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APPROACH TO A LEAK ON AN LNG TANK BOTTOM

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Summary

A leak on an LNG tank bottom often presents a challenge in identifying its location, type of leak and its cause. This is due to the lack of accessibility and inadequate instrumentation. Safety considerations, however, dictate that at some point, the leak must be repaired and the tank certified fit for service. This paper addresses some of the practical considerations required to prepare materials, manpower and procedures for tank repair.

Introduction

Large liquefied natural gas (LNG) tanks are typically designed for a vapour pressure of the order of 6.9 kPa, in accordance with API 620, Appendix Q [1]. The LNG is contained in a primary container, suitable for the liquid temperature, surrounded by sufficient insulation to maintain the rate of boil-off within the design specification.

An outer tank made out of carbon steel keeps the insulation in position and provides a vapour barrier for the boil-off gas generated in tanks with a suspended deck. The outer shell and roof are exposed to the site ambient conditions. A heating system installed under the outer tank bottom maintains a temperature of approximately 4°C, to prevent the frost line from penetrating the tank foundation. Natural ventilation on elevated foundation slab designs meet the same objective.

A failure in the carbon steel outer tank bottom results in the release of boil-off gas only. The latter circulates from the tank dome space, along the annular space, to the leaking point, for tanks with a suspended deck. Figure 1 illustrates the tank design referred to in this paper. A failure in the primary container bottom results in LNG liquid leakage into the tank bottom insulation. Depending on the size of the leak, the outer tank bottom may be breached when exposed to the cryogenic liquid at −161°C and LNG may be released into the foundations.

Typically, a leak problem on an LNG tank bottom manifests itself by low

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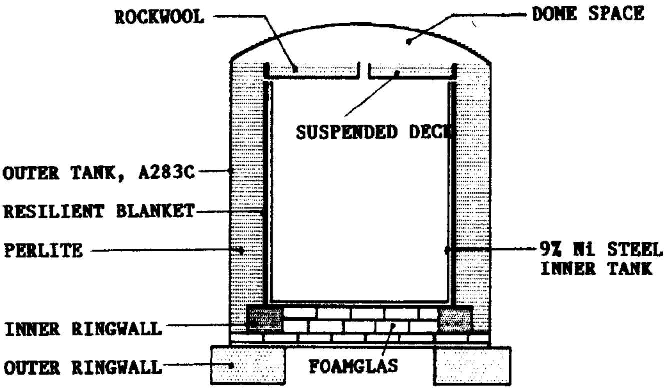

Fig. 1. The 48,000 m^3 LNG tank configuration.

foundation temperature readings. When the carbon steel outer tank bottom is breached, a gas leak is generally present at the outer tank base.

LNG tank integrity

Since the first LNG disaster caused by the brittle fracture of the Cleveland, Ohio, 3.5% Ni stainless steel LNG tank, in 1944, there has been a sustained effort in the LNG industry to improve the safety of storage tanks. On the whole, inner tank construction materials, such as 9% Ni steel, have performed fairly well. In general, LNG tanks with a leak problem are subjected, depending on the nature of the problem, to a strict follow-up pending permanent satisfactory repairs or immediate shutdown.

In some cases, the confidence level in the repairs was not considered adequate and new tanks were built. This is the example of the two 150,000 m^3 LNG tanks on Das Island, UAE. One of the tanks developed a crack in the bottom penetration [2]. The replacement tanks were of the double integrity type, i.e., both the inner and outer tanks are capable of containing the cryogenic liquid. The provision of internal submerged pumps further eliminated all tank penetrations below the liquid level. Most of the LNG tanks built in recent years are of the double integrity type.

Assessment of source and cause of low foundation temperature

The first step in tackling a problem of this type is to effect an external inspection of the tank for any indications of a problem, including checking for flammable gas and carrying out functional checks on the instrumentation to ensure correct temperature readings.

Thereafter, a comprehensive evaluation of the problem is carried out to determine what actions need to be taken:

(a) Should the tank continue to be operated normally under close observation, pending eventual decommissioning for repairs?
(b) Should the maximum operating level be reduced?
(c) Should the tank be decommissioned immediately?
(d) Can the repairs be effected without decommissioning the tank?

Each leak problem determines its own requirements. For the tank referred to in this paper, it was concluded that the tank be scheduled for decommissioning to effect the necessary repairs.

