

SAFE OFFSHORE LNG OPERATIONS



Gutteling

It is important to be able to quantify risks in order to determine LNG behaviour and to ensure its containment. This facilitates comprehensive safety management. Quantitative risk assessments are necessary to enable the selection of preventive and protective measures that suit the situation. Every situation demands a different measure in terms of protection and comfort.

TNO has years of experience in developing intricate consequence models and damage models; in fact, it is one of its core expertises. The models depict such things as how a toxic vapour cloud might disperse or the effect of thermal radiation on a tank filled with compressed liquefied gas. Of course, no reliable assertions can be made until the physical/chemical models have been validated. TNO performs experiments either on scaled-down models or when necessary on a realistic geometrical scale. Our experimental activities include:

- testing and design of explosion safe equipment, venting configurations, blast relief panels and blast-resistant constructions;
- calculation of explosion loads in all possible environments;
- explosion safety audits of process installations;
- accident analysis and consultancy on preventive and protective measures.

PREVENTION AND PROTECTION

Over many years, TNO has built up wide-ranging experience and expertise on energetic materials. Our consultancy and research projects include hazard analysis, thermal stability and runaway reactions, safety during the production, transport, storage and use of hazardous materials, reactivity and compatibility, gas and dust explosions, fire and flammability studies, and deflagrative and detonative behaviour.

SHIP STRUCTURAL INTEGRITY

Our experts use special applications of finite element analysis for the structural assessment of LNG carriers in case of ship collisions. Failure models are based on both laboratory measurements as well as on unique full scale experiments on colliding inland waterway vessels. TNO offers a quantitative approach to the risk assessment by calculating the collision energy required for tank penetration. Combined with information on the LNG terminal environment, e.g. ship types and ship movements in the area, a formal risk analysis of LNG spill can be presented. In addition we monitor the effect of ‘sloshing’ in partially filled LNG tanks.

COLLABORATIVE LNG RESEARCH AND DEVELOPMENT



EXAMPLE RESEARCH JIP: IMPACT OF BOILING LIQUID ON FLUID-VAPOUR-WALL INTERACTION IN LNG TRANSFER SYSTEMS (FLUVAVINT)

New transfer technologies and methods have to guarantee maximum availability without making concessions to safety, reliability and operability in floating LNG Processes. LNG is stored and transported at near to boiling conditions (–162° C and around atmospheric pressure. Pressure and temperature fluctuations can cause vapour (gas bubbles) to develop. This is of particular relevance in corrugated hose/ pipeline systems, where due to the inner profile local pressure and velocity fluctuations occur near the hose/pipe wall, a potential cause for bubbles to form. These vapour bubbles can dramatically affect the flow behaviour and impose operational complications.

Knowledge transfer and cooperation can make development faster, better and less expensive. With its position between universities and industry, it is in TNO’s nature to develop and lead joint-industry (JIP) research and development projects. A newly developed and unique R&D program on LNG technology will be executed in close collaboration with the Industry and the Dutch Universities. The program will be funded with participation fees supplemented with governmental grants. The ambition is to realise a full R&D program with a targeted funding of 15 M€ in a period from 2011 until 2018. The R&D program aims to perform fundamental research which finally will contribute to the further development of offshore and small scale LNG; in addition it will make the LNG industry become even more sustainable.

The interaction between the wall and the boiling liquid at flow conditions is not well understood. Also the influence and effect on boiling phenomena, either positive or negative, on the overall flow is unknown. To gain a better understanding of the fluid-vapour-wall interaction of a liquid in near-to-boiling conditions, in-depth studying and numerical as well as physical modelling will be required. The objective of the project FLUVAVINT is to develop a prediction model of the impact of boil-off gas in LNG transfer on the pressure loss of multi-composite hoses and corrugated piping. Pressure loss prediction so far is based on water flow testing and a limited number of LNG transfer tests as performed by TNO.

A combined numerical/experimental investigation will be carried out on the effect of boiling in pipe flow with both smooth and corrugated walls. This project builds on existing expertise in observing gas bubbles in wall turbulence and in investigating multiphase flow in pipes. The

effect of gas bubbles on the flow in smooth and corrugated pipes will be investigated both by measuring the pressure drop and distribution of gas bubbles in pipes under various operating conditions (gas volume fraction, bubble size, etc.), and by more detailed experiments on the underlying phenomenon’s. The final goal of the project is to obtain a validated prediction model for gas formation in LNG transfer and the impact on pressure loss in corrugated hoses and pipes, throughout the operating envelope.

The 4-year project, which has been started in 2010, is a joint cooperation of TNO, the Delft University of Technology and industrial partners.

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FUELLING THE FUTURE WITH LNG



LNG liquefaction plant of Statoil at Snohvit

TNO innovation
for life

LNG will be playing an increasing role in the coming years to meet the global demand for energy. The security of energy supply, taking into account the decrease of indigenous production of gas in Europe, will drive the import of LNG to supplement the European natural gas grid. With the global availability of LNG and the planned production growth in mind, the interest in using LNG as a substitute for liquid transportation fuels has significantly increased. The development of LNG as an alternative fuel for heavy duty transport such as trucks and ships is mainly driven by the rising oil prices and increasingly stringent emission regulations for marine and road transport.

Growing global demand for gas has also increased interest in monetising gas fields which were previously not economically attractive. The majority of these so-called stranded gas fields are located offshore. Liquefying the natural gas offshore is seen as one of the most feasible solutions to develop these fields. Moving on-shore LNG technology towards offshore poses many technological challenges and will trigger further development of medium size LNG production.

All these developments are bringing new dynamics to the traditional LNG industry. The combination of evaluation, qualification and innovation makes it a challenging environment for TNO. TNO combines knowledge and experience from over 40 years as a research contractor in the oil and gas production and supply chain with a broad spectrum of expertise relevant for state of the art technology.

This makes TNO an independent partner to assist you in innovation, qualification and optimisation of your LNG operations.

OFFSHORE LNG TRANSFER SYSTEMS



Exmar-Excelerate

The ship-to-ship transfer of LNG is crucial for the development of an offshore LNG supply chain. Offloading from a floating liquefaction unit and loading to a floating regasification vessel in all weathers is vital for the availability of these systems and thus to secure the supply of gas. TNO enhances the development of offshore transfer systems by independently proving the reliability of these new systems.

Flexible pipes and hoses for ship-to-ship LNG transfer needs to be qualified by EN1474-part 2. Although this standard EN1474 specifies the baseline for qualification, many issues need to be detailed and new ground broken. Not only the test methods need to be developed, but also rules need to be interpreted and requirements detailed. Together with the complex behaviour of flexible pipes and hoses, this results in challenging projects which are much more than just executing specified tests and comparing results to unambiguous requirements. TNO is capable of proposing a multilevel test programme and

developing models to predict the behaviour of the transfer system. Such an approach provides a better understanding of the behaviour of the transfer system under all possible loading conditions and thus results in greater confidence in the system. In addition, it potentially provides a basis to qualify different hose configurations using a simpler programme.

FLOW DYNAMICS AND MECHANICAL BEHAVIOUR

A part of this extensive test programme focuses on mechanical behaviour: static, fatigue and damage tolerance tests at both ambient and cryogenic conditions. Supplementary to the EN1474 requirements, a multi-level test programme can be performed to better understand the mechanical behaviour. Some flexible hoses appear to have complex mechanical behaviour: elastic non-linear, coupling of deformation modes and hysteresis. The damage tolerance tests, such as impact and crushing beyond the EN1474 requirements, could show the performance of composite flexible hoses during incidents.

Another part of this extensive test programme focuses on the flow dynamics. Full-scale flow tests are performed at ambient (water) and cryogenic (LNG)

temperature. Pressure losses across the flexible hose, maximum allowable flow, modal analyses and pulsation and vibration measurements are included in the flow test. Testing with water at ambient temperature are performed on flexible hoses to determine friction factors that depend on line diameter, hose profile, internal roughness and Reynolds number.

FAST TRANSIENTS

Offshore offloading systems have to function under harsh conditions. Systems should be flexible to deal with the ships moving relative to each other. Moreover the offloading system has to transfer LNG at the highest possible rate, which requires that the equipment has to withstand high flow velocities and pressures. At the same time the system integrity has to be safeguarded effectively so that a spill of LNG is ruled out.

In ship to ship transfer water hammer can occur when the flow is suddenly stopped for instance due to an emergency shut down and there is no time to run down the pumps properly. In that case the valves in the break away coupling, which close quickly to minimize the spill of LNG, will stop the flow almost instantaneously causing a large pressure surge in the upstream and downstream system. The combination of a high transfer rate, which means a high flow velocity and a fast closing valve, may lead to high amplitude shock waves. TNO has investigated the effect of fast transient in offshore transfer systems and offers system dynamic analyses and design evaluation of LNG offloading concepts. The water hammer analyses include the complete piping system upstream and downstream of the ESD system. In view of the possible dynamic loads we recommend to minimize the transients by optimizing the layout of the system in the design phase.

FLOATING LNG PROCESSING



SBM Offshore

The LNG industry has had an excellent safety record for decades; to maximise uptime in the planned offshore LNG supply chain, components must be able to perform continuously, reliably and safely. Expertise on material behaviour, structural mechanics, flow dynamics and safety are valuable to further development of the offshore LNG chain. TNO's expertise and experience in measuring, modelling, testing and optimising installations goes back 40 years.

A current trend is to produce LNG on large floating vessels. One important choice in designing such a vessel is the liquefaction process. Several processes have been developed in recent years, ranging from mixed refrigerants processes, cascade processes and expander processes. Using knowledge and experience from onshore LNG liquefaction plants, the different processes can be rated to the relevance for offshore operations. Little quantitative information is available in the open literature and therefore a large number of questions remain open. TNO has started an investigation with respect to offshore functionalities like small footprint, efficiency, flexibility and robustness, safety, availability, and sensitivity to ship motions.

FLOW AND STRUCTURAL INTEGRITY

Unacceptable pulsations and mechanical vibrations in a gas or LNG process installation may result from flow, even in the absence of compressors and pumps.

For instance, cross-flow may cause vortex shedding on tubes in a shell and tube heat exchanger, in typical piping configurations like flow along closed side branches or corrugated flexible and risers. If unsteady flow excites acoustic or mechanical resonance, high pulsation and vibration levels can occur, and this may affect the pipe system integrity or have an impact on instrumentation like flow meters. TNO has extensive experience in the area of pulsation and vibration modelling and offers a wide range of consultancy services from field measurement, route cause analysis to design evaluation studies which will result in practical solutions.

HEAT FLUX SENSING AT CRYOGENIC PIPES

An important performance parameter for cryogenic pipes such as used for LNG transport is the thermal insulating value. Poor insulation will result in increased boil off. Available pipe insulation test methods are used only above room temperature and not for cryogenic applications. TNO studied the use of large-area heat flux and temperature sensor (HFT) for the evaluation of the insulation value of cryogenic pipes. The HFT is flexible and clamp-on. The test method is relatively simple and can be used in-situ. The HFT makes it possible to monitor insulation performance over elongated times and to study localised effects (thermal bridges).

LNG AS FUEL FOR SHIPPING



Anthony Veder

LNG is considered to be a very suitable fuel for heavy transport over long distances. Using clean LNG as a shipping fuel fits in with the aim of making port, inland waterway and short-sea shipping as well as ferrying and fishing more sustