ABSTRACT

This paper discusses an alternate to the commonly used but costly system of locating Liquefied Natural Gas (LNG) loading pumps within LNG storage tanks. The paper proposes safe, side entry nozzles on tanks for piping and pumping systems located outside the tank. This renders the entire pumping system readily accessible for regular operational monitoring, inspection and maintenance purposes. In modern plants, LNG pumps are immersed within pump columns supported from the tank roof. The cost associated with the design, installation and subsequent maintenance of these in-tank pumps can be significant and in-tank pumps do have their disadvantages despite their excellent operating record.

Column mounted pumps require significant structures to support the piping, valving manifolds, the pumps themselves and maintenance (hoisting) equipment. Vibration resistant pump columns, usually designed for relatively high pressure and vacuum conditions are required to contain the pumps. The pumps must be constructed to permit the pump, its motor and power cables to operate immersed in LNG and to be removed from the tank when components require maintenance, which requires special safety precautions to be taken. This paper demonstrates how side entry pump suction nozzles
can be safely and effectively incorporated into the design of double containment LNG storage tanks which are subjected to low temperature service and operational fatigue. With these specially designed side entry nozzles, the pumping systems can be located at grade or in a pit which reduces the heel and thus increases the available net storage capacity.

The paper provides details for the design of the proposed tank wall penetrations through both the inner and outer steel walls (single integrity) and also through outer concrete (double/full integrity) containment walls and demonstrates that these penetrations do not affect the integrity of the tanks and maintains the required reliability of the overall system. The paper also indicates an overall relative cost savings for a two tank 10,000 cubic meter per hour grade mounted LNG loading pump system compared to an in-tank system.

**RESUME**

Dans cette article, les auteurs présentent une alternative pour les pompes de chargement de GNL immergées dans le réservoir, une configuration souvent appliquée mais chère. Les auteurs proposent des connections latérales sûres avec des pompes à l'extérieur du réservoir. Ceci facilite l'accès au matériel pour des raisons de surveillance opératoire, d'inspection et d'entretien. Dans les usines modernes, les pompes de GNL sont immergées dans une colonne à l'aide d’une structure supportée par le toit. Les coûts associés au design, l'installation et l'entretien de ces pompes à l'intérieur du réservoir peuvent être importants et les désavantages de cette configuration sont multiples malgré son excellent record d’opération.

Des pompes installées dans une colonne nécessitent des structures importantes pour supporter les lignes, les vannes, les pompes elles-mêmes et l'équipement d'entretien (équipement de levage). Elles normalement exigent des structures contenant la pompe qui résistent à des pressions relativement hautes et au vide et la construction des pompes doit permettre d'opérer la pompe, le moteur et le cablage électrique immergés dans le GNL et de les enlever quand ils ont besoin d'entretien, ce qui nécessite des précautions de sécurité spéciales. Cet article démontre comment des pompes avec aspiration latérale par le paroi du réservoir peuvent être réconciliées avec le design des réservoirs de GNL à double paroi et sujets à des températures basses et fatigue opérationnelle. Avec ces raccordements latéraux spécialement concus, les systèmes de pompage peuvent être situés à l'extérieur du réservoir à la surface ou dans un puits, ce qui réduit les structures et augmente la capacité nette du stockage.

En plus, l'article donne des détails sur le design de la pénétration de la paroi métallique intérieure et extérieure (single intégrité) et de la paroi extérieure en béton (double intégrité) et il démontre que les pénétrations n'ont pas d'influence négative sur l'intégrité du réservoir et maintiennent la fiabilité requise du système entier. Il contient aussi des économies indicatives pour des pompes de chargement de GNL montées à l'extérieur à la surface de deux réservoirs et dix mille mètres cube par heure comparées aux pompes immergées.
INTRODUCTION

In modern LNG plants incorporating storage facilities, the LNG pumps are generally immersed in the storage tanks and rest on a suction valve at the tank floor. The pumps are located within vertical pump wells or columns. The pumps are removed for maintenance by removal from the pump columns projecting through the tank roof using hoisting equipment located on a support structure on top of the tank as indicated in Figure 1. Although submersible pumps have been proven to work exceptionally well and have excellent safety features, they do have some disadvantages.

The pumping capacity of each pump is generally limited by the maintenance philosophy of the plant and by the size of the pump that can be readily handled by the hoisting equipment on each tank. Each pump requires a pump well within the tank and the discharge piping and valve manifold has to be inconveniently located at the top of a tank on a platform which needs to be designed to support the valving manifolds and the pumps after pump retraction. The additional piping system not only requires supporting from the tank or a structure, but also adds a significant extra cost related to the tankage system as is evident from Figure 1.

FIGURE 1: A DOUBLE INTEGRITY LNG TANK WITH IN-TANK PUMPS

On the other hand, the benefits of a reliable side entry tank suction system can be considerable. External pumps located at grade require less piping and greatly facilitate maintenance. An open pit mounted pump system can also provide the extra benefit of added net positive suction head (NPSH) as measured from the bottom of the tank and may permit the tank to be pumped to lower levels without reducing the discharge rate.

PROBLEMS ASSOCIATED WITH SIDE ENTRY TANK NOZZLES

The tendency in LNG tankage system design in the past few decades has been to move away from side entry tank nozzles. The reliability and technology improvement in column mounted pumps has been one of the key contributors to the increase in popularity of column mounted retractable pumps. Some of the significant considerations in the movement away from side entry tank nozzles has been related to tank wall penetrations and the ability to properly examine these during construction. Other considerations include the requirement for in line nozzle expansion joints between the inner and outer tank walls.
and the inability to examine and monitor these joints and the concern for expansion joint rupture. Also, the National Fire Protection Association (NFPA 59A)² requirement for impounding areas, the consideration of design spills for tanks with penetrations below the liquid level and the concern for line rupture within the piping system provide added momentum to this tendency.

FEATURES OF THE PROPOSED SIDE ENTRY NOZZLE SYSTEM

The nozzle/shell penetration system proposed in this paper for a single or double integrity LNG tank system together with the nozzle expansion joint overcomes the problems that have been partially responsible for movement away from side entry nozzles. Figures 2 and 3 indicate typical 750 mm (30 inch) side entry pump suction nozzles combined with an external expansion joint system. The external expansion joint system is constructed in such a manner that each bellows weld joint is radiographable at the bellows attachment. The main feature of the inner tank nozzle attachment to the tank shell is the thickened (75 mm) shell insert plate in the tank shell at the nozzle location with an extrusion for the nozzle neck as indicated in Figure 4. The internal tank is a 140,000 cubic meter gross capacity tank with a 75 meter internal diameter and a 120,000 cubic meter net capacity. The 9% nickel alloy tank designed in accordance with API 620 Appendix Q³ has a bottom shell course thickness of 37 mm and hydrotest conditions govern the design of the shell courses.

This type of design serves four main purposes. First of all the thickened insert plate provides reinforcement in the shell plate for the nozzle penetration. From Figure 5, which is a finite element analysis (FEA) stress plot of the nozzle penetration (units in Kgm/mm²), it can be seen that the stresses in the nozzle are generally less than the stresses in the shell area away from the nozzle. Under normal operating conditions the tank bottom course plate stress calculated per API 620 is 150 Mpa and under hydrotest conditions, the stress is 300 Mpa. The allowable stresses are 218 Mpa and 307 Mpa respectively. It can be seen from the FEA stress plot, which also accounts for shell discontinuity stresses, that the maximum operating stress intensity adjacent to the nozzle occurs at the inside top surface of the nozzle. This stress intensity is 186 Mpa and is significantly less than the allowable operation stress of 218 Mpa. The nozzle design also needs to be carefully evaluated to ensure that piping imposed loadings and hydrotest conditions do not exceed the allowable stresses imposed for localized loads.

Also, the thickened insert plate is constructed in such a manner that it can be stress relieved after forming and the plate edges are tapered so that all butt welds to the insert plate are no larger in size than the adjacent butt welds in the shell. Secondly, this design permits full radiography of the nozzle piping attachment at the shell which normally cannot be carried out with meaningful interpretation without this type of attachment or an insert forging. Thirdly, the extruded insert plate provides a means for the nozzle stress redistribution into the shell resulting from the operating line loadings within the piping system and also from the differential movement between the internal and external tanks and helps to keep the shell to nozzle intersection stresses at acceptable levels. Finally, the contoured radius geometry of the extrusion alleviates stress concentrations at the shell nozzle neck interface and provides for minimal stress concentration construction which is a benefit in the design against fatigue and for subsequent trouble free operation.
FIGURE 2: PROPOSED SIDE ENTRY PUMP SUCTION NOZZLE FOR A FULL INTEGRITY LNG TANK

FIGURE 3: PROPOSED SIDE ENTRY PUMP SUCTION NOZZLE FOR A SINGLE INTEGRITY LNG TANK
Other important features of the proposed side entry nozzle system are that the expansion joint can be radiographed and ultrasonically tested during fabrication, the bellows system consists of a two ply system with redundancy in one of the plies, the plies can be monitored for leakage with an interply monitoring system, the bellows can be readily inspected and monitored from outside of the tank and if necessary, the expansion joint can be removed from the tank and piping system.

