LNG LINE BLOCKAGES: CAUSES, PREVENTIONS AND CURES

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ABSTRACT

LNG peak-shaving facilities will occasionally develop a blockage within their fill line that prevents LNG from being added to the tank until the blockage is removed. The typical historical method for removing a blockage is the use of a vacuum pump to pull a vacuum on the fill line, thereby removing the offending plug material. Removing a blockage can take as little as a few hours, but generally takes weeks to months, and sometimes even years depending upon conditions within the blockage and the surrounding area. We will discuss the results of blockage component analysis, theories on blockage formation, what an LNG Peak-shaving facility can do to help prevent blockage formation, and finally, in the event that a blockage of the fill line does occur, a method which has been reliably used several times in multiple plants that has consistently cleared the blockage in minutes to hours instead of weeks to months; is inexpensive and generally easy to implement using parts and supplies normally found at an LNG facility.

INTRODUCTION

LNG peak-shaving facilities will occasionally develop a blockage within their fill line, vapor return line, cold boxes, or other areas that prevents LNG from being added to the tank, or impairs other plant functions, until the blockage is removed. The typical historical method for removing a blockage is the use of a vacuum pump to pull a vacuum on the affected line, thereby removing the offending plug material. Removing a blockage with a vacuum pump can take as little as a few hours, but generally takes weeks to months, and sometimes even years depending upon conditions within the blockage and the surrounding area. We will discuss the results of blockage component analysis, theories on blockage formation, what an LNG Peak-shaving facility can do to help prevent blockage formation, and finally, in the event that a blockage does occur, a method which has been reliably used several times in multiple plants that has consistently cleared the blockage in a few hours instead of weeks to months; the process is inexpensive and generally easy to implement using parts and supplies normally found at an LNG facility.

OBJECTIVE

1) Discuss how a plug forms in an LNG line.

2) Propose modifications to plant operations to prevent a plug from forming.

3) Describe how to remove a plug from an LNG line.
WHAT CAUSES PLUG FORMATION TO OCCUR

LNG typically contains 90% or more of methane, less than 5% Ethane, and correspondingly smaller quantities of each of the higher hydrocarbons such as Propane, Butane etc. When LNG is stored in a container without an active cooling system, i.e. nearly all LNG storage tanks, the LNG temperature is maintained at the boiling temperature of the mixture by some of the liquid becoming a gas, thereby taking a quantity of heat equal to the latent heat of vaporization with it. When the LNG is freshly made, the primary component of the boiloff gas is Methane. As Methane has the lowest boiling point (-258.7°F at atmospheric pressure) of the components that make up LNG, and is the most abundant component in the mixture, it is therefore nearly the only component of the boiloff gas. Over time the total amount of LNG and the mole fraction of methane within the LNG are constantly being reduced, however the total amount of the other components remains essentially unchanged. This causes the mole fraction of Ethane, Propane and Butane to steadily climb, see Figure 1 for a graphical representation of this concept. It should be obvious that the higher the initial concentrations of Butane, the less time it will take for the Butane concentration to increase.

As the composition steadily becomes richer in the higher hydrocarbons the boiling point of the mixture slowly increases, as does the percentage the higher hydrocarbons in the gas phase, with Ethane initially increasing its vapor fraction the most, followed in order of course by Propane and Butane.

Given that the main storage tank(s) of an LNG plant is(are) so well insulated, this process occurs slowly inside them and generally doesn’t start to become problematic until several years have passed without the addition of fresh LNG. However in LNG pumps and piping that are exterior to the tank, as well as other pieces of equipment that aren’t as well insulated, this process occurs much faster. Some LNG peak-shaving plants will cool their pumps down slowly over several hours at the start of the heating season and keep them cold until the heating season is over, that way the plant is ready to vaporize whenever their services are required; this also has the beneficial effect of reducing the thermal cycles the pumps go through.
As the pumps might be cooled down for 4 to 6 months, the aging of the LNG in the pumps can on occasion cause problems. The aging process of the LNG in the pumps is a little different than the process described above but very similar. Since the pumps are external to the main supply of LNG, when a quantity of Methane from the LNG is converted into the gas phase within the pump and associated piping, it is replaced by a quantity of liquid that is a mixture of all the hydrocarbons in the tank, maintaining a near constant volume of LNG external to the tank and slowly causing the Ethane, Propane and Butane concentrations of the LNG in the pumps to increase. Figure 2 illustrates the concept of how the concentration of the components changes over time. You will note that the change in concentration of the components is more gradual over time as compared to the aging process inside a tank.

