LIQUEFIED PETROLEUM GAS STORAGE IN SALT CAVERNS AT MONT BELVIEU, TEXAS, USA

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ABSTRACT

The Barbers Hill salt dome in Mont Belvieu, Texas, USA, is home to 134 solution-mined caverns (and 135 wells) used primarily for liquefied petroleum gas (LPG) storage and distribution and brine production. The development of the world's largest underground LPG storage complex began more than 50 years ago and continues today, with the most recent storage well completed in 2008. The existing solution-mined cavern volume today is nearly 350 million petroleum barrels. The complex is permitted for expansion to more than 600 million petroleum barrels. This paper describes the local geology, the Barbers Hill salt dome salt properties, structural geology as it impacts solution mining, ground motion monitoring, and the historic cavern development and operations including regulatory developments.

Keywords: Caverns, LPG, Domal Salt

INTRODUCTION

The Barbers Hill salt dome, located about 30 miles east of Houston, Texas, is located at Mont Belvieu, Texas. Mineral exploitation at the dome began in 1916 with the discovery of oil. In the very late 1940s and early 1950s, brine production was initiated at the dome, and development of solution-mined liquefied petroleum gas (LPG) storage caverns began soon thereafter. Since the early 1950s, additional solution-mined storage caverns have been developed to the point that today, there are 135 wells that access more than 350 million barrels of liquid hydrocarbon storage space and brine production in 134 caverns. Of the 135 wells accessing solution-mined space, 110 are active LPG storage wells, 1 is permitted for either LPG or natural gas, 6 are temporarily inactive, 14 are permanently inactive, and 4 are active brine production wells.

State permits are held by the current operators at the complex that allow for the development of more than 600 million petroleum barrels of storage space. Figure 1 illustrates the maximum radius outline of the existing storage caverns in the Barbers Hill salt dome. Products stored in the solution-mined caverns include propane, butane, propylene, ethylene, natural gasoline, ethane, refined motor fuels, and other light liquid hydrocarbons. One permit exists for natural gas storage. However, to date, no natural gas storage wells have been placed into service at Mont Belvieu.

Figure 1. Barbers Hills Salt Dome Storage Caverns at Mont Belvieu, Texas.Liquid

hydrocarbon pipelines connect the Mont Belvieu storage complex with virtually every oil- and gas-producing region in the United States and every LPG import facility on the Gulf Coast. The Mont Belvieu complex is an integral component of the liquid hydrocarbon transportation and storage infrastructure in the United States and will remain so long into the future. The current storage operators at the dome include Enterprise Products Operating L.L.C.; Equistar Chemical, LP; ExxonMobil Pipeline Company; LDH Energy; ONEOK Hydrocarbon Southwest, L.L.C.; and Targa Resources, Inc. Texas Brine operates three brine production wells.

BARBERS HILL SALT DOME

Bevier [1926] provides an excellent history of the early oil exploration drilling and production at the Barbers Hill salt dome. Mr. E. W. Barber encountered inflammable gas while drilling a water well in 1889. The well was reported to have produced inflammable gas for many years. Numerous wells were drilled both on the dome as well on the flanks of the dome. The first oil-and-gas leases were recorded in 1902. However, it was not until 1916 that the first significant oil-producing well (40 barrels per day) was drilled by the Gulf Production Company. Since that time, hundreds of wells have been drilled on the flanks of the dome, and oil production continues to this day.

The Barbers Hill salt dome is a typical Gulf Coast salt dome with a slightly elliptical horizontal cross section with a major axis of about 12,000 feet and a minor axis of about 9,250 feet. The top of the dome is located at a depth of about 1,400 feet and has very little relief, typical of most Gulf Coast domes. Overhangs exist on the north and southeastern regions of the dome. Several boundary shear zones (separating apparent salt spines in the dome) are apparent from the characteristic solution mining of the caverns in the dome. Figure 2 illustrates a group of caverns intersected by a boundary shear zone. Boundary shear zones intersected by solution-mined caverns exhibit some preferred dissolution over that of the intact domal salt. Such intersections of caverns and boundary shear zones are reasonably common in the Gulf Coast salt domes and do not necessarily result in deterrents to successful hydrocarbon storage.