The nature of the problem did not lend itself to pinpointing the leak point. However, from the foundation temperature measurements shown in Fig. 2, it was determined that the problem was confined to the bottom discharge nozzles area.

A weighted fault tree, based on the following items, was developed to address the possible causes:

(a) One of the fabricated discharge nozzles shown on Figs. 2 and 3 developed a crack.
(b) The nozzle to inner tank floor weld failed.
(c) The perlite insulation within the nozzle's pit settled.
(d) The inner tank floor plate or lap joints developed a crack.
(e) The heating system failed or was inadequate.
(f) Because of the bottom fill line penetration through the annular space, condensation of heavy ends may have formed on the outer tank bottom.

Review of the operating history, checks on the heating system, the localized low temperature readings and external observations led to the conclusion that (a), (b) or (d) above was the cause of the low temperature readings.

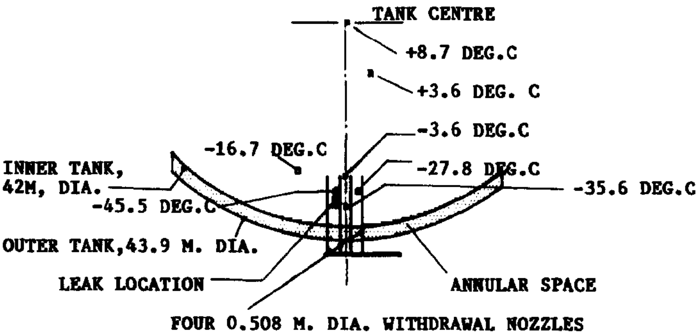

Fig. 2. Sample point temperature readings in foundations and on outer tank bottom (□) as a result of an inner tank floor weld repair failure; (■) leak location after tank entry.

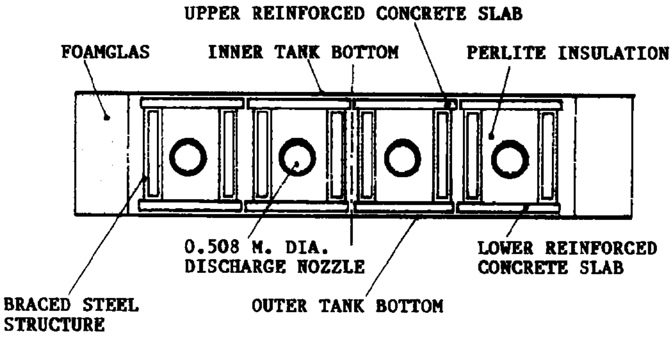

Fig. 3. Discharge nozzles - cross-sectional view.

Repair guidelines

Recertification of the LNG tank after repairs requires a strict control of the repair procedures:

• Every effort should be made to minimize tampering with the inner tank. Every step in the repair program must be preceded by thorough inspections and evaluations, in order to eliminate unnecessary work.

• The inner tank bottom entry and closure shall be conditioned by exacting procedures including:

- Marking and labelling each element removed.
- Recording dimensions and orientations.
- Making a model of the nozzles pit inclusive of all bracing and structural elements for training the repair crew.
- Establishing welding procedures and qualifying welders.

• Control of handling loads during repairs and load distribution on the tank floor during the entire duration of the decommissioning.

Investigative work with the LNG tank in service

The LNG tank operated without any problems for approximately 12 years. After this period the foundation thermocouples began indicating low temperature readings under the discharge nozzles. The temperature dropped as low as $-79\,^{\circ}C$. A sample temperature record is shown in Fig. 2. Externally, there was no evidence of any problem. A survey around the tank outer ringwall and at the entry/exit of the heating and thermocouple cable conduits indicated there was no flammable gas present.

Although the temperature readings varied over a few months, there were no marked variations that could be correlated to changes in liquid head or vapour pressure inside the tank.

Tests on all thermocouples indicated there were no malfunctions.

