Bureau of Water | Geology & Well Technology Unit
Underground Hydrocarbon Storage (UHS)

Program Overview
2019

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This document serves as an overview of the regulatory program within the Kansas Department of Health and Environment (KDHE). The Geology and Well Technology Unit and the Underground Hydrocarbon Storage (UHS) program regulates hydrocarbon storage facilities in Kansas. It is not intended to be an all-inclusive listing of requirements or conditions for underground hydrocarbon storage wells and brine ponds. This document may not be used in a court of law. Many of the requirements listed have been taken from the official Kansas Administrative Regulations publication. Permit applications, permits, policies, guidance, statutes, and rules and regulations establish the specific requirements for a UHS facility and can be obtained by contacting the UHS program manager: http://www.kdheks.gov/uhs/index.html
WHAT ARE HYDROCARBON GAS LIQUIDS (HGLs)?

According to the U.S. Department of Energy, hydrocarbons are molecules of carbon and hydrogen in various combinations. Hydrocarbon gas liquids (HGLs) are hydrocarbons that occur as gases at atmospheric pressure and as liquids under moderate to high pressures. HGLs can also be liquefied by cooling. The specific pressures and temperatures at which the gases liquefy vary by the type of HGL. HGLs are found in natural gas and crude oil and are extracted from natural gas at natural gas processing plants and when crude oil is refined into petroleum products. The UHS program typically uses the simple term “hydrocarbons” to refer to the different types of liquid petroleum gas (LPGs), liquefied hydrocarbons, and liquid hydrocarbons stored in caverns in Kansas including: ethane, propane, normal butane, isobutane, natural gasoline, and refinery olefins (Fig. 1).

**Figure 1** | Naming of Hydrocarbons (U.S. DOE, 2018)

**Sources, production, and types of hydrocarbon gas liquids**

\[ \text{NGPL} + \text{LRG} = \text{HGL} = \text{NGL} + \text{refinery olefins} \]

- **Natural gas liquids (NGL)**
  - ethane
  - propane
  - normal butane
  - isobutane
  - natural gasoline

- **Refinery olefins**
  - ethylene
  - propylene
  - butylene
  - isobutylene

- **Hydrocarbon gas liquids (HGL)**

- **Natural gas plant liquids (NGPL)**
  - ethane
  - propane
  - normal butane
  - isobutane
  - natural gasoline

- **Liquefied refinery gases (LRG)**
  - ethane
  - propane
  - normal butanes
  - isobutane
  - natural gasoline
  - refinery olefins

- **Dry gas**
  - Natural gas processing plant/fractionator

- **Wet gas**
  - Field/lease separator

- **Water**

Source: U.S. Energy Information Administration
FRACTIONATION

Several of the Kansas storage facilities are located adjacent to fractionation plants. Fractionators separate raw product into different distinct products of ethane, propane, normal butane, isobutene, and natural gasoline, by fractional distillation in column distillers (Fig. 2).

Figure 2 | Fractionation Process
In Kansas, storage caverns are developed in the Hutchinson Salt Member of the Wellington Formation. The Wellington Formation is Permian in age (about 275 million years old), and may be as much as 700 ft. thick in central Kansas (KGS, 2009). The Wellington Formation consists of two main units; the upper unit of mostly shale and silty shale, is red and gray in color and is about 300 ft. thick. Underlying the upper unit is the Hutchinson Salt Member, which ranges from 200 to 600 ft. thick and generally consists of beds of halite interbedded with gray shale and anhydrite. The Hutchinson Salt underlies an area of ~37,000 square miles in the subsurface of central and south-central Kansas (KGS, 2009). This formation was deposited in a subsiding basin and has a roughly circular shape; it is thickest near the center and thins out toward the edges (Fig. 3). The boundary of the Hutchinson Salt is a depositional boundary except on the east side, where the edge of the salt has been gradually removed by groundwater dissolution.