As the composition of the LNG within the pump becomes leaner in methane, and richer in higher hydrocarbons such as Butane, the temperature of the LNG rises. When the partial pressure of Butane in the boiloff gas from the comparatively warm LNG in the pump gets high enough, then the Butane will condense out of the vapor phase while returning to the tank and then solidify (freezing/melting point of Butane is -220°F to -209°F), forming a semi-porous solid blockage of the line. Since the liquid level in the tank is constantly dropping, when liquid is not being made, the plug periodically partially thaws when the pipe and blockage are in the relatively warm, gas phase area of the tank; the Butane re-solidifies when the liquid Butane reaches the colder section of the pipe that is in contact with the liquid phase inside the tank, thereby reforming the plug at about the liquid level of the tank. See Figure 3 for a visual interpretation of this idea.
Two LNG plants on opposite coasts of the United States were able to independently determine, using two different methods, that the blockage in each plant was inside their recycle/tank-fill lines where the line went into the LNG inside the main tank. At each plant it was determined that the LNG that was inside the recycle line was warmer than normal and significantly higher in Propane and Butane than normal.

Although additional anecdotal evidence indicates that LNG high in Butane content due to aging appears to be the predominant reason for blockages forming in pipe and other equipment, it does not rule out other causes for relatively high partial pressure Butane from reaching areas within the plant that are cold enough to liquefy and subsequently solidify Butane, therefore you may develop blockages for other reasons such as leaking valves in various parts of the process.

For example: A facility that did not cool their pumps down for the heating season had a very small leak on a pump inlet valve that went un-noticed for several months. Eventually a plug formed in the vapor return line even though this line terminated in the vapor space of the tank. Several contributing factors were the insulation being 5 feet thick, the vapor return line being close to the internal tank wall, and the leak though the valve was small resulting in the gas having a slow velocity through the pipe. The plug formed just a few feet inside the tank adjacent to where the liquid was.

It is even possible for some plants to develop a leak from their inlet/outlet pipeline gas to the tank. In a case like this it is quite conceivable that the moisture in the pipeline gas could exacerbate the problem. It is believed that the method of clearing the plug presented later in this paper would still be effective in this case.

The general pattern that has been observed is that a gas source, higher in Butane concentration than is normal, is chilled below the freezing point of Butane and this process continues for days, weeks, or months before the problem is noticed. This process slowly builds up a solid layer of Butane inside the pipe or other equipment. Generally by the time the problem is noticed, the plug has formed and you have to remove it.

WHAT PLANT OPERATIONS CAN DO TO PREVENT A PLUG FROM FORMING

Now that we understand how a blockage is formed, we can develop methods for preventing the blockage formation by eliminating or stopping the conditions that lead to higher Butane content in the piping and pump boiloff. The following are in no particular order, the ease of implementation and cost would vary for each plant.

1) Cool down pumps only when needed. Advantages: This will prevent plug formation as pumps willonly be cooled down for a few days or weeks at the most. This will reduce plant boil-off rate, slowing the aging process, and reducing the amount of replacement liquid that needs to be made, although this might be fairly negligible. Easy to implement. Disadvantages: This will result in a greater number of thermal cycles on the equipment, potentially slowly damaging the equipment. Depending on weather and plant operating protocols this could potentially increase the amount of time between when vaporization is requested and when it can be accomplished.

2) Stop small leaks from the tank valve(s). If LNG is leaking past the tank outlet valves towards the pumps, but the pumps aren’t cooled down, a similar situation to the LNG aging inside the pumps can arise. Advantages: Prevents plug formation. Reduces boiloff. It could be as easy as making sure a valve is fully closed. Disadvantages: Depending on reason for leakage and location of valve in relation to other valves, it could be difficult to repair the offending valve.
3) Flush LNG from pumps periodically, operational evidence indicates flushing every two to four months should be sufficient in most cases. The flushing can be accomplished several ways.

1) Turn on main pumps. Advantages: quick it generally only takes a few seconds for a pump to replace all of the LNG within the outlet piping and pumps with fresh LNG from the tank. Easy – very little training involved, and the training is directly related to vaporization, and all fully trained plant operators should already know how to start the main sendout pumps. Disadvantages: increased pump wear, potential power cost impacts.

2) If a truck fill pump exists and the piping and valving permits: use a truck fill pump to flush system. Advantages: Lower peak electrical demand than when main sendout pumps are used, thereby potentially saving money on electricity and extending time between repairs of main pumps. Disadvantages: Has the potential to be complex manual procedure which can lead to errors, more involved training program.

3) Piston LNG from the pumps back into the main tank through the tank’s outlet valve. Advantages: Little to no electrical power required, only gas pressure needed. Disadvantages: Highest probability of something catastrophically going wrong if proper procedures are not followed. If the tank has an outlet valve it likely was not designed for backward flow. Too much force on the valve in the wrong direction can damage the valve or tank. This method can be accomplished safely, however it is imperative that proper calculations be performed and controls be put into place to limit the velocity of the LNG flowing backwards through the outlet valve.

4) Improve insulation of the pumps and associated piping. Advantages: No operational changes needed, decreased boiloff rate, no increase in thermal cycles on pumps. Disadvantages: Cost of improved insulation, insulation improvement may not be adequate to solve the problem.

HOW TO CLEAR A BLOCKAGE OF AN LNG PIPELINE

As indicated earlier the typical historical method for removing a blockage is the use of a vacuum pump to pull a vacuum on the line that is blocked, thereby slowly removing the offending plug material. Removing a blockage can take as little as a few hours if caught early, but generally takes weeks to months and sometimes even years depending upon conditions within the blockage and the surrounding area. NW Natural, until 2007 had used this method on the occasions we developed a plugged line. The shortest amount of time it took us to clear a blockage using the vacuum method was one day; the longest was about a month and a half, with most attempts taking about a month. In 2007 we ran a 10 horsepower (hp) vacuum pump maintaining a vacuum of 28"Hg (28 inches of Mercury, atmospheric pressure is 29.92"Hg) for a week and made no apparent progress on clearing the blockage. We needed to clear the blockage so we could start the liquefaction process in order to refill the tank in time for the winter heating season since the vacuum process wasn’t working fast enough. I therefore developed an alternative method to remove a blockage. This new method of clearing a blocked pipeline in an LNG plant is quite simple and has always proved quickly effective; our new method uses Helium (He) to break up the blockage. The He can be the relatively inexpensive balloon grade He instead of the more expensive chromatograph grade He typically used in an LNG plant, however you can of course use chromatograph grade He if that is all you have access to. I have personally used this method four times at two different LNG plants, three times to clear a blockage in a pipe inside the main tank, and the fourth time to clear a blockage in a cold box. The procedure has also been used twice at an LNG plant on the East coast of the United States to clear blockages in their recycle and or vapor return lines.

The theory as to why this works is that the He is small enough to make its way through the very very small pores of the solid Butane blockage, slowly heating, and reducing the partial pressure of the Butane that is forming the blockage, eventually creating a small tunnel through the Butane blockage that larger molecules
can freely flow through. Helium will behave as an ideal gas and won’t become a liquid in the conditions it experiences during this procedure, as it is a long way away from its critical temperature and pressure (-450°F and 33.2 psia). Once the tunnel exists in the blockage, relatively warm natural gas is quickly pushed through the hole, widening the hole until no blockage exists at all.

Examination of Figure 4 while reviewing the basics of the operation below is helpful in aiding comprehension:

1) Make the volume of the equipment you will be adding the He to as small as practically possible, by closing valve(s) or using blind flanges, this will reduce the amount of He needed.

2) Safely drain any liquids from the line that is plugged. The line will likely contain liquid Propane and Butane as these can exist as a liquid at relatively warm temperatures as compared to LNG, and their mole fraction at the pumps is much higher than inside the tank.

3) Connect the He supply and increase the initial pressure to roughly 50 pounds per square inch gauge (psig), if suitable for the equipment/piping and situation. Higher pressures may or may not be suitable depending on the equipment, piping, and the plug. The highest pressure I’ve used, or been able to generate with a 300 cubic foot (300 cuft) 2400 psig cylinder, is 495 psig on a 1500 psig Maximum Allowable Operating Pressure (MAOP) line. Some blockages have been cleared in 2 to 4 hours while never exceeding a pressure of 200 psig.

4) Loosely monitor flow rate out of the He bottle and periodically check the lowest pressure the He leaks down to, the latter can generally be done while swapping He cylinders.

5) Replace spent He cylinders with fresh ones as fast as is practical until the lowest pressure the He leaks down to is the pressure on the other side of the blockage. This has taken 2 to 9 cylinders of He (approximately 300 cuft nominal volume/cylinder) and 2 to 5 hours to clear a plug the six times I’m aware of this process being used.

6) Connect a source of warm natural gas to where the He was being injected and flow as much gas as practical into the line. Freshly compressed boil-off gas works well since it has no moisture and is typically warmer than pipeline gas. Every 10 to 30 seconds or so shut off the warm gas supply and check how long it takes the pressure to bleed down. Doing this immediately after you start flowing the warm natural gas will help you understand when the blockage has been cleared, for example: If it takes 20 seconds to bleed the pressure down the first time, you can be fairly confident that the blockage has been completely cleared when the last two times you closed the valve it only took 3 seconds to go from 300 psig to 9 psig.
When the He is first introduced to the piping it will likely appear as if nothing is happening. This is a good
time to check for leaks on all fittings, connections, and valves. A soap solution works fine for this. The higher
the pressure of the He in the pipe, the faster the process clears the blockage. If you flow the He out of each
cylinder as fast as the regulator and plug will allow, the maximum pressure obtained will be lower with each
subsequent cylinder. Note that while changing cylinders the pressure within the pipe will drop faster with
each subsequent cylinder.

If the line that the He is being injected into goes to the bottom of the tank, the pressure on the other side of
the blockage is essentially the pressure at the bottom of the tank which is the sum of the hydrostatic head
pressure of the liquid in the tank plus the gas pressure in the tank. You don’t subtract the hydrostatic head
from the blockage in the pipe to the pipe opening as this liquid has been completely replaced with He by the
time there is a hole through the blockage.

The addition of the He to the tank will not significantly affect energy content of the outlet gas. However let’s
analyze a couple of hypothetical situations to illustrate why:

1) A relatively small tank capable of holding 0.6 Billion standard Cubic Feet (BCF) of natural gas in liquid
form would likely have over 500,000 cubic feet (cuft) of gas within the tank. Even if it took 3,000 cuft of He to
clear the plug the resulting reduction in energy content per cubic foot of gas would be relatively small.

\[
1012 \text{ Btu/cuft} \times \frac{(500,000 \text{ cuft} - 3,000 \text{ cuft})}{500,000 \text{ cuft}} = 1005.9 \text{ Btu/cuft}
\]

Where 500,000cuft is the available gas space inside the tank, 3,000cuft is the volume of He that is displacing
the boiloff gas and 1012 Btu/cuft is the number of British Thermal Units contained in one cubic foot of
methane.
The percentage change this represents is small.

\[ 100\% \times \frac{(1012 - 1005.9)}{1012} = 0.60\% \]

As 0.60\% represents the upper end of the error in energy content for a few hours, the effect on metering accuracy for customers receiving boiloff gas directly from the plant with no dilution from other sources, the worst possible case, will not appreciably affect their monthly bill. Using normal chromatograph techniques the presence of the He in the boiloff gas will not be detected since He is the carrier gas in the chromatograph. Consequently the boiloff gas composition as reported by the Gas Chromatograph will likely show no deviation from normal.

2) For a larger tank with less liquid inside, that, for whatever reason, didn’t need as much He to clear the plug, the effect on Btu content is of course much smaller:

\[ 1012 \text{ Btu/cuft} \times \frac{(3,000,000\text{cuft} - 1,500\text{cuft})}{3,000,000\text{cuft}} = 1011.5 \text{ Btu/cuft or 0.05\% error} \]

SUMMARY

When blockages form inside piping or equipment in an LNG plant, the blockage typically is caused by solid Butane. It is relatively simple and inexpensive to remove the blockage by using Helium to create a small tunnel through the blockage. Once we have a continuous hole all the way through the blockage we use warm natural gas to fully remove the rest of the Butane blockage. The dilution of energy content in the boiloff gas for a few hours is not problematic in most situations.

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