CRYOGENIC INDUSTRIES

FROSTBYTE

A newsletter from Cryogenic Industries | Spring 2016

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.

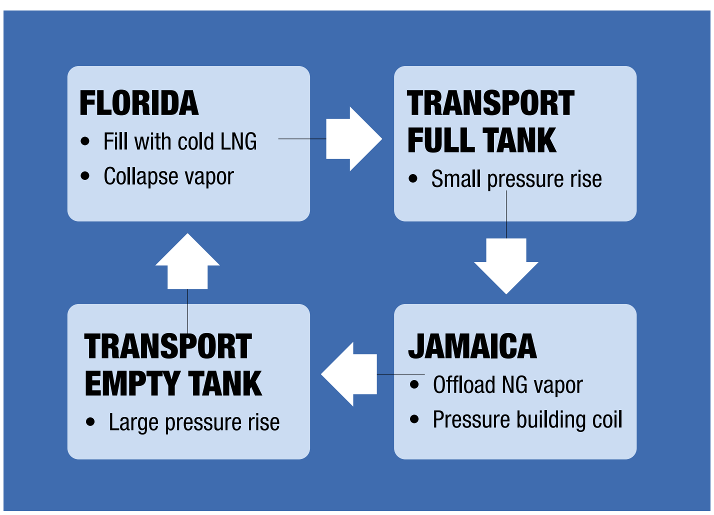


Figure 1: Simplified process flow for the virtul pipeline

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

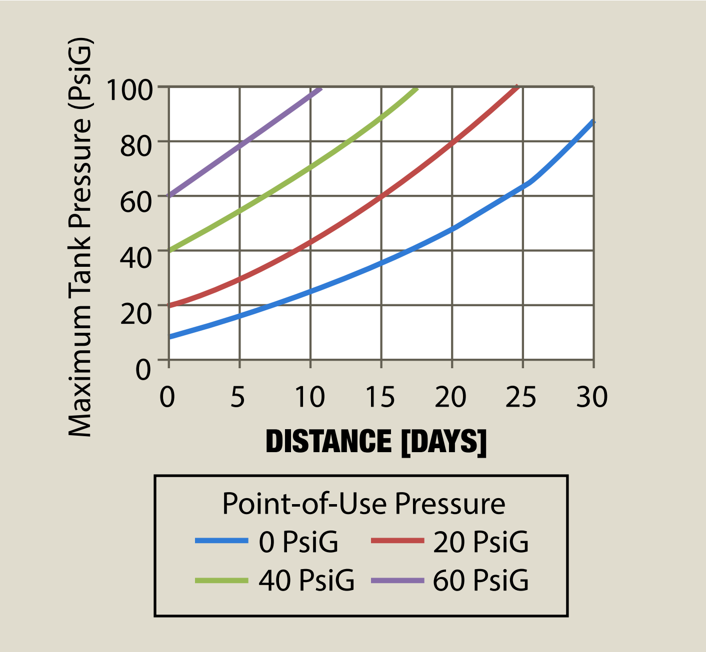


Figure 2: Maximum tank pressure as a function of one-way travel distance and point-of-use pressure