Figure 3 | Extent and Thickness of the Hutchinson Salt Member of the Wellington Formation (KGS, 2009)
The Permian bedrock in central Kansas generally dips to the west at about 15-20 ft/mile (Fig. 4). In areas where storage caverns are developed, the top of the Hutchinson Salt is as shallow as 400 ft. in the Conway area just west of McPherson, and about 950 ft. deep at Bushton in Ellsworth County. Although the Wellington Formation and other bedrock formations dip to the west in central Kansas, the ground surface generally slopes from west to east (Fig. 4). As a result, formations exposed at the surface are progressively older from west to east across the area. For example, at Bushton, the Wellington Formation is overlain by ~300 ft. of the Ninnescah Shale, also Permian in age. The Ninnescah Shale consists primarily of red and gray shale, silty shale, siltstone, and some gypsum. The Ninnescah Shale is overlain by the Kiowa Formation and the Dakota Formation, both Cretaceous in age. The Dakota Formation, consists of interbedded sandstone and shale and is the near-surface bedrock unit at Bushton. Further to the southeast, in the direction of the Conway area and Hutchinson, the bedrock units overlying the Wellington Formation have been removed by erosion. At the Conway area, the Wellington Formation is overlain by only an incomplete section of Ninnescah Shale, which thins progressively eastward until it is missing completely just to the east of the Conway area.

Interaction of groundwater with the evaporate beds in the Wellington Formation has dissolved the salt, creating void spaces in the bedrock. Collapse of overlying insoluble shale beds has resulted in a topographic low which has been filled with sand and gravel deposits by surface streams. The sand and gravel-filled channel forms part of an extensive fresh water aquifer system which extends from McPherson to Wichita.
HYDROCARBON STORAGE IN KANSAS

Salt has been mined by solution-mining techniques since the late 1800s and solution-mined caverns developed in the Hutchinson Salt have been utilized for hydrocarbon and natural gas storage since the 1950’s. Caverns in the Hutchinson Salt are well suited for storage of hydrocarbons and natural gas as rock salt like the Hutchinson Salt is essentially impervious to liquid and gas. Rock salt exhibits very low permeability because the hydraulic conductivity of its matrix is extremely small; values as small as $K = 10^{-22}$ to $10^{-20} \text{ m}^2$ are reported (Bérest and Brouard, 2003).

Rock salt has compressive strength comparable to concrete under the pressure of overlying rock and is considered a “self-healing” material; salt is a plastic viscoelastic material that creeps or flows under stress (IOGCC, 1998). Any fracture or void that develops in the salt when the maximum allowable operating pressure is exceeded, will seal itself when the pressure returns to normal. Salt can withstand large deformation by creeping without failing (IOGCC, 1998).

Underground storage of LPGs, natural gas, and crude oil is beneficial for many reasons. Storage facilities can store surplus products during periods of low demand and provide products during periods of high demand. Storage of hydrocarbon products underground is more economical than surface storage of products in high pressure containers and the hazards of above ground storage are eliminated. Kansas Administrative Regulations (K.A.R.), Article 45 regulates hydrocarbon storage, Article 45a regulates natural gas storage, and Article 45b regulates crude oil storage; these regulations can be found online: http://www.kdheks.gov/uhs. Hydrocarbon storage facilities are the only type currently permitted and active in Kansas.
STORAGE CAVERNS DEVELOPMENT

The solution-mining process begins by drilling a borehole from the surface down into the salt formation. As the borehole is drilled, several strings of steel casing are set into the borehole. The shallowest casing string, installed from the surface to below groundwater, is called the surface casing. It is typically a few hundred feet in length and is cemented to the formation from bottom to top. The borehole is then drilled through shale bedrock into the Hutchinson Salt, and another string of steel casing is cemented in place, at least 100 feet below the top of the salt formation (Fig. 5).

