Easing the GAS BURDEN

Jeff Odell, Cosmodyne, USA, offers an analysis of boil-off gas management systems at an LNG facility.

There are many sources of boil-off gas (BOG) generation in LNG facilities. However, there are only a handful of methods for efficiently managing the gas. Through careful inspection, the magnitude of the primary sources of BOG can be estimated, and the advantages and disadvantages of the solutions evaluated.

The BOG management system in an LNG facility must maintain the pressure of the storage tank within the tank's minimum and maximum allowable operating pressure range. Therefore, it is wise to first take a moment to consider exactly how BOG and pressure relate. Immediately upon adding BOG into the system, the pressure increases, as there is more gas in the vapour head above the LNG. Eventually, a portion of this vapour condenses as a reaction to the increased pressure. Without a detailed study dedicated solely to the understanding of how heat moves throughout a given tank geometry at a given fill level, the rate at which the condensation occurs is not known. Thus, it is prudent to assume that only the gas head absorbs the BOG with no condensing effects. The result of this is that the tank pressure is highly sensitive to BOG addition. Any BOG added to the system must be quickly met with a matched cooling duty, potentially requiring that transient operations, such as production or filling, be slowed or halted as the BOG tries to keep up.

Therefore, it is important that the BOG management solution is

able to cover the baseline heating, as well as the peak heat load, such that interruptions do not occur. Even if the peak BOG load is not expected to occur often, resulting in a low average duty, such averaging would likely lead to dramatically increased tank pressures when condensation is not considered.

Sources of heat leak

Heat leak can be broken down into three primary categories: constant heat leak, production heat leak, and filling heat leak. Constant heat leak is a heat leak that occurs constantly throughout the life of the LNG system. Production heat leak is the heat leak that is encountered due to the production of LNG added into the storage system. Finally, filling heat leak occurs during the process of preparing and filling LNG rail cars, trailers, and barges for shipment.

Constant heating effects cover three sources of heat: tank heat leak, pipe heat leak, and pump heating. LNG tanks typically advertise their heat leaks as a percentage of capacity lost per day. This represents a simple, yet significant, source of constant heat leak. To calculate the BOG related to this, the total tank volume must be multiplied by the tank's fractional heat leak (typically a fraction of 1%). This provides the volume of liquid that is converted to BOG; using the density and latent heat of vaporisation, the heating duty is calculated. The length of pipe and the type of insulation primarily drives LNG piping heat leak. Facilities with long pipe runs, such as to a barge terminal, will have more piping length than those that serve a local use or a nearby truck filling station. While vacuum insulated pipe may be more costly than traditionally insulated pipe, the heat leak of a traditionally insulated pipe is roughly ten times more than a vacuum insulated system. Using conventional insulation turns a relatively minor heat source into a major contributor and should be avoided in all but the shortest of piping runs. Finally, a small pump can be used to keep LNG circulating through the pipes to keep them cold. All of the power used by this pump to increase the fluid's pressure must eventually be cooled by the BOG management system.

If the facility produces LNG, whenever the main liquefier is running, two effects must be analysed for their impact on the heat balance of the system. Firstly, the liquid added to the tank reduces the vapour space for the BOG, thus increasing the pressure within the tank. If pressure is to be maintained – which is the fundamental duty of a BOG management system – then the same volume of liquid added must be handled by the BOG system. After the liquefaction, the LNG product pressure is equalised to the tank pressure. Depending on the degree of cooling in the cycle, a fraction of the LNG may flash into vapour in this process, directly contributing to the BOG. Typically, nitrogen cycles do not generate flash. Furthermore, some nitrogen cycles can be designed to cool the LNG to the point where they remain subcooled after the pressure reduction valve, thus condensing some or all of the BOG in the tank.

The final heat load category covers heating incurred during the process of filling a container, be it a rail car, trailer, or barge. The filling system, tubes and hoses that connect the container with the main piping system are typically minimally insulated. Thus, while these lengths are short, they contribute to the filling heat loss. Furthermore, because these hoses are not kept cold during normal operation, they must be cooled from ambient temperatures to LNG temperature. Many transport containers do not contain a BOG management system, opting instead to allow the storage pressure to increase. Depending on the specifics of the LNG system and the container, there are two options to deal with these high pressure (and thus high temperature) containers. The first option is simply to add LNG, which will collapse much of the vapour, bringing storage pressure to an intermediate pressure between its starting pressure and the LNG storage pressure. The second option is to blowdown the container into the main LNG tank, where it is treated as BOG. Once the container pressure has been reduced to that of the tank, LNG is added while maintaining the storage tank's pressure within the container. Saturation temperature increases with pressure, thus the high pressure mixture and the tank that contains it are of a higher temperature than the incoming LNG. When calculating blowdown heating, one must take into account the specific heat and mass of the container's shell to cool it from the high pressure to low pressure saturation temperature. The final heat source is from the pumps. Unlike the recirculation case, wherein a low flowrate and low pressures were required, filling operations often require a much higher