In the past, the design and construction features of process expansion joints did not readily lend themselves to meaningful radiographic interpretation. The two ply stainless steel system expansion joint system indicated in Figure 3 provides a butt weld construction feature at the attachment of each ply to the bellows body which permits the individual ply welds to the body to be able to be radiographed and be ultrasonically tested. Each of the two plies is designed to take the full head of LNG fluid and also the differential movement between the inner and outer tank. The radial movement of the shell of a nominal 75 meter diameter LNG tank is around 90 mm as it cools down to LNG operating temperatures of -160°C. Thus, if one of the plies fails the other ply will still hold against the full hydrostatic head of the tank. An important feature of the bellows is that during normal operation, the expansion bellows is operating under minimal pressure and ambient temperatures.
A further feature of the two ply system is that a vacuum can be pulled on the space between the bellows. This vacuum can be monitored with gauges or a tell tale indicator device which indicates when the evacuated space between the bellows loses its vacuum condition after the rupture of one of the plies or its attachment weld. Thus, monitoring of the bellows can be effectively carried out during the operation of the tank to determine the actual condition of the bellows and even if a rupture occurs in one ply, the second ply acts as a redundant backup to fully restrain any head of LNG fluid. Another feature of the expansion joint is that it can be made removable for maintenance purposes. For removal, the bolting at the external tank to nozzle flange is removed together with the bolting at the front of the nozzle interconnecting the bellows system to the piping. The bellows system can be removed and replaced by utilizing a short section piping spool piece. If required, the entire external bellows/nozzle system can be protected against the impact of flying objects as the result of an explosion as specified in BS 7777 by locating a protective cover system over the nozzle.

**IN-TANK VALVES**

NFPA 59A impounding area rules and design spill requirements virtually mandate the need for in-tank shut off valves at side entry nozzles. The requirements for these valves are that they must provide tight shut-off, the valve must be remotely controlled, it must be quick closing, it must have a means for manual operation and be designed with a special seat that prevents leakage or malfunction due to low temperature distortion.

A valve proposed by AMRI for such a service meeting these requirements is stainless steel butt welded Danais Series butterfly valve. A typical in-tank valve installation is indicated in Figure 6. This valve designed for cryogenic applications achieves leak tightness by a double eccentric kinematic design. The shafts are off-set in relation to the valve axis and eccentric to the pipe axis eliminating the possibility of friction between the disc edge and the metallic seat during operation and ensuring long lasting service and tight shut-off characteristics. The leak tightness of the valve is achieved by a flexible metallic seat which is suitable for an extremely wide temperature range and large operating temperature gradients. Due to its flexibility the metallic seat is self compensating for large temperature changes and the seat self centers around the disc to assure leak tightness.
The valve is normally actuated by a motor operated actuator mounted on the top of the tank. The valve is also equipped with a manual operating feature. Torque to close the valve is transmitted to the valve disc through an actuator stem that is guided internally from the tank wall and is supported by a thrust bearing outside the internal tank insulation. Upper and lower universal joints as indicated in Figure 6 and a dilation/construction device located within the tank account for the tank/valve/actuator relative movement resulting from temperature changes within the tank. A tank roof seal system seals the LNG vapors from exiting to the atmosphere and is designed to prevent icing and malfunctioning of the actuator system.

**COMPARISON OF INTERNAL/EXTERNAL PUMPING SYSTEMS**

The evaluation in this paper is based upon a two tank export terminal with each tank providing a 140,000 cubic meter storage capacity and is based on an LNG loading pump system only. For simplicity, other pumping systems which may be required for the terminal operation have not been included in this cost comparison. The pumping system utilizing the in-tank pumps consists of four 1,250 cubic meter per hour column mounted retractable pumps located within each tank giving a total pumping capacity of 10,000 cubic meters per hour of LNG. While these are relatively large pumps from a handling view point, they are relatively common in export terminals and the pumps can be installed and retracted for servicing without any significant problems.

It is recognized that in a few cases larger in-tank retractable pumps have been successfully used in LNG tank service and have proven themselves in operation. However, larger pumps increase the problems associated with handling the pump during installation and retraction and it is believed that a 1,250 cubic meter per hour capacity is near the limit of the pump size that most owners want to utilize in their tanks from a maintenance view point. On the other hand, suction vessel mounted pumps located at or near grade can be
much more readily handled and serviced because of their location. For this reason, the out
tank pumps used as a comparison in this paper are 2,500 cubic meter per hour suction
vessel mounted retractable pumps located in an open pit.

Figure 7 indicates the basic Piping and Instrumentation Diagram (P&ID) for the
column mounted pumps located within the tank. The nitrogen purge connections for the
column and pump cable seals are omitted for clarity. In this case, four 1,250 cubic meter
per hour pumps on each tank provide a total pumping capacity of 10,000 cubic meters per
hour. Each pump discharges through a 12 inch 300 pound rating stainless steel piping
system into a common 24 inch manifold. The piping system including control valves and
manifold are located on the tank top on a platform supported from the tank wall. The
platform located 35 to 40 meters above grade serves as an operating platform as well as a
maintenance platform when pumps are removed and installed. The top platform also
includes a pair of cantilever hoists as shows in Figure 1 to permit pump installation and
retraction.

In the external pump case indicated in Figure 8, two 2,500 cubic meter/hour pumps at
each tank also provide a total pumping capacity of 10,000 cubic meters per hour. Locating
each pump a nominal 50 meters from the outside of the tank, as indicated in Figure 9,
provides a total suction loss for the suction piping, valves and fittings which is estimated
to be around 600 mm. In this installation, the pumps which are suction vessel pumps are
located in an open pit with the pit base sloping into a local containment area sized to
handle leakages from flanges and small bore piping. The open pit which has a bottom
approximately 1.5 meters below grade slopes into its containment area which is connected
to a storm water drainage system through an LNG/gas trap.

From process considerations, the external pump system concept differs slightly from
the column mounted pump system in that a pump vent line is required for each pump. This
vent line, normally 6 inch in size (increased to 8 inch for two pumps), can tie into the
common thermal relief valve header which discharges into each associated tank vapor
space. Also, the minimum flow control system discharge on each pump can be routed back
to its corresponding tank vapor space by tying into the LNG rundown line on each tank.
This can be achieved by increasing the size of each rundown line from the pump station to
the tank. Accordingly, for the external pump design case, the rundown system should be
designed to allow pump spill back operation.

The advantage of an external pump system becomes evident from Figures 7 - 9. There
is a potential savings of a minimum of 1 meter in tank height with an external pump
system. The in-tank pumps require a nominal static head of 2 meters of LNG above the
pump datum line for start up, and normally, the start up case is used to set the tank
minimum level and the pump trip for protection during pump down. The external pit
located pump is provided its static head by its datum being located below the tank bottom.
The total pump head in this case is 2693 mm as indicated in Figure 9. The external pump
system has a potential of reducing the net height of each tank by one meter since the
minimum tank liquid level (LL) can be reduced from 2300 mm to 1300 mm resulting in
significant cost savings.
FIGURE 7: A TYPICAL P&ID FOR AN IN-TANK LOADING PUMP SYSTEM

FIGURE 8: A TYPICAL P&ID FOR AN EXTERNAL LOADING PUMP SYSTEM

B.8- 10
FIGURE 9: AN ELEVATION VIEW OF AN EXTERNAL DISCHARGE PUMP PIT

It is acknowledged that net storage volume of the column mounted in-tank pump tankage system could be increased by providing a sump in the tank bottom at each pump well or by instrumenting the system so that pumping to lower levels can be achieved by decreasing the pump out rate. Sumps however, are not recommended because settlement, bulging and movement of the tank bottom provide a potential for tank bottom failure at the sump location. Additionally, for in-tank pumps, turndowns are normally maintained at 70%-80% of pump capacity. The controls required become complicated with the number of pumps involved and the potential for pump operational problems to occur upon pump start up and pumping to minimum levels increases significantly as operators are given more options for pump operation. Thus, neither the sump mounted pump nor the instrumentation option for increasing net tank capacity are considered viable for safe tank operation.

COST DIFFERENTIALS BETWEEN INTERNAL AND EXTERNAL PUMP SYSTEMS

Table 1 provides a tabulation of the cost of differences between the internal and external pump systems. The self explanatory table provides the cost of individual components of the two different pump systems based on a total of two tanks. In each case the total cost for the pump system component is indicated. However, for the additional one meter height of the LNG tank with the four in-tank pumps, only the incremental tank cost is included.

