process of storage of chemical substances will be well managed and sufficient measures will be taken to minimize the risk, aboveground part of the technology for extracting of shale gas does not represent a significant difference from warehouses in chemical production plants.

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Acknowledgements

This article has been supported by Project No. FSI-S-11-5 entitled “Environmental and safety aspects of the development, manufacture and operation of machines” and Project No. CZ.1.05/2.1.00/01.0002 entitled “NETME Centre”.

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