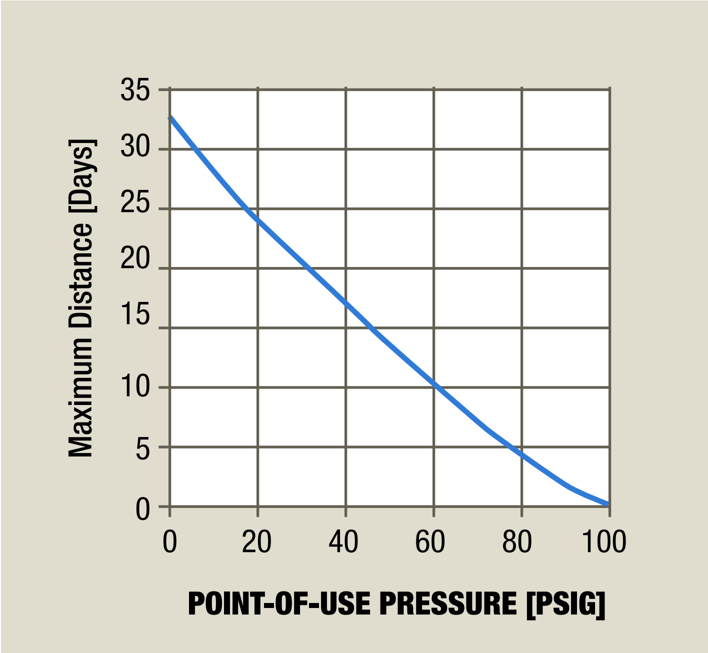


Figure 3: Maximum number of days spent each way as a function of the point-of-use pressure

- 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.

