Critical Components of Salt Cavern-Based Liquefied Natural Gas Receiving Terminal Undergo Field Tests

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Field tests of the mooring system, high-pressure pumps as well as a high-capacity, high-efficiency, water-warmed heat exchanger have been successfully completed.

Liquefied natural gas (LNG) receiving terminals combined with salt cavern gas storage is moving closer to commercial reality. The unique and previously unknown combination of gas storage in manmade salt caverns with LNG importation presents the possibility for LNG receiving terminals with large storage capacity and gas send out flow rates. In particular, the use of salt formations for cavern development and LNG receiving in the Gulf of Mexico has the potential for offshore facilities combining easy ship access, large storage and large send out to the gas pipeline grid. Technical validations through field tests of the critical components of a salt cavern-based LNG receiving terminal are part of a U.S. Department of Energy (DOE) cooperative research project commissioned by the National Energy Technology Laboratory (NETL) with cost sharing participants from an array of energy industry companies.

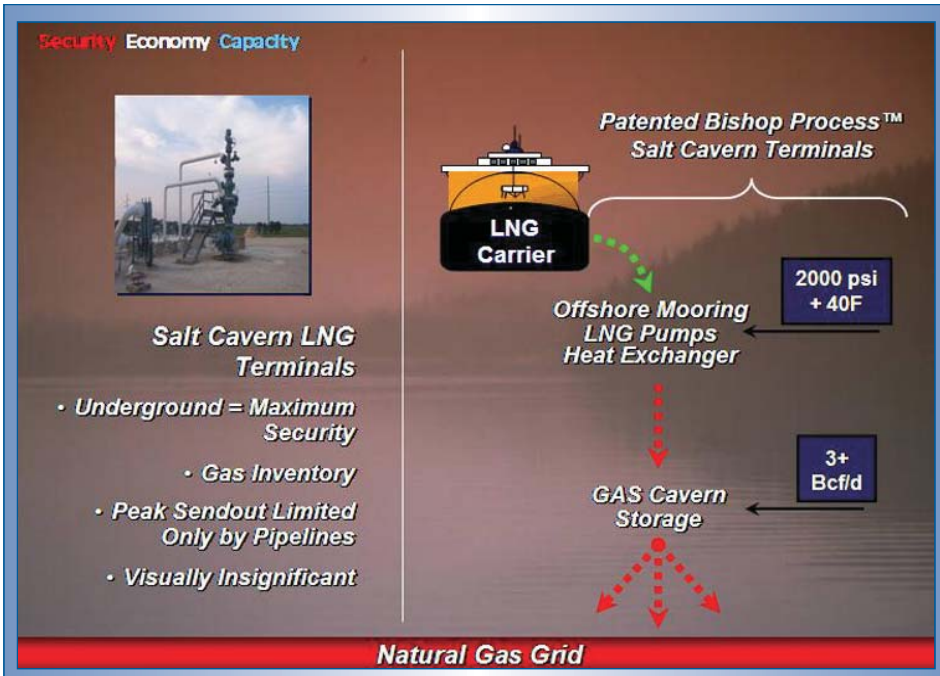

Figure 1. The Bishop Process salt cavern-based liquefied natural gas terminal.

LNG imports supply less than 2% of the current U.S. natural gas supply. Many predict that number will significantly increase during the next 20 years. This volume growth would require a number of new import terminals to augment the four existing LNG import terminals in the United States. There are more than 40 LNG import terminals in the world, all of which are designed around cryogenic liquid storage tanks. The LNG tanks are the most expensive and visible component of the facility. Significant scale increases have been introduced into the world's LNG business in liquefaction and shipping, but tank-based terminals are difficult to scale up because of the tank cost and space required to site them. Salt cavern-based terminals can provide the corresponding scale increases needed in LNG receiving terminals with storage capacity and send-out volumes exceeding the tank-based terminal model. Offshore mooring and unloading of the LNG ships into offshore salt caverns could reduce port congestion and avoid some of the not-in-my-backyard problems faced by facility siting in some coastal communities.

Salt caverns provide an answer

Manmade salt caverns are an integral part of the U.S. energy infrastructure. The entire Strategic Petroleum Reserve, totaling more than 650 million bbl of crude oil, is stored in salt caverns on the Gulf Coast. In addition, there are more than 600 million bbl of products owned by private industries including hydrogen, natural gas, natural gas liquids, olefins, refined products and crude oil stored in salt caverns in the United States and Canada. This high-deliverability storage is a critical logistical link between the natural gas, gas processing, petrochemical and refining industries. Salt cavern storage is a well-known technology and is well developed, acceptable to the community and low cost. Salt caverns, thousands of feet below the Earth's surface, have been used to store hydrocarbons for more than 60 years.