Figure 5 | Typical Storage Cavern Construction.
Kansas regulations require installation and cementation of a second string of full-length steel casing within the first string, which provides double casing protection throughout the entire well. The double casing requirement applies only to newly permitted storage wells, however, many existing storage wells had a liner installed to give the well double casing protection. After the final casing is cemented, the borehole is drilled through the length of salt that will be developed as a storage cavern; this part of the borehole is not cased (Fig. 5). After the borehole is drilled to the desired depth, another string of pipe is run into the open hole, called the tubing string, wash string, or brine string. The tubing string is not cemented in the well but is suspended from the surface wellhead. Water is injected into the tubing string, dissolving the salt, and creating the cavern over many months of circulation. The brine is returned to the surface in the annular space between the tubing and cemented casing. Sonar surveys are conducted periodically during the solution mining process to check on cavern development. Fully developed caverns average ~100,000 to 200,000 barrels in volume (Fig. 6).

**Figure 6** | Typical sonar of a storage cavern.
STORAGE FACILITY OPERATION

Storage facilities transfer product from pipelines to storage caverns. Prior to transferring product into a storage cavern, the cavern is filled with saturated brine (~10,000 mg/L total dissolved solids (TDS) or more). Saturated brine is used at all times to prevent growth of the storage cavern as freshwater will continually dissolve the salt. The product is stored at pressures high enough to keep the product in liquid form inside the caverns. A cavern is always full of either brine or both product and brine. An empty cavern open to atmospheric pressure would be unstable and subject to subsidence or collapse.

The transfer of product into and out of a storage cavern is done through the annular space between the cemented casing and the brine string (Fig. 5). The brine string is only used for the transfer of brine into and out of the storage cavern. Product is transferred into a storage cavern by pumping it down the annular space; as product is transferred into the cavern, brine is displaced through the brine string. The brine is stored in brine ponds when it is not being used (Fig. 7; Fig. 8).

Figure 7 | Storage Operations Diagram
When storage caverns are at maximum storage capacity, there may be more brine than can be stored in the available brine ponds. Excess brine is disposed of into Class I Underground Injection Control (UIC) disposal wells. These wells are completed in the Arbuckle Formation, several thousands of feet underground.

Figure 8 | HDPE Lined Brine Pond

Each storage facility has several brine storage ponds. The brine ponds are lined with impermeable plastic liners to prevent leakage of brine into the soil which could contaminate groundwater. Kansas regulations require new brine ponds to be double lined with high density polyethylene (HDPE) liners (Fig. 8). Existing, single lined brine ponds must be upgraded to double liners when replacement or significant repairs are required. Brine ponds are permitted by KDHE and permits must be obtained before brine pond construction.

Figure 9 | Vertical Degassifier Flare

For safety reasons, brine ponds are required to be equipped with a degassifier system to remove any product that may become mixed with brine. Product may become mixed with brine as a result of overfilling caverns, breaks in brine tubing, or other problems. To prevent volatile product from reaching the atmosphere at the brine ponds, the brine is passed through the degassifier, where any entrained product is removed and sent to a flare where it is burned (Fig. 9; Fig. 10). The degassed brine is then returned to the brine ponds.
Figure 10 | Degassifier and Flare: As product is pumped into a cavern, brine is displaced. The displaced brine contains small amounts of hydrocarbon product caused by the high pressure in the cavern. As brine comes to the surface, it’s directed to a degassifier where the hydrocarbons, under reduced pressure, separate from the brine. A pilot light ensures a continuing flame which burns the hydrocarbons as they are released from the brine. (Sarnia-Lambton Environmental Association, 2005)
PRESSURE CONSIDERATIONS & GEOLOGY

The overburden pressure or the lithostatic pressure is the pressure or stress imposed on a layer of rock by the overlying material. Lithostatic pressure must be considered when determining a location of a potential storage cavern; the lithostatic pressure must be sufficient to contain the products at storage pressures. In general, the lithostatic pressure increases with depth at about 1 psi/ft. Hydrocarbons are stored at pressures high enough to keep the product in a liquid state. Natural gas, however, is stored as a gas under pressure in order to store as much product in a cavern as possible.

Pressures required to keep hydrocarbon products liquid varies with the type of product stored. To store propane as a liquid, pressures greater than 122 psi at a temperature of 70°F are required. To store ethane as a liquid, pressures need to be 543 psi at a temperature of 70°F. Since the dip of bedrock in Kansas is generally towards the west, and the Hutchinson Salt becomes progressively deeper from east to west, certain products cannot be stored in caverns developed in areas where the salt beds are shallow.

MAXIMUM ALLOWABLE OPERATING PRESSURE (MAOP)

Pressure within the storage cavern must not be allowed to exceed the lithostatic pressure to avoid fracturing the surrounding rock and losing the structural integrity of the cavern. In order to prevent overpressuring of storage caverns, Kansas regulations limit the maximum pressure at which the product can be stored to a value less than the pressure that could fracture the surrounding rock. The maximum allowable operating pressure (MAOP) must not exceed 0.8 psi per foot of depth measured at the base of the cemented casing for hydrocarbon storage wells. The gradient of 0.8 psi/ft is allowed only for storage wells that have continuous pressure monitoring systems installed at the wellhead. If the storage well is not equipped for continuous pressure monitoring, then 0.75 psi/ft is the MAOP. The MAOP for natural gas storage wells is also 0.75 psi/ft.

KDHE REGULATORY HISTORY

Regulations for underground hydrocarbon storage wells were first promulgated by KDHE in 1981 after several incidents occurred, including the blowout of propane southeast of Hutchinson and the release of propane into the shallow aquifer beneath Conway, Kansas. The later incident resulted in property damage, contamination of water supplies, and posed a significant safety risk. As a result of these incidents, KDHE developed basic regulations for the hydrocarbon storage industry including gamma-density logs to monitor salt roof thickness, sonar surveys to monitor cavern capacity, annual summaries of storage pressures, and groundwater monitoring.
In January 2001, a significant incident occurred. A casing leak in a natural gas storage well located at the Yaggy storage facility subsequently released pressurized natural gas into a shallow subsurface zone. The gas migrated under pressure for a distance of approximately seven miles southeast towards the City of Hutchinson. The pressurized gas surfaced through unplugged abandoned legacy brine wells resulting in numerous injuries and two deaths, destruction of property due to fire and explosions, and contamination of soil from brine ejected onto the ground surface.

As a result of this incident, the Kansas Legislature held several public hearings that year, including testimony from citizens, experts, industry, government agencies, and the City of Hutchinson. The Legislature determined that more stringent regulations for the storage industry were necessary. As a result, the Legislature passed Kansas Statute Annotated (K.S.A.) 565-1,117. This statute instructed and authorized KDHE to develop regulations for the safe and secure storage of hydrocarbons in salt caverns for the purpose of protecting public health, safety, and the environment. KDHE worked with the industry and numerous experts to develop regulations which would accomplish the intended goals of the Legislature. KDHE held public hearings and established a public comment period for the proposed regulations to receive input, information, and testimony to ensure the development of appropriate protective regulations. Temporary regulations were implemented in April 2003, with the final regulations becoming effective on August 8, 2003. In 2008 the Kansas Legislature instructed KDHE to develop regulations for the storage crude oil.

Currently, underground hydrocarbon storage regulations are being revised to allow for technological advancements with the industry and provide a much needed update to the permitting process. However, regulation revisions can take years to complete.
INVENTORY

There are nine active hydrocarbon storage facilities in Kansas (Fig. 11). ONEOK Yaggy was previously a natural gas storage facility and is no longer active; all storage wells and caverns are in monitoring status. As of August 2019, the UHS program regulates 368 active status storage wells and caverns with a storage capacity of ~73 million barrels, 227 monitoring status storage wells and caverns, and 49 brine ponds.

Figure 11 | Storage Facilities in Kansas
PLUGGING & ABANDONMENT

Upon the end of useful life of a storage well, KDHE regulations require the well to be properly plugged to protect public health, safety, and the environment (Fig. 12).

Figure 12 | Typical Well Plugging
REFERENCES