It can be seen from Table 1 that the installed cost difference between the two loading pump cases is approximately US $5.1 million dollars. Thus anticipated savings in the range of $4 to $6 million dollars may be achievable in a two tank export terminal with a total bulk capacity of 280,000 cubic meters loading at 10,000 cubic meters per hour utilizing four externally mounted 2,500 cubic meter per hour pumps. A slightly higher net savings may be realized by the use of multiple suction nozzles to reduce the effective distance between the tank bottom and the top of the tank suction nozzle.

B.8-11
TABLE 1: COST COMPARISON OF INTERNAL AND EXTERNAL PUMP SYSTEMS FOR TWO DOUBLE INTEGRITY LNG STORAGE TANKS

<table>
<thead>
<tr>
<th></th>
<th>Four In-Tank Pumps</th>
<th>Two External Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pump System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps Including Spare</td>
<td>$4,590,000.00 (9)</td>
<td>$3,375,000.00 (5)</td>
</tr>
<tr>
<td>Columns/Roof Penetrations</td>
<td>$1,600,000.00 (8)</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Piping System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piping/Fittings</td>
<td>950,000.00</td>
<td>1,800,000.00</td>
</tr>
<tr>
<td>Control Valves</td>
<td>72,000.00</td>
<td>48,000.00</td>
</tr>
<tr>
<td>Other Valves</td>
<td>664,000.00</td>
<td>900,000.00</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>84,000.00</td>
<td>44,000.00</td>
</tr>
<tr>
<td>Insulation</td>
<td>446,000.00</td>
<td>538,000.00</td>
</tr>
<tr>
<td><strong>Impounding Area (Additional) Tank</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Tank Height</td>
<td>N/A</td>
<td>75,000.00</td>
</tr>
<tr>
<td>Tank Side Nozzles (4)</td>
<td>N/A</td>
<td>792,000.00</td>
</tr>
<tr>
<td>In-Tank Valves (4)</td>
<td>N/A</td>
<td>396,000.00</td>
</tr>
<tr>
<td>Platforming</td>
<td>700,000.00</td>
<td>200,000.00</td>
</tr>
<tr>
<td>Tank Hoists/Pit Monorail</td>
<td>800,000.00</td>
<td>120,000.00</td>
</tr>
<tr>
<td><strong>Pump Pit/Containment Area</strong></td>
<td>N/A</td>
<td>60,000.00</td>
</tr>
<tr>
<td>Totals</td>
<td>$13,446,000.00</td>
<td>$8,348,000.00</td>
</tr>
</tbody>
</table>

**SUMMARY**

This paper has indicated that side entry nozzles on LNG tanks can be designed and fabricated to provide safe LNG operation. With side entry nozzles, in-tank valves should be used to comply with NFPA 59A impounding area rules and design spill requirements.

The paper proposes a tight sealing cryogenic butterfly shut-off valve for this service with a tank top mounted valve actuator. The design of the shell nozzle penetration is accomplished by an extruded integral reinforcement plate which not only provides shell reinforcement for the penetration but also redistributes piping loads back into the tank inner shell and provides a fully radiographable nozzle to shell attachment weld. The expansion joint system proposed for connecting the inner tank to the outer concrete or steel tank is also a radiographable two ply bellows system with an interply pressure monitoring system to monitor the full integrity of the bellows at all times during operation. The proposed side entry nozzle system incorporating an in-tank valve and an external pump system provides a safe alternate to a column mounted retractable in-tank pump system, however, for severe seismic areas a thorough design and hazard analysis of the entire tank and pumping system is recommended.

The paper has provided a comparison of the P&ID’s for both the column mounted and external loading pump cases and has indicated how one meter of tank height can be saved by using a pit mounted external pump system. The paper included a cost comparison between the two systems. The external pump system has the potential of US $4-$6 million cost savings in a two tank export terminal with a 10,000 cubic meter per hour capacity.
REFERENCES

1 LNG Tank picture courtesy of IHI & Osaka gas. IHI carried out the design and construction of the tank and associated piping on this project.


4 British Standards Institute, publication BS 7777, Flat-Bottomed, Vertical, Cylindrical Storage Tanks for Low Temperature Service, 1993.

5 Private Communication from AMRI dated November 6, 1997.

ACKNOWLEDGMENTS:

The authors wish to thank and acknowledge the following:


2 Messrs. W.G. Haesloop and J.H. Goodrich, Jr. of Ebara International Corporation for their assistance with LNG pumps.

3 Mr. T. Gérardin of AMRI Inc. for his assistance with cryogenic valves.

4 Mr. M. Pollok of Senior Flexonics, Inc. for his assistance with expansion joints.