The caprock overlying the salt plug is massive and, near the center of the dome, is nearly 1,000 feet thick. As with many Gulf Coast salt domes, portions of the caprock are vugular and can present massive drilling problems. Hydrologic test wells in the caprock have demonstrated well-developed hydraulic interconnectivity in the caprock porosity. Arguments are presented in the literature (on both sides) as to whether or not the caprock aquifer is connected to the shallower overlying freshwater aquifers.

Salt and Caprock Characteristics

Salt core has been recovered from eight different wells on the dome, and caprock core has been recovered from three of these wells. Much of this core has been tested in the laboratory for deformation and strength properties as well as mineralogic characteristics. Over the range of stress and temperature expected in the vicinity of the Barbers Hill storage caverns, the deformation rate of the salt is dominated by elastic deformation associated with time-varying loads and by viscoplastic (creep) deformation. The elastic deformation, creep deformation, and strength properties of the Barbers Hill salt dome (as reported by Pfeifle et al. [1995]) are discussed briefly below.

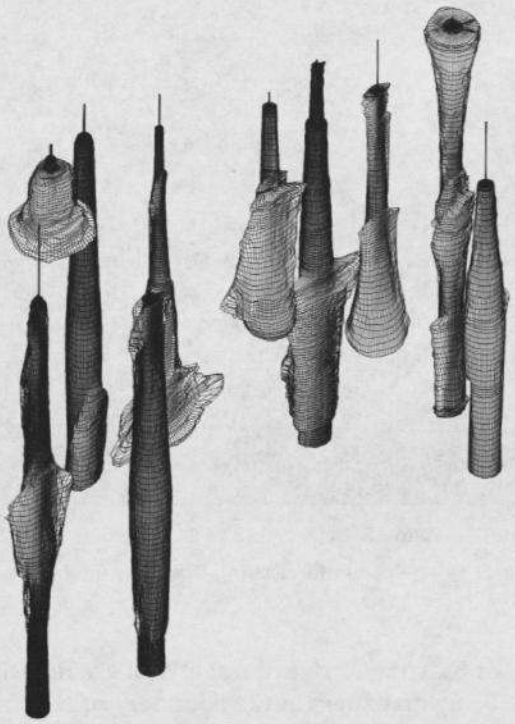

Figure 2. Solution-Mined Caverns Intersected by Boundary Shear Zone or Plane of Preferred Dissolution.

The average values of Young's modulus and Poisson's ratio obtained from salt core tests are 3.14(10^6) psi and 0.31, respectively. The time-dependent creep deformation characteristics of the Barbers Hill salt is reasonably consistent from well to well and is similar to that measured on most other Gulf Coast salt domes. The average tensile and compressive strength of the Barbers Hill salt are 240 psi and 3,640 psi, respectively. These strength values are somewhat higher than the average strengths exhibited by salt from many other Gulf Coast salt domes.

In Situ Temperature

The in situ temperature in the Barbers Hill salt dome is accurately characterized in a January 1987 temperature log performed in Targa (then Warren) Well No. 27. The temperature at the top of the salt is approximately 115°F and increases at a rate of 0.01°F/foot of depth throughout the salt.

CAVERN DEVELOPMENT AT MONT BELVIEU

With the exception of one cavern, all solution-mined storage or brine production caverns in the Barbers Hill salt dome are single-well caverns. The diameter of the final cemented casing in the wells varies from well to well. The earlier wells had final cemented casing diameters of about 9⅝ inches; whereas, the more recently completed wells often have a final cemented casing diameter of 24 inches. Figure 3 illustrates the distribution of final cemented casing diameters at Mont Belvieu. The 24-inch production casings have offered challenges to casing inspection technologies. Recently, a casing inspection tool has been developed for inspecting the inside and outside diameter of these large-diameter production casings [van Agthoven, 2005].

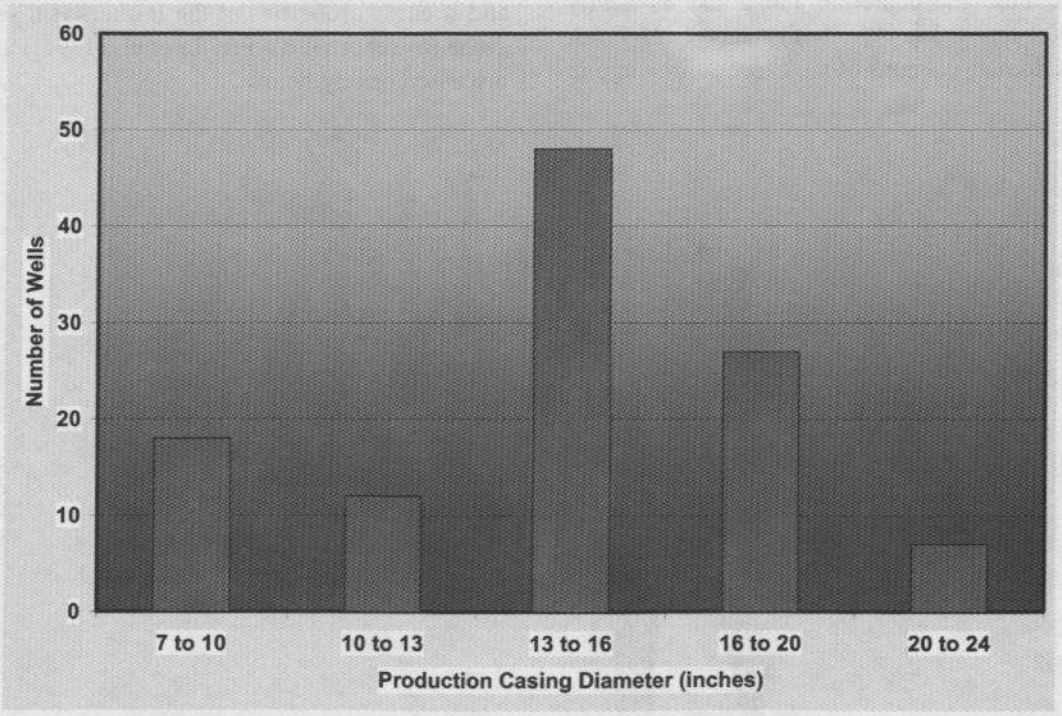

Figure 3. Distribution of Existing Active Storage Well Casing Diameters at Mont Belvieu, Texas (Casing diameters at the boundary of the histogram intervals are included in the histogram interval over the smallest diameters; e.g., 16-inch-diameter casings are included in the interval from 13 to 16 inches).

As with the production casing diameters, the individual cavern volumes in the Barbers Hill salt dome also vary considerably from less than 1 million petroleum barrels (MMbbls) to

more than 12 MMbbls. Figure 4 illustrates the distribution of cavern volumes at Mont Belvieu. Generally speaking, the larger cavern volumes are associated with brine production caverns that were converted to hydrocarbon storage after the brine production ceased from the cavern. The majority of the caverns are 1 to 2.5 MMbbls in size. Very few (less than about 10 percent) are larger than 5 MMbbls.