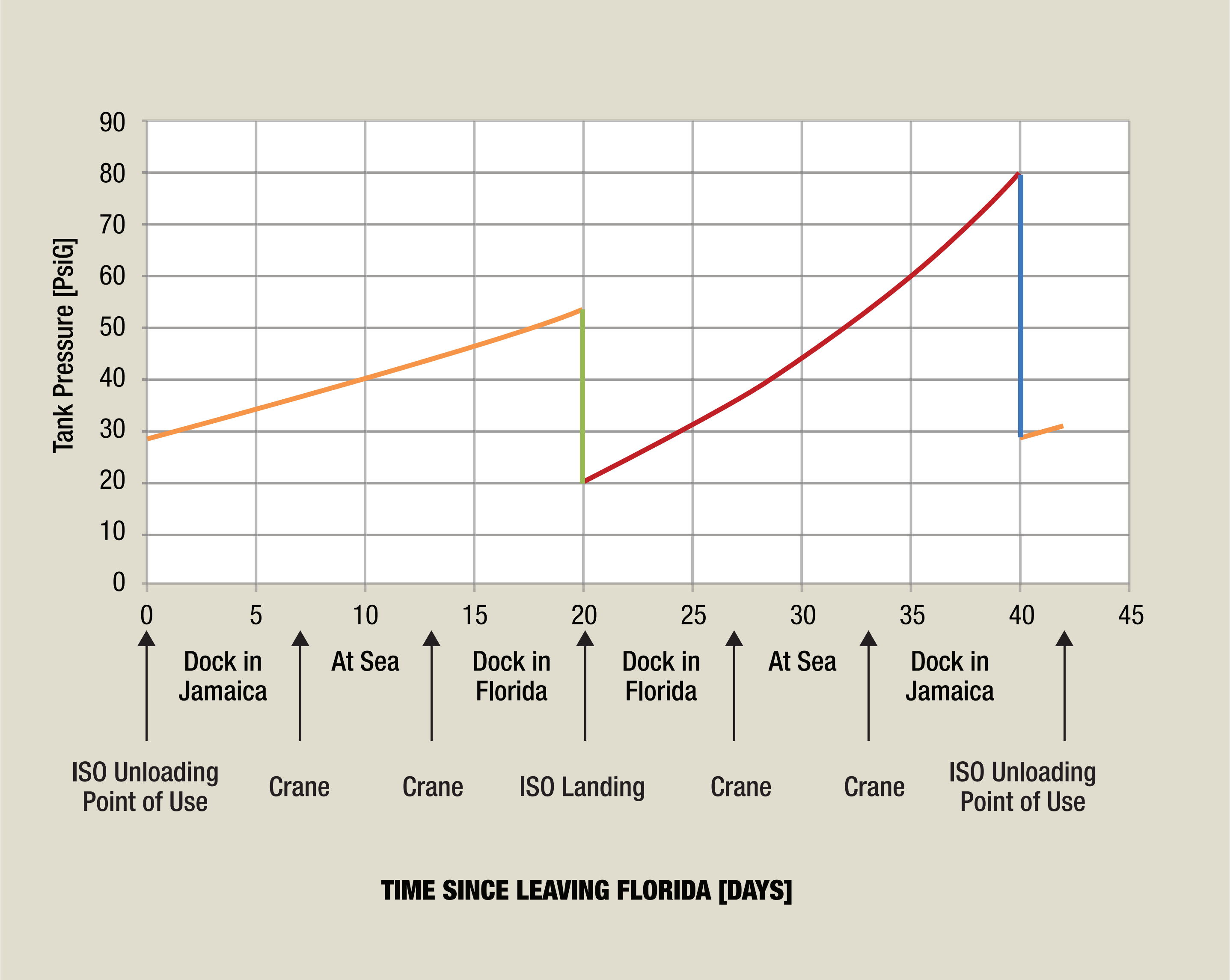


Figure 4: Daily tank pressure over the course of a journey with 20-day point-to-point distances and a point-of-use pressure of 20 psig

Reduced NO_x Emissions for Natural Gas Fired Water Bath Vaporizer

Natural gas is one of the foremost combustion fuels used throughout the country. It is primarily used to generate industrial and utility electric power, produce industrial process steam and heat, and heat residential and commercial space. Cryoquip has long taken advantage of this cheap and abundant energy source to provide process heat for our Natural Gas Fired Water Bath Vaporizers. Due to the flexibility inherent in the natural gas combustion process, these vaporizers are consistently offered as a reliable and economical option in a wide range of process flow rate capacities.

Figure 1: Natural Gas Fired Water Bath Vaporizers

As with any winning strategy, continuous improvement and innovation are vital components to success in the future. Cryoquip strives to never let past success give pause to the steady course of progress. As such, we consistently look for potential enhancements that can be made to benefit both the customer and the industry. One particular area of interest that comes to light when discussing natural gas combustion is emissions levels, and the ever-changing landscape of federal and state air quality standards. Although natural gas is already known to be the cleanest burning of all the fossil fuels, as evidenced in the Environmental Protection Agency's data comparisons in Figure 2, it is still clear that the combustion process produces trace amounts of pollutants in the exhaust gases that, in large concentrations, are known to be harmful to humans and the environment.

Fossil Fuel Emission Levels
Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Figure 2: Source *Eia - Natural Gas Issues And Trends* 1998

Reduction of carbon dioxide emissions is always a chief concern from an environmental stand point, however, 99.9 percent of the carbon dioxide produced during natural gas combustion is a direct result of the combustion process itself. Therefore, aside from the benefit gained from using natural gas as a fuel source, versus using other fossil fuels, there can be only minor improvements to the amount of carbon dioxide produced. These improvements come solely from having a burner system that is properly tuned and efficient. Another lesser-known focus that has become more prevalent in recent years is the reduction of the emissions of nitrogen oxides from natural gas combustion sources.

Nitrogen oxides, or NOx, is a generic term for the mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). NOx gases are formed solely as a byproduct of the natural gas combustion process, and not as a direct product of the combustion reaction. They are produced whenever combustion occurs in the presence of nitrogen, as is the case when air is used as the source of oxygen, and are also produced naturally by lightning in the atmosphere.

NOx formation occurs by three fundamentally different mechanisms. The principal mechanism of NOx formation in natural gas combustion is called thermal NOx. The thermal NOx mechanism occurs through the thermal dissociation and subsequent oxidation of the diatomic nitrogen molecules found in the combustion air. Most NOx formed through the thermal NOx mechanism occurs in the high temperature flame zone near the burners, and are dependent on oxygen concentration, peak temperature and length of time of exposure at peak temperature.

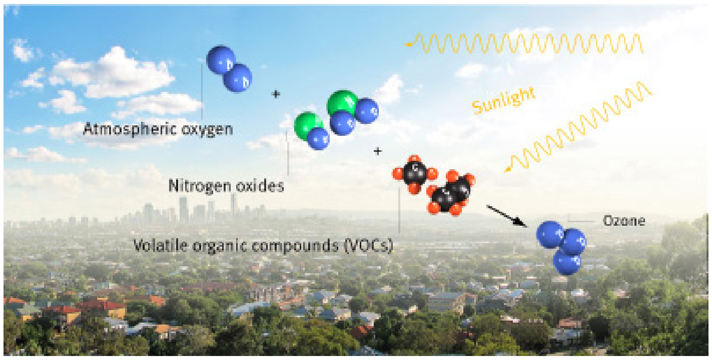
The second mechanism of NOx formation is called prompt NOx. The prompt NOx mechanism takes place in the earliest stage of combustion through reactions of nitrogen molecules in the combustion air and hydrocarbon radicals form the fuel. Prompt NOx reactions occur within the flame and are generally regarded as negligible when compared to the amount of NOx formed through the thermal NOx mechanism. The exception to this is when dealing with ultra-low-NOx which can successfully achieve thermal NOx formation values in the realm of single digit ppm concentrations.

The third and final mechanism of NOx formation, called fuel NOx, arises from the evolution and reaction of fuel-bound nitrogen molecules with oxygen in the combustion air. This mechanism is easily ignored in natural

Photochemical smog over Mexico City, 2010

gas combustion, due to the fact that the characteristically low nitrogen content of natural gas, NOx formation from fuel NOx is insignificant.

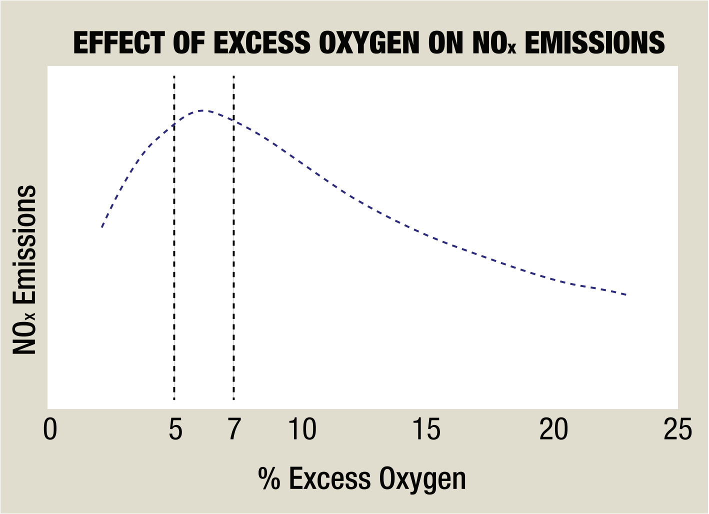
So, why worry about reducing NOx emissions when most are concerned with eliminating greenhouse gases, in the form of CO_2 emissions? There are several answers to that question. The first is an issue we are all too familiar with, being located in Southern California. Smog. Specifically, photochemical smog, a major component of which is NO_2. The majority of NOx produced during combustion (approximately 95 percent) is in the form of NO. Once emitted into the atmosphere, however, NO is rapidly and continuously oxidized to form NO_2. Where high concentrations of



Ozone formation

this compound and certain other volatile organic compounds (VOCs) accumulate and react in the presence of sunlight, photochemical smog is formed. NO_2 molecules themselves, in high concentrations, have been found to cause damage to sensitive lung tissue in senior citizens, children, and those with preexisting heart and lung conditions.

Another major component of photochemical smog is tropospheric ozone, which is also produced as a byproduct of NOx emissions. Tropospheric ozone is ozone (O_3) which is formed and concentrated near ground level, when sunlight causes an NO_2 molecule to react with a VOC molecule to produce NO and ozone. The NO molecule then reacts with free radicals in the atmosphere to produce a new NO_2 molecule. In this way, each molecule of NO can produce ozone multiple times. This process repeats until the VOC molecules are reduced to short chains of carbon compounds that cease to be photo reactive. A VOC molecule can usually support this process about 5 times. Ozone is exceedingly dangerous, because it reacts strongly to destroy or alter many biological molecules, and can reduce forest growth and crop yields in high concentrations. In humans, ozone can reduce lung capacity and worsen pre-existing heart and lung conditions. The negative effects of tropospheric, ground level ozone contrast sharply with the protection from harmful UV-B radiation provided by the layer of stratospheric, or upper atmospheric, ozone, known as the ozone layer.



Effect Of Excess Oxygen On Nox Emissions

A third effect caused by excessive NOx emissions is acid rain. NO_2 can dissolve in atmospheric moisture to form nitric acid, a component of acid rain. Although nitric acid is not particularly harmful to humans, except in concentrations much higher than could be achieved by this process, it can be harmful to plant life and structures. By the same process that creates nitric acid in the atmosphere, NO_2 has been found to contribute the eutrophication of coastal and stagnant waters. Eutrophication occurs when a body of water suffers an increase in nutrients that leads to a reduction in the amount of oxygen in the water. This produces an environment that is destructive to fish and other wildlife.

Factoring in all of the effects that NOx gases contribute to, it quickly becomes clear that there are a number of benefits to reducing the population and environmental exposure to these gases. This is why in 1971, the Environmental Protection Agency (EPA) set ambient pollutant standards for NO_2 as part of the National Ambient Air Quality Standard (NAAQS). NO_2 is used as the indicator, because it forms quickly from combustion emissions, and it is not only itself a harmful air pollutant, but the contributing reactant to the formation of ground level ozone and acid rain. Since then, it has been found that over 90 percent of NOx emissions are anthropogenic (generated by human activity), 49 percent of which is formed from transportation sources, and 46 percent of which is from fuel combustion sources. As a result of state and federal efforts to meet and exceed the NO_2 concentrations standards, the average annual ambient NO_2 concentrations have decreased by more than 40 percent since 1980. With the increased use of low NOx-emitting burners, these numbers will continue their decreasing trend.

NOx emissions can be reduced for natural gas combustion in a number of ways. The most common and economical ways focus on reducing the flame temperature during combustion. This can be accomplished using a few different techniques.

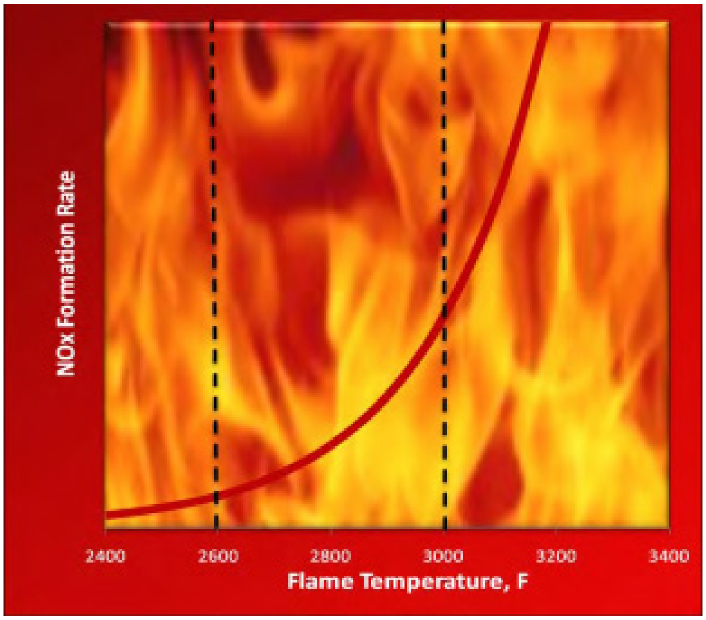
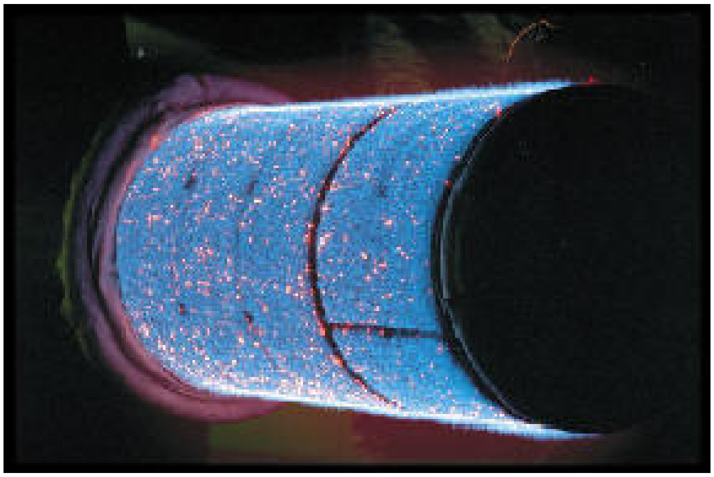


Figure X: Flame Temperature vs. NOx Formation Rates

The first technique is to use a flue gas recirculation (FGR) system. In a FGR system, a portion of the exhaust gas (flue gas) is recycled from the exhaust stack to the burner air intake, mixed with the incoming combustion air, and fed into the burner. The recycled flue gas consists of combustion products which act as inerts during the combustion of the fuel/air mixture. This serves to reduce the formation of NOx, by two mechanisms. Primarily, the recirculated gas acts as a dilutent to reduce the combustion temperatures, thus suppressing the thermal NOx mechanism. As a secondary mechanism, FGR also reduces NOx formation by limiting the amount of oxygen available for the dissociated nitrogen atoms to react with, because the majority of the oxygen in the flue gas has already been consumed by the initial combustion process. With this process, we are able to reduce NOx emissions by over 60 percent

Figure 6: FGR Piping

Another technique that has been implemented by burner manufacturers, which we have found to be a very robust solution to reducing NOx emissions, has been the use of pre-mixed surface stabilized combustion burner designs. This method reduces the flame temperature through the use of excess air in the combustion gas. Typically, the implementation of high excess air (fuel lean) mixtures results in flame instability at high capacities. By pre-mixing the fuel and air in a primary chamber, distributing the mixture through a mesh of metal or ceramic fiber, and maintaining combustion uniformly across the surface of this mesh, combustion stability is preserved, and NOx formation is greatly reduced. This technique eliminates the need for external piping required for the FGR system, and achieves a lower flame temperature by operating leaner, while at the same time creating a homogenous mixture of fuel and air to prevent the existence of fuel rich combustion zones. In certain applications, this system is capable of reducing the formation of NOx by as much as 90 percent.



Surface Stabilized Combustion

A third method that may soon become an option to further reduce NOx emissions, employs the process of fuel staging. In this method, the fuel is divided into primary and secondary streams and injected into separate combustion zones. In the primary zone, fuel lean combustion reduces flame temperature. In the secondary zone, the oxygen depleted air from the primary zone prevents further NOx formation. This is typically a less economical solution, but with the combustion of fuel staging and external FGR, NOx levels can be reduced to meet and exceed even the most exacting local emissions standards.

Employing any one of these techniques also requires the use more sensitive control systems in order to ensure that the burner system is always running at the optimal efficiency. To achieve the most efficient combustion throughout the entire capacity range of a given burner system, we have employed several strategies which allow for a more fine tuned combustion curve under various conditions. By adding a variable speed drive to the blower motor, a system is able to achieve the desired air flow within a much smaller range to maintain the proper fuel/air ratio needed for optimal combustion. In addition, exhaust gas monitoring systems, such as an O_2 trim system, monitors the amount of excess O_2 present in the exhaust gas and automatically adjusts the variable frequency drive (VFD) setting to compensate for high or low readings caused by varying ambient conditions. A burner system operating with these components in place can provide the highest level of emissions control yet possible for a natural gas fired vaporizer.

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Email Dwayne Ferraro at dferraro@cihouston.com for further information or to register to attend.

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GAWDA Spring Management Conference
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Exhibiting

LNG18
Perth, Australia
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Offshore Technology Conference (OTC)
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May 2-5, 2016
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IWDC
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May 17-19, 2016
Exhibiting

Global Petroleum Show
Calgary, Canada
June 7-9, 2016
Exhibiting – Booth #1180

GAWDA Annual Convention
Kihei, HI
September 25-28, 2016
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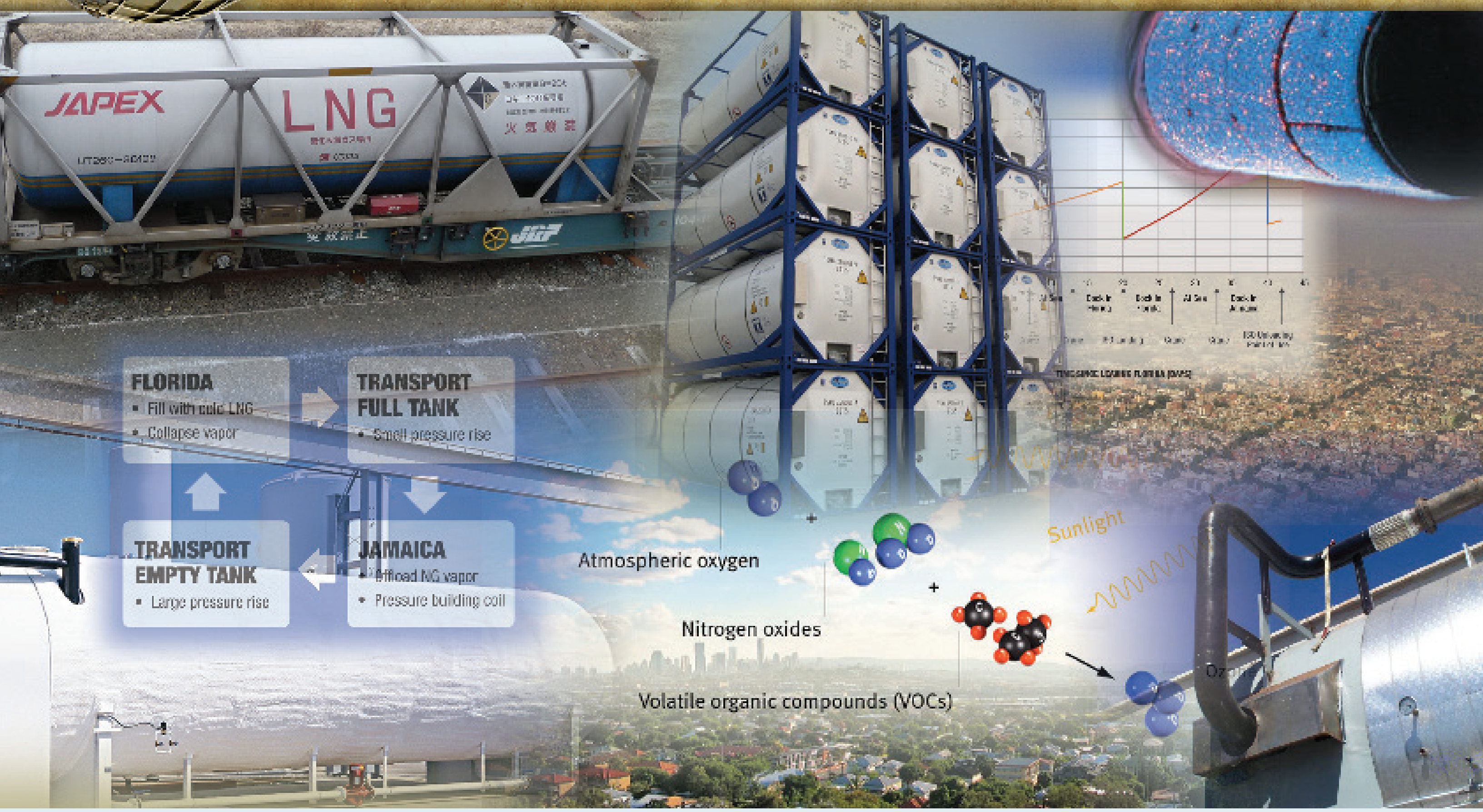

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