GAS MIGRATION FROM LNG FULL CONTAINMENT TANKS

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INTRODUCTION
Liquefied Natural Gas (LNG) is stored in large tanks at liquefaction and regasification terminals. Whilst several tank designs are available, the majority of LNG storage tanks constructed recently have been full containment tanks. These tanks consist of:
- primary containment - 9% Nickel steel inner tank;
- secondary containment - pre-stressed concrete structure equipped with thermal protection system (TPS) and carbon steel vapour barrier; and
- annulus space between primary and secondary containment, filled with insulation.
Experience in operation has identified small bubbles of hydrocarbon dissolving through the secondary containment. This has attracted the attention of the Regulatory Authorities, whose concerns include:
- Environment - demonstration that gas migration does not contribute significantly to environmental pollution;
- Safety - demonstration that gas migration could not lead to a fire / explosion hazard and from a mechanical integrity perspective, demonstration that the secondary containment will survive a leakage of LNG into the annulus space.
In this poster, knowledge of the extent of the gas migration issue and implications for the design and operation of full containment tanks is shared.
The role of the TPS in preventing thermal shock on the lower portion of the secondary containment in the event of leakage of LNG in to the annulus space is explained. Finally, the challenges faced by the industry considering the observed emissions and possible ways forward for new and existing LNG facilities are discussed.

OBSERVATIONS FROM OPERATING FACILITIES
Full containment tanks typically include a carbon steel liner, as an integral part of their design, which are specified to be vapour tight. The reason for this is that concrete, which is the material used for the secondary containment, is not gas tight. In spite of this, loss of containment of gas through the vapour barrier has been experienced at a number of facilities. This behaviour manifests itself as low pressure gas passing through the tank walls at discrete locations, gas permeation into the micrometer tubes, and gas migration through the gravel around the foundations. Such occurrences are of concern to the Regulatory Authorities where they require a demonstration that the risks are as low as reasonably practicable (ALARP) - safety from a fire and explosion perspective and emissions from an environmental perspective. Whilst low Methane concentrations are typically detected at release locations, they have been shown to exceed the lower explosive limit. Total gas emissions have been measured up to 25 tonnes per year.
There are several possible paths for the gas to find its way to the concrete structure. Liners are typically made of plates which are welded to plates embedded in the concrete tank. Several kilometres of welds are needed to install the liners. Given that this is not a considered structural element and due to its limited accessibility, the degree of inspection is less than for critical welds, e.g. inner tank butt welds. A Thermal Protection System (TPS) is typically provided in concrete tanks with rigid connection between slab and wall. The function of the TPS is to prevent the lower part of the tank to be exposed to cryogenic temperatures. It consists of 9% Nickel steel plates and insulation which are placed on top of the tanks slab and lower portion of the well. The steel plates on the top of the TPS are anchored in the concrete wall.
The TPS is more robust than the liner and due to its function. It is expected that it is given more focus during design and construction. As a result, no gas emissions would be expected behind it. Nevertheless, observations from the site show that gas emissions are also seen in these areas.

DISCUSSION
The foregoing presents a number of challenges:
- Terminal Operating Company: With regard to gas migration, it is necessary to:
  - review / update the hazardous area classification, identifying the sources and grades of release and extent of the affected area;
  - in addition, it is necessary to demonstrate that electrical equipment is suitable for use in hazardous areas.
This is particularly the case for systems where gas has been detected such as micrometer tubes used to monitor tank settlements and the tank base slab heating system. For the latter, it is possible to use equipment including Nitrogen purging which will exclude air and prevent a reaction of;
- report on the quantities of Methane emitted as part of environmental permit;
- LNG Tank designers / manufacturers: It is necessary to:
  - improve the design and construction techniques such that the secondary containment does indeed exhibit vapour tight behaviour.
  - understand and report the reasons behind the observed gas emissions in operating tanks: are emissions caused by many small defects or few large defects? Are these defects sufficient to allow for gas migration but not for significant leakage of LNG in case of an accidental spill? Given that there is insulation behind the TPS, even if there would be leakage of LNG through the TPS, would the concrete tank experience detrimental low temperatures?
  - assess consequences for the tank integrity and serviceability requirements in tanks having gas emissions.

For new build structures, mitigating measures are: providing a better detailing of the liner and TPS, improving construction follow-up, considering design cases in which the TPS does not provide full thermal protection in case of an accidental spill, ensuring the robustness of the structure by e.g., providing cryogenic reinforcement behind the TPS, etc. Because the TPS is assumed to provide full thermal protection, some designers choose not to use cryogenic reinforcement behind the TPS.

Industry standards focus on performance requirements for the TPS. The top of the TPS, where it connects to the concrete wall, is identified as a focus area. However, there are few, if any, recommendations on how to deal this area to mitigate the potential for cracking and consequently leakage behind the TPS in case of accidental spill.

For existing structures, advanced non-linear FE analysis and laboratory testing could be looked to to investigate the integrity of the tank under scenarios outside the original design basis. When using non-linear FE analysis, realistic yet conservative, analysis assumptions need to be considered based on different load scenarios (mechanical and thermal), material constitutive laws, construction / built-in defects, etc. Validation of concrete modelling for failure modes associated with tensile strength, e.g. shear failure, is fundamental to gain confidence on the results of the analysis.

Laboratory testing is helpful to better characterize material properties of containment components especially at cryogenic temperatures.
Concrete at cryogenic temperatures exhibits increased strength, depending on the humidity conditions, than at ambient temperature. Regular reinforcement, which is not expected to be ductile in low temperatures, may reveal, through testing, better performance than anticipated. Laboratory results for use in documentation of structural capacity shall be considered in light of safety format and design philosophy of the governing standard.

REFERENCES
1/ EN1473, Installation and equipment for liquefied natural gas - Design of onshore installation, 2000
2/ EN14620, Parts 1 to 5, Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C, 2007

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