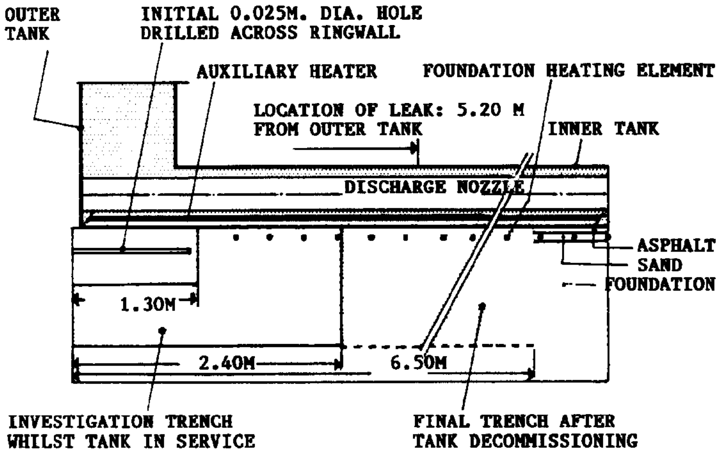

Fig. 4. Foundation investigation.

Since there was no external indication of icing, condensation, or other symptoms of a leak, it was decided to carry out the following:

(a) A 25-mm diameter hole was drilled to over 90% of the depth of the outer ringwall as shown on Fig. 4. The temperature was found to decrease with depth. At 1.10 m depth the temperature was −2.5 °C

(b) Due to the rebar steel reinforcement in the outer ringwall, the drilling was terminated and a trench 1 m deep by 1 m wide was carefully dug under the ringwall. The tank foundations, consisting of a sandy substrate, were found to be frozen inside the ringwall, but there was no evidence of any free ice formation or other indication of frost heave.

The trench was terminated at approximately 2.4 m from the outer tank shell, as shown in Fig. 4. The exposed heating conduits were found to be completely corroded. The absence of any flammable gas suggested that the outer tank bottom was not breached.

A 0.90 m deep hole was drilled into the foundations, at the furthest point of the trench, indicated a temperature of −5.5 °C at 0.50 m below the tank bottom. A thermocouple was installed in this hole, so that the foundation temperature can be monitored during tank warm-up. The trench was temporarily backfilled.

Determination of the scope of repairs

Since the exact cause of the problem could not be determined prior to the tank decommissioning, procurement of materials and tooling was based on the worst case, i.e., one of the discharge nozzles has failed. A quick turn-around requires that materials, equipment and repair procedures are available upon tank decommissioning.

The assumption of a discharge nozzle failure implies a significant repair effort which requires:

(a) Removal of the inner tank bottom plates over the affected area to gain access into the nozzles pit shown in Fig. 3.

(b) Removal of the upper concrete slabs over the bracing in the nozzles pit.

(c) Removal of the fibreglass and perlite insulation in the nozzles pit.

(d) Removal of the steel bracing around the failed nozzle to permit repairs or replacement.

(e) As a contingency for frost heave damage or excessive thermal stresses on the outer tank bottom, in the area directly under the leakpoint, provisions are made to:

- Remove the concrete slabs over the outer tank bottom for inspection.
- Remove the cracked outer tank bottom plates.

(f) Provide adequate Foamglas blocks for replacement in case the outer tank bottom failure extends outside the nozzles pit.

(g) Effect the necessary repairs and testing, and restore the tank bottom to its original state.

(h) The level of planned inspection and repair activities inside the tank led to opting for a lateral opening to permit entry and exit of materials and tooling with dimensions exceeding the diameter of the lower manhole. The access port was positioned and sized, so that it was at least one foot away from any butt weld of the inner and outer shells. Also, to get away from the high stress area of the shell to floor weld joint, the opening was planned on the second course of the inner shell. This led to making provisions for replacement plates to the inner and outer shells.

Inspection upon tank entry

Induced residual magnetism in 9% Ni steel makes the material difficult to weld. Because of this, Magnetic Particle Non-Destructive Testing was prohibited. Magnetic equipment was also not permitted inside the tank. The inspection techniques used consisted of Vacuum Box, Liquid Penetrant and Soap Test.

Because the problem area was fairly well defined, the leak point was identified almost immediately with the Vacuum Box: A weld repair of approximately 25 mm dia, on a floor plate was found to be the cause of the problem. Non-Destructive Testing over the affected area showed no other major defects or failures. The discharged nozzles were checked internally with Liquid Penetrant and pressure tested to the equivalent of the maximum liquid level. All were found to be free of any defects.