Salt caverns provide about 5% of the natural gas storage capacity in the United States but about 15% of the deliverability of natural gas into the gas grid. This ratio illustrates the high deliverability nature of natural gas

Figure 2. Bluewater Offshore's "Big Sweep" undergoing wave tank model testing.

Figure 3. Bluewater Offshore's "Big Sweep" illustration.

storage in salt caverns, and demonstrates their fundamental value in LNG receiving and natural gas distribution.

Salt formations will not tolerate direct LNG injection because of the low temperatures. The development of the patented Bishop Process™ LNG terminal, however, began with the basic premise that LNG technologies and salt cavern storage technologies can be combined in some form.

New "class" of LNG terminal

Phase 1 of the DOE research consisted of site research for locations that have salt formations, pipelines and water depths suitable for the approach of LNG ships. It also incorporated mathematical analyses about power requirements, necessary heat exchanges to warm the LNG, and preliminary cavern design and operating characteristics. Industry partners included BP, Bluewater Offshore and HNG Storage. The results, presented in April 2003, confirmed not only the feasibility of the process, but also illustrated that commercial applications would not be undertaken without further "proof" to a conservative energy industry and financial community. The incentive to develop this terminal technology is substantial, as salt cavern-based LNG receiving terminals, in the initial analysis, have material advantages to tank design terminals in lower capital and operating costs, greater volume of storage and rapid response to changes in send-out rate demand. **Vermilion Block 179** in the Gulf of Mexico was selected for the research because it is in shallow water (100ft) about 47 miles south of the Louisiana coast, has an ideal salt dome formation (top of the salt is less than 1000ft below water surface) and is adjacent to several major gas gathering pipelines.

Major portions of the equipment and systems being incorporated into this design have been well-proven in other applications. Other critical pieces of equipment have not been well proven and require field testing for industry acceptance.

DOE cooperative research expansion

In September 2003, the DOE, through the NETL, expanded the cooperative research agreement to include field tests of the critical components (high-pressure LNG pumps, Bishop Process™ Heat Exchanger, and off-

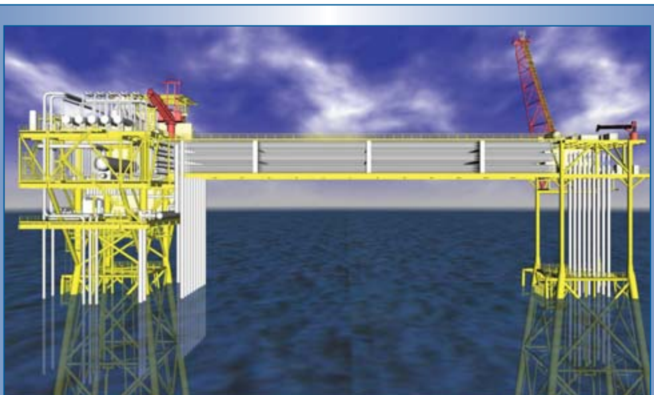

Figure 4. Paragon Engineering's liquefied natural gas process platform design.

Figure 5. SBM-Imodco Offshore's liquefied natural gas mooring system.

Figure 6. FMC Sofec Offshore's liquefied natural gas mooring system.

shore mooring and product transfer) and conceptual designs of their application in the Bishop Process™ salt cavern-based LNG receiving terminal (Figure 1). The goal of the DOE's cooperative research program is to move technology from concept to commercialization as rapidly as possible using the industry's joint financial participation with the DOE to fund the process and provide technical and operating expertise. These field tests are part of a DOE $2.7 million cooperative research project led by Conversion Gas Imports. The DOE is funding $1.8 million and the industry cost sharing of $0.9 million is provided by an expanded group of industry participants including, American Bureau of Shipping, A.D. Little, AGL Resources, Bluewater Offshore, BP, Carter Cryogenics, Credit Suisse First Boston, Det Norske Veritas, Dominion, Ebara, Ecology & Environment Inc., Encana, ExxonMobil, Fluor, FMC Sofec, Golar, HNG Storage, Hoegh LNG, International LNG Association, Marathon, Marsh & McLennan, Nikkiso Cryogenics, Northstar Industries, Paragon Engineering, PB Energy Storage Services, PEMEX, Remora Technology, RRS Engineering, SBM-Imodco and the U.S. Coast Guard.

The Bishop Process LNG import terminal works in the following manner: the LNG ship is offloaded through its internal pumps at its normal offload rates. The LNG cargo discharge from the ship is the inlet to a series of high-pressure LNG pumps, which receive the LNG at relatively low pressures from the ship and achieve cavern injection pressures at their discharge. The heat exchanger receives the LNG at high rates, high pressures and low temperatures and then warms it at discharge to cavern and pipeline compatible temperatures.

The gas can be directly injected into salt caverns without further compression or into the pipeline grid or a combination of the two. This one-step process converts the cold "exotic" LNG into warm "ordinary" natural gas. The ship can be turned around in the same amount of time as at a conventional cryogenic tank-based receiving terminal, but when it leaves, there is little LNG stored at the site – only enough to keep the cryogenic equipment cold between ship arrivals.

Designing the salt cavern-based LNG terminal

There are three distinct components to an offshore LNG receiving terminal: the LNG ship mooring and transfer systems; the process design and equipment; and the gas storage salt caverns. The DOE research has made considerable progress toward the goal of a workable and safe basis of design. Field tests of the mooring system; the high-pressure pumps; and a high-capacity, high-efficiency, water-warmed heat exchanger have been successfully completed. The field test results are being analyzed and will be incorporated into the mathematical models of these systems. The final product of the research project is the integration of the test results into designs, operability and maintainability studies, environmental studies, and cost analyses on the construction and operation of salt cavern-based LNG receiving terminals.

LNG ship mooring and transfer system

Offshore mooring and transfer of crude oil has been a well-established practice for more than 40 years with an excellent safety and environmental record. Building on this body of experience, Bluewater Offshore model tested in a wave tank facility a mooring system for offshore transfer of LNG in April (Figure 2). Bluewater's system transfers the LNG to a nearby platform containing the process equipment, power, pumps, heat exchanger, measurement, salt cavern wellheads and more (Figure 3). Paragon Engineering Systems provides the platform and process design and engineering (Figure 4). Other LNG ship mooring and transfer systems by SBM, FMC and Remora have been submitted as part of the research

Figure 7. Remora Technology's "Hi Load" liquefied natural gas mooring system.

Figure 8. Ebara's liquefied natural gas pump in assembly.

Figure 9. Nikkiso Cryo's liquefied natural gas pump undergoing tests.

Figure 10. The Bishop Process heat exchanger being field tested.


Figure 11. Research participants observing a test in progress.

(Figures 5, 6 and 7, respectively). High system availability and suitability for non-dedicated vessels characterize all designs.

High system availability—The investments made in the LNG production and transport chain are large, as are the costs associated with downtime of LNG production and/or demurrage of the carriers. High system availability is achieved by using weathervaning mooring systems, a robust flow path and a minimum number of cryogenic mechanical components.

Suitability for non-dedicated vessels—The current LNG fleet of more than 150 vessels and the more than 50 on order all have midship manifolds. Thus, transfer of LNG in all systems takes place at the midship manifold and only a minimum of adaptation of the LNG carrier is required.

High-pressure LNG pumps

LNG pumps in common use are of multistage centrifugal design. Those used in terminals receive LNG from the storage tanks at atmospheric pressures and discharge at pipeline pressures as high as 1,440psi. To obtain direct cavern injection, pumps must be capable of achieving discharge pressures in excess of 2,000psi. Ebara and Nikkiso Cryogenics, two of the largest LNG pump manufacturers, developed new designs with greater capability. Both manufacturers' designs have been field tested – Figures 8 and 9 – (Ebara – September 2003; Nikkiso Cryogenics – February 2004) with the results included in the research program.

High capacity LNG heat exchanger

There are several designs for LNG vaporizers or heat exchangers, but all those in use operate at maximum pressures below those necessary for direct injection of the warmed gas into salt cavern storage facilities. For the study, Northstar Industries designed and constructed a new design incorporating a cryogenic pipe within a water warmant pipe. This serial No. 1 Bishop Process Heat Exchanger was field tested April 12-16, at full scale, at the AGL Resources LNG plant near Canton, Ga. (Figure 10). Tests were performed at varying LNG rates, varying warmant water ratios and water temperatures. Flow rates as high as 170 MMcf/d were recorded, which in multiples can warm the LNG ship discharge at 10,000 m^3/hour or greater.

Initial observations were that the test results were similar to the mathematical predictions but with corrected models. A number of important design changes will improve operations in commercial applications. The patented Bishop Proccess LNG receiving terminal could utilized other vaporizer designs if modified to operate at higher pressures.

Preliminary research conclusions

The field work on the field tests of the critical components is complete. Commercialization of this technology requires a rigorous analysis of the test results, vetting of the conclusions by the industry participants and incorporation of what was learned into the process simulations. Then, the rating agencies and specialists in operability, maintainability, environmental impacts and safety can review the equipment and process designs, equipment lists and operating parameters (Figure 11). The total project completion is expected by year end.

No "show stoppers" have appeared in the field tests. Subsequent analysis will probe for workable solutions to move this technology forward to commercial applications. There have been several observations by the industry participants that the elimination of large volume cryogenic storage tanks makes the process design and operation simpler than those normally seen in the LNG industry. A startling contrast in a salt cavern-based terminal is that with permits in hand, it is estimated construction could be accomplished in about 2 years. This is at least 1 year less than tank-based designs and 2 years less than offshore tank-based gravity structure terminals.

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