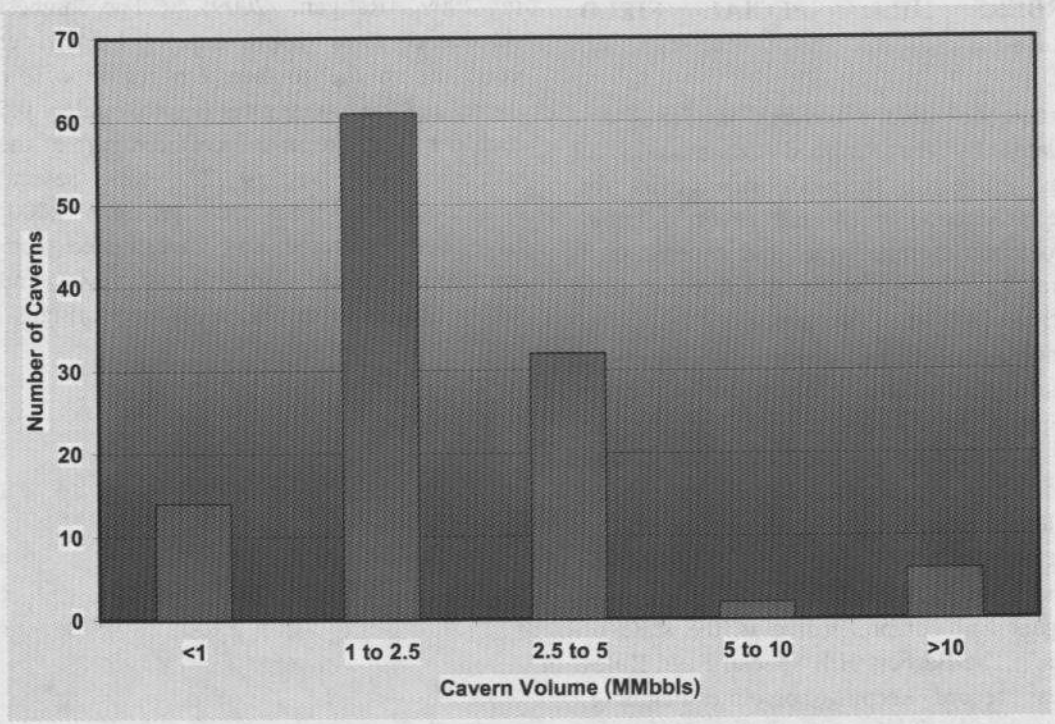

Figure 4. Distribution of Active Storage Well Cavern Volumes at Mont Belvieu, Texas.

BRINE MANAGEMENT

Large volumes of brine have been produced at Mont Belvieu from the solution mining of the storage and brine production caverns and to satisfy the continual need for liquid hydrocarbon displacement from the storage caverns. Development of 350 MMbbls of solution-mined storage space has resulted in the production of more than 2 billion barrels of brine. Some of this brine (less than about 20 million barrels) remains in surface storage ponds. Some of the brine volume was (and continues to be) supplied to the chemical industry, and the remaining volume has been injected in brine disposal wells. A very limited amount of brine was reportedly disposed in a surface feature called Cedar Bayou.

Brine disposal wells at the Barbers Hill salt dome were completed in the caprock of the dome. More than a dozen such wells were completed at various depths in the caprock. Caprock disposal wells completed in the (geologically) shallow portion of the caprock resulted in voids created in the caprock at the base of the injection casing. One of the void spaces was of sufficient size that the owner elected to fill the void with sand and gravel to mitigate the possibility of a sinkhole. Another shallow caprock disposal is believed to have contributed to the development of a sinkhole in 1994 [Cartwright et al., 2000]. Caprock well brine disposal at Mont Belvieu was discontinued in 1994 as directed by the Railroad Commission of Texas, and all subsequent brine disposal has been into five off-dome disposal wells completed in the Frio and shallower Miocene sands. Over the last

20 years, additional surface brine storage (ponds) have been constructed, and this has contributed significantly to the decreasing need for brine disposal.

BARBERS HILL SPECIAL FIELD RULES

Hydrocarbon storage caverns in Texas are regulated by the Railroad Commission of Texas. Specific statewide rules exist for brine production wells and caverns, liquid hydrocarbon storage wells and caverns, and natural gas storage wells and caverns. In addition to the statewide rules, the solution-mined storage caverns and the wells accessing the caverns in Texas can be subject to "Special Field Rules." In this context, the term "Field" refers to the producing oil and gas field in which the caverns have been developed. The storage wells and caverns at Mont Belvieu are subject to the Barbers Hill Special Field Rules; arguably, the most stringent and comprehensive in the state of Texas. The Barbers Hill Special Field Rules address record keeping, pipeline mapping, wellhead physical protection, subsidence monitoring, well casing inspections, and requirements for special investigations. The cavern and well casing inspection requirements include the following requirements:

1. Casing inspection logging and evaluation every 5 years.
2. Cavern sonar surveys every 5 years.
3. Gyroscopic logs every 5 years.

The results of the subsidence monitoring that has been performed at Mont Belvieu are briefly discussed below.

Ground surface subsidence monitoring was initiated at Mont Belvieu in 1987 and was later required by Special Field Rule in 1991 and 2001. The Mont Belvieu subsidence monitoring network includes more than 300 monitoring stations (benchmarks and wellheads) and a sophisticated Global Positioning System elevation reference.

Over the last more than 20 years, the annual subsidence monitoring program has enabled an accurate characterization of the vertical subsidence rate experienced at Mont Belvieu. Figure 5 illustrates the vertical subsidence rate reported to the Railroad Commission of Texas in 2009 [Ratigan, 2009]. The highest subsidence rates (approximately 1 inch per year) are in the southeastern region of the dome, and the lowest rates (approximately 0.5 inch per year) are in the northern part of the dome. Over the last 20 years, several anomalous subsidence areas [Ratigan, 2000] have been detected and investigated with microgravity and seismic surveys and additional ground displacement monitoring.

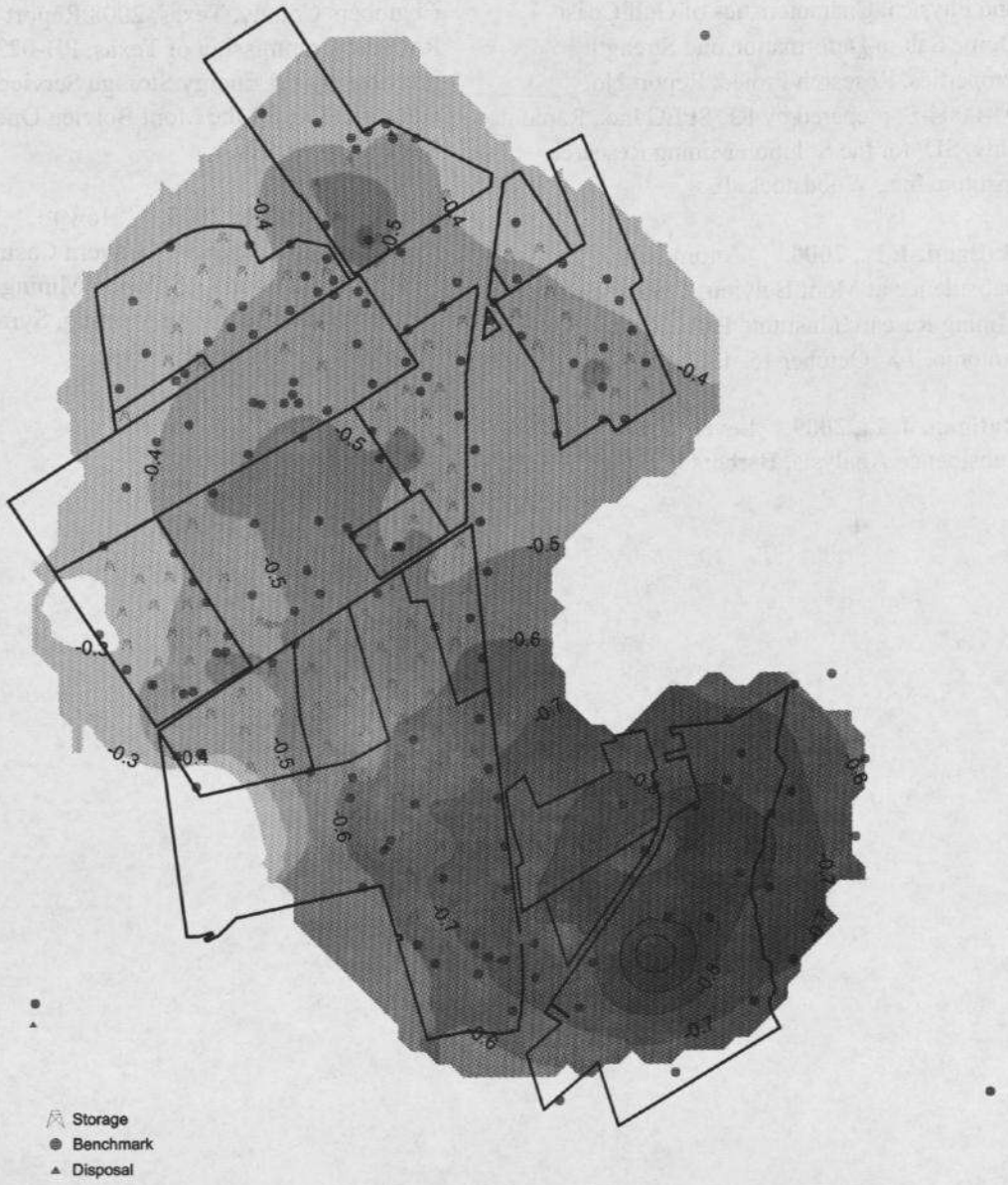

Figure 5. Subsidence Rates (Inches/Year) at Mont Belvieu for Calendar Years 1992 Through 2008 [Ratigan, 2009].

ACKNOWLEDGEMENT

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