Due to the location of the leak point, it was not necessary to disturb the inner tank floor, or make a lateral access for materials and tooling. Tank entry was effected through the lower manhole. Additional tests over the entire inner tank floor and the two lower shell courses did not locate any other penetrating cracks. There remained, however, a question on the integrity of the outer tank bottom due to the excessively low temperatures recorded. The fact that the foundation substrate was frozen may have prevented free escape of leaking gas. After decommissioning, the tank bottom is free of flammable gas and therefore testing for flammable gas is not a useful test.

To test for the possibility of an outer tank bottom leak, the trench under the tank was extended beyond the leak point as shown in Fig. 4. The sand and asphalt underlays beneath the outer tank bottom were removed, and the bottom sandblasted. Dye Penetrant, Soap Tests and visual inspection did not show any defects. Also the bottom plates were not corroded.

Comments on weld defect

The leak was due to an inadequate weld repair in the middle of a floor plate between the nozzle openings and the inner shell. This location was remote from the high stress area of the footer plate to shell weld-joint. The 2.28 m × 6.3 mm thick plate was made of 9% Ni, Double Normalized and Tempered steel. The crack was confined to the periphery of the weld filler metal as shown in Fig. 5. During the first 12 years of operation, the low temperature problem was not evident, suggesting that the crack developed fully at a later date.

The bevelling of the plate surface preparation prior to weld repair is believed to account for crack closure with increasing liquid head, hence minimizing the effect of the hydrostatic head on leakage rate. Thus, temperature variations with increasing LNG level were not detected. Also, the leak point was located away from the joints of the concrete slabs above and under the bracing of the nozzles pit, resulting in the small quantity of leaked LNG being spread over a large area. This may have accounted for the outer tank bottom plate not being breached.

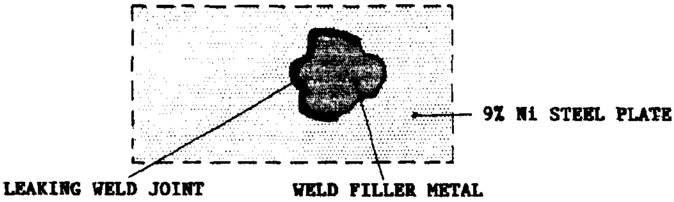

Fig. 5. Inside-tank view of a weld repair leakage line.

Backfill of trench under tank bottom

The confined space within the trench did not allow the backfill to be compacted. A multi-section, double-layered concrete backfill was used, as it met the following criteria:
(a) It must not significantly change the local support stiffness. This prevents introducing a soft or hard spot into the foundations.
(b) It must not produce localized relative settlement between the backfill and the existing substrate, thus preventing the formation of voids.
(c) The backfill must not transfer any bearing load to the heating elements.
(d) The thermal conductivity of the backfill around the heating elements must be as close as possible to that of the installed sand underlay.
(e) The backfill must have minimal shrinkage.
In addition to the above, the asphalt underlay was reinstated over the exposed areas of the outer tank bottom.

Safety considerations

Tank entry after decommissioning, particularly under an air atmosphere, requires special safety measures. Although LNG tank purging principles are well established [3,4], there has been a number of major accidents. Practically all accidents occurred several weeks after tank entry, when safety checks are relaxed or not complied with. The Staten Island, New York, LNG tank explosion on February 10th, 1973 [5], illustrates this type of accident.

For the LNG tank referred to in this paper, extensive safety provisions were put in place inside and outside of the tank, and in the trench. The details of these provisions are outside the scope of this paper. However, it is thought relevant to draw attention to the risk of asphyxia in the trench where nitrogen is used for purging. On this project, during replacement of the heating elements, it was noted that significant amounts of water was present in the conduits. Before any heating elements were installed, the conduits were dried by nitrogen purge. Because the heater conduits were perforated as a result of corrosion, the nitrogen purge was replaced with dry instrument air over the area of the trench.
The decommissioned tank was totally isolated from all process lines.

Conclusions

Although 9% Ni steel has a good notch toughness at LNG temperature, the problem reported herein highlights the need for a strict quality control on plates, repairs and field fabrication.

A careful approach to investigative work on tank bottom leaks can eliminate unnecessary tampering with the inner containment. This approach minimized or eliminates expensive and sometimes unacceptable full proving tests, prior to recommissioning.

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