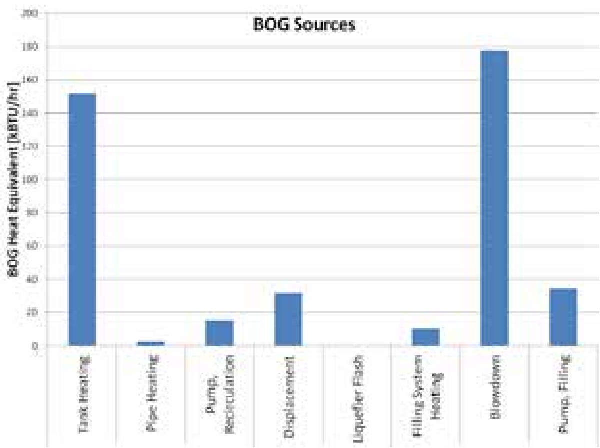

Figure 1. Relative magnitudes of the sources of heat leak in an example LNG production (N_2 cycle) and export terminal.

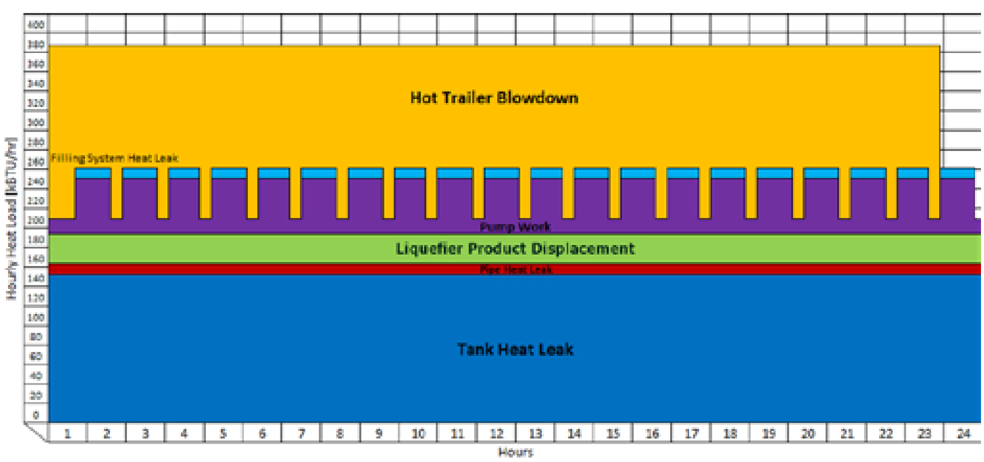

Figure 2. Example daily schedule of expected heat loads when filling 20 high pressure 10 000 gal. trailers.

flowrate and, in some applications, a higher pressure, leading to a substantial increase in pump heating.

Of these BOG contributions, two items stand out as the primary heating contributions. Figure 1 shows an LNG plant with a 200 000 gal./d LNG production facility and a 3.5 million gal. storage tank. The tank heat leak and blowdown dominate BOG production. The tank heat leak requires approximately 150 000 Btu/hr of cooling duty to offset. The blowdown is a more complex number to understand. While tank heat leak has a constant heating duty, the blowdown process has a fixed amount of energy that can be spread across time to reach a desired duty. Thus, the blowdown duty has been selected to meet scheduling constraints and to match the approximate size of the constant heat leak effects, to maximise the cost-effectiveness of an independent recondensing unit, as will be described later. Figure 2 shows how the system can handle the worst-case expected scenario for the example plant, wherein all of its daily production must be loaded onto trailers that arrive at high pressure and must depart at storage pressure.

BOG solutions

There are a number of methods to deal with BOG, each with its own advantages and disadvantages. These methods fall into three categories: flare, sell, and recondense.

Natural gas flares provide a relatively simple method of disposing of excess gas. Once the pressure reaches a set point, gas is sent through a series of knockout drums and other safety mechanisms, and is then combusted. Flaring, however, has numerous drawbacks. Regulation of flaring activities and complete loss of value from gas provide strong economic disincentives.

The second method is to compress the BOG and sell it to a nearby CNG user. This method returns some economic value to the operator for the gas. However, it relies on buyers being available to take the gas whenever it is produced, or on a separate CNG storage tank for short-term storage. These options can dramatically increase logistical issues when external CNG consumers dictate LNG facility operation.

There are multiple techniques to recondense BOG. The first is where BOG is recompressed and fed back into the main liquefier. This method can be the most efficient of the recondensation methods due to the high efficiency of the main reliquefier. This requires either a separate low temperature process or the main liquefier to be designed to accommodate this BOG stream. This method works well in many cases, but cannot be used exclusively. Consider the case wherein the storage tank is full due to low sales and the liquefier is shut down. In this case, more LNG cannot be made, meaning that the main liquefier cannot be used, and thus BOG cannot be reliquefied.

Dedicated coolers, such as the one shown in Figure 3, act as independent systems to condense the BOG either directly, or by spraying subcooled LNG into the vapour space to promote condensation. These systems can either utilise a closed loop refrigeration cycle or an open loop cycle using liquid nitrogen (LIN). The primary drawback of the independent closed loop cycle is that it cannot achieve the same efficiency as the main liquefier. The open loop cooler requires the production or purchasing of LIN, leading to more logistical issues, but it requires minimal CAPEX. While the closed loop cycle requires more capital than the open loop cycle, the cost difference between a dedicated closed loop recondenser and a recompressor may not be significant, depending on the specific situation. Both of these solutions offer operation independent of the main liquefier. Dedicated BOG recondensers offer capabilities to existing plants that are looking to move away from flaring or selling CNG, and cannot or choose not to expand their main liquefaction capacity.

The sizing of the BOG management system depends greatly on the specific requirements of each LNG system. However, some choices have been shown to be typically advantageous. For new main liquefier designs, subcooling the LNG to offset the displacement heating is recommended. This choice will allow the remaining sizing to be independent of the operation of the main liquefier. Alternatively, if the main liquefier is capable of producing enough cooling to offset the entire constant heat load, then the BOG solution is efficient. If the plant operations schedule allows, it is recommended to carry out a filling operation in an amount of time such that the filling heat load is equal to the baseline heat load. This allows for the use of multiple, identical, independent recondensation units. If sized as such, only one of the units must be operational to carry out the required constant heating duty. This maximises redundancy for ensured operation, thereby decreasing the reliance on flaring or selling the gas.

Conclusion

A great amount of detail can go into honing the heat balance of an LNG facility in each operation mode of the plant. For initial sizing, however, tank heat leak and container blowdown are the typical drivers. Recondensing methods of BOG management offer an alternative to flaring and selling CNG, which come with many regulatory and logistical issues. Recompressing BOG into the feed stream of the main liquefier at first glance offers the most cost-effective BOG management, but site-specific considerations can lead to increased costs. Independent recondensers, on the other hand, provide substantial freedom in operation and redundancy. By estimating these heating loads, weighing the advantages of each BOG management system, and sizing the solutions smartly, BOG management does not need to be a logistical burden to an LNG plant operator. **LNG**

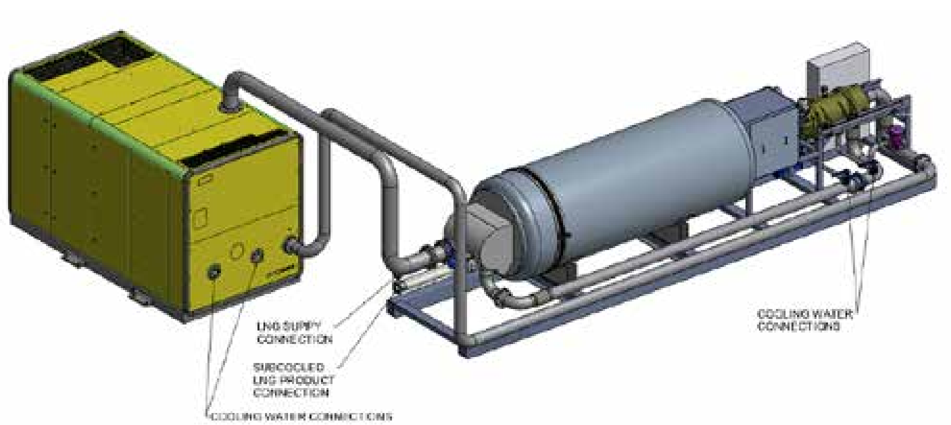

Figure 3. A Cosmodyne closed loop boil-off gas (BOG) condensor for marine or land-based applications.