CRYOGENIC INDUSTRIES

FROSTBYTE

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Establishing a Virtual Pipeline for Developing Natural Gas Markets

Introduction

Natural gas can be transported through a multitude of methods, but the primary carriers are dedicated trucks, barges and pipelines. The natural gas is stored in trucks and barges as a cryogenic liquid, LNG, to densify the fuel. In the liquid state, the transportation is safer and the capacity is increased. As the cryogen sits in the tank, heat leaks through the container walls. This heating boils the liquid which increases the pressure in the tank. At the tank's maximum allowable working pressure (MAWP), the pressure must be reduced either by cooling, or releasing a portion of the stored natural gas –both of these options severely affect operating costs. Transporting natural gas via pipelines has low operating costs, but there must be a physical pipeline, which requres a large capital investment. A "virtual pipeline" as depicted in Figure 1 is proposed where there is no onboard cooling, no nominal venting, and no physical pipeline.

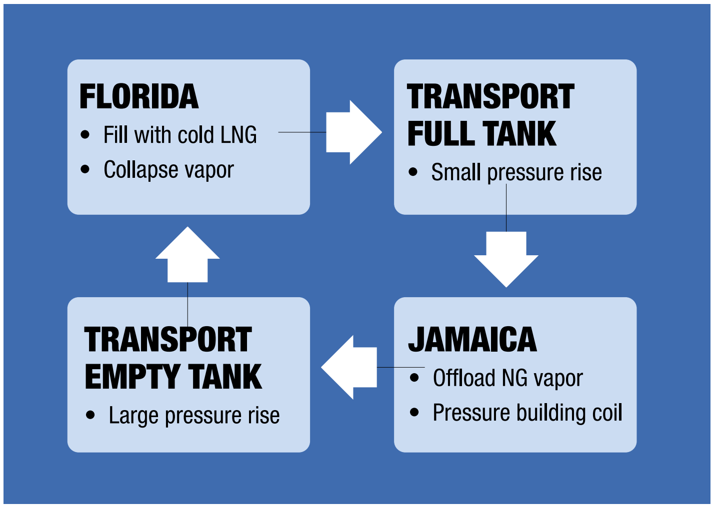

Figure 1: Simplified process flow for the virtul pipeline

The key behind the virtual pipeline is the use of International Organization for Standardization (ISO) compliant containers to carry the LNG. These containers are widely accepted and their use provides a range of transport solutions. By using an ISO container, any cargo truck, train, or barge can carry the LNG. Transferring from one mode of transit to another merely requires moving the container, a typical operation at a cargo terminal. Compare this to using dedicated LNG trailers, rail cars and barges, wherein one dedicated vessel would pump the liquid to another. This pumping operation is logistically complex, allows additional heat to enter the fluid, and often requires the ownership of multiple dedicated vessels for a single route.

In the Figure 1 example, the natural gas distribution site is on the Florida coast and the point-of-use is inland Jamaica. By leveraging the existing transportation resources and distributing by a virtual pipeline, you eliminate the need for specialized vehicles. This provides the opportunity to penetrate emerging markets that cannot justify a large-scale capital investment.

Assumptions

At the heart of this proof of concept is a set of assumptions that estimate the expected conditions. Care is taken to ground the assumptions with real-world data and operational parameters. While the true operating conditions vary from one day and container to another, these assumptions attempt to represent a true-to-life condition.

ISO Container

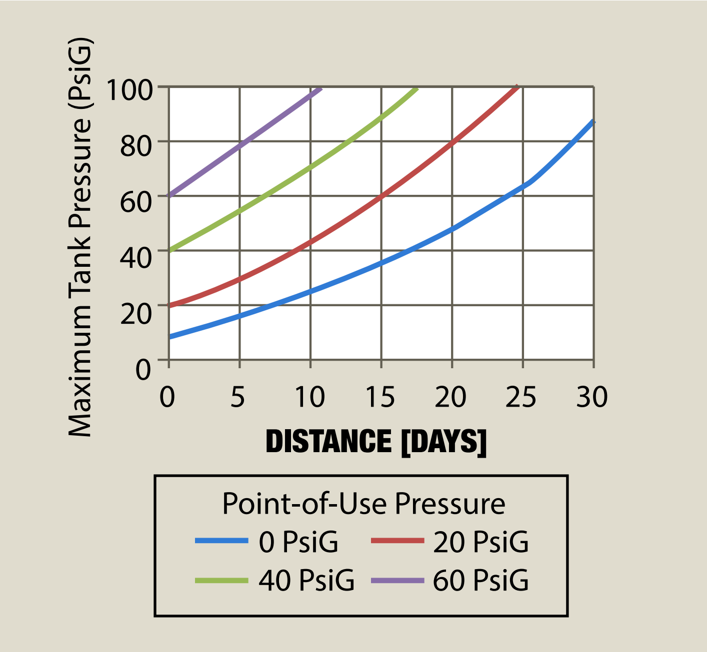

Figure 2: Maximum tank pressure as a function of one-way travel distance and point-of-use pressure

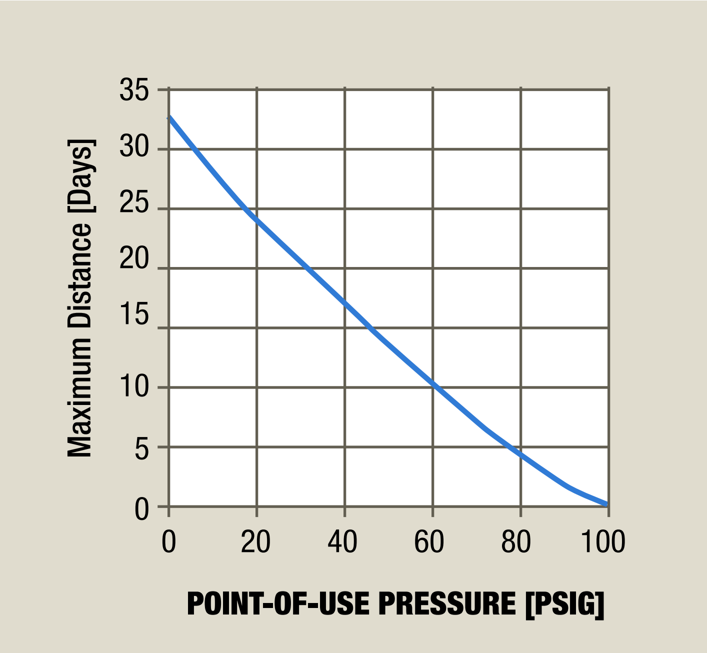

Figure 3: Maximum number of days spent each way as a function of the point-of-use pressure

- Tank: Chart ICC-115-P-100
  - Capacity: 11,495 gal
  - MAWP: 100 psig
  - Evaporation rate: 0.20% per day
- LNG Source: Atmospheric Tank
  - Pressure: 1.25 psig
  - State: Saturated liquid
  - 96% Methane
  - 2% Ethane
  - 0.6% Nitrogen
  - Remainder C3+
- Point-of-use
  - Pressure: Varied
  - State: Vapor
- Loading & Unloading Parameters
  - Heel: 800 gal
  - Ullage: 550 gal
  - Travel time: Varied

In the above assumptions, two parameters are left as variables. The most impactful is the travel time from Jamaica to Florida. While the model allows the time to Jamaica to differ from the time returning from Jamaica, we assume these are equal to simplify calculations. The other important parameter is the pressure at which the point-of-use is using its gasified LNG. If this value is very high then the ISO tank is able to release less of the pressure it built up on the journey to Jamaica to the point-of-use. This provides less pressure budget for the return trip, reducing maximum travel time.

Results

We constructed a process model in the program VMGSim that allows for the simulation of each step of the process. Using the assumptions stated above, the model has been converged while case studies on the variable quantities are conducted. These studies generate the data shown in Figure 2. This figure provides the relationship between maximum pressure across the journey, the length of the journey, and the point-of-use pressure. One can see that increasing either the point-of-use pressure or the one-way journey duration increases the maximum pressure. In most cases, the tank

Stacked LNG tanks waiting for transport

achieved maximum pressure after it had been emptied then heated from its return trip to Florida. Only in the case of very short duration, low point-of-use pressure, does the maximum pressure occur elsewhere. With minor modifications to the model, we are able to find the maximum number of days the container can be in transit before the tank pressure reaches 100 psig. The results of this formulation are provided in Figure 3.

The procedures of point-of-use unloading ensure that the ISO tank pressure and the point-of-use pressure are always equilibrated. If the tank arrives at a lower pressure (colder) than the point-of-use pressure, then a pressure building coil is activated to increase the pressure to the set point. Another case is when a high pressure (warmer) tank arrives, wherein the vapor is used until the set pressure has been reached. After this initial pressurized vapor is removed and the pressure reduced, the coil will maintain the pressure as more LNG is removed as a vapor.

The pressure of the ISO tank after it has been filled from the LNG source is not a fixed variable, unlike the point-of-use pressure. Instead, it varies to accommodate the heat that has leaked into the system over the duration of the journey as well as any heat that may have been added with the pressure building coil. This filling step is the only introduction of cooling to the system, thus the majority of the ISO tank pressure drop typically occurs at this step. The net result of these phases of transport, loading, and unloading are presented in Figure 4.

By conducting this investigation, we have shown that an ISO container can be utilized to transport LNG from a terminal to an end user up to one month away. Although the Florida-Jamaica route is the explicit target of the study, this method's flexibility allows us to apply our findings to many possible alternate routes. The primary restriction on routes is the one-month travel time. This restriction, however, is still a generous allotment of time for a one-way journey. Even when allowing margin for unexpected shipping delays, one month allows for the penetration into many developing markets far from established LNG terminals. The flexibility of using ISO containers capitalizes on existing cargo trucks, rail cars, and barges to transport the LNG to a wide range of developing markets. Developing a network of dedicated transport vehicles or pipelines to serve the same markets would require substantial capital expenditure, even if the market were still small. Thus, the financial and logistical case for a network of cargo vessels carrying ISO containers of LNG into developing markets is strong.

For further information, go to www.Cosmodyne.com.

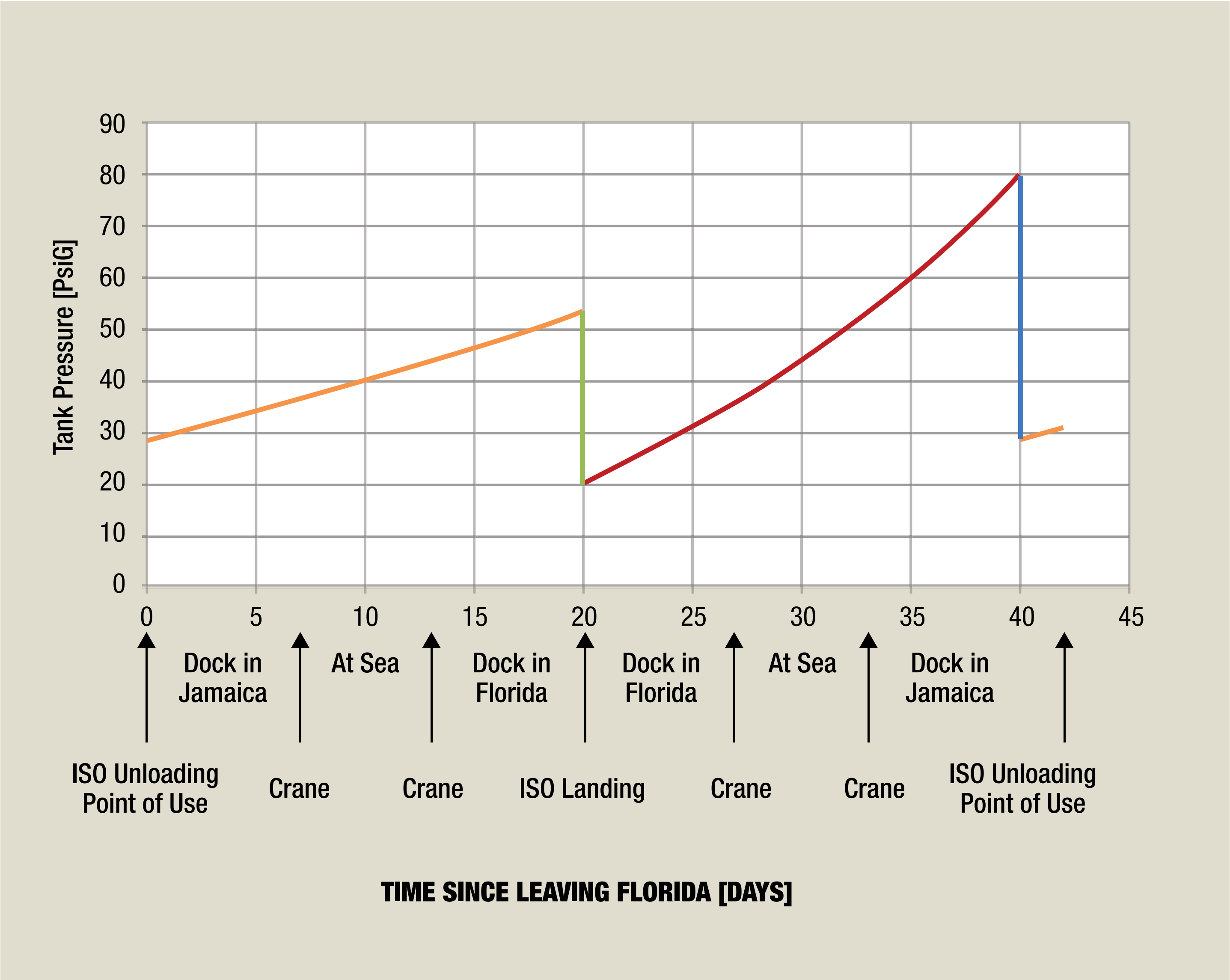

Figure 4: Daily tank pressure over the course of a journey with 20-day point-to-point distances and a point-of-use pressure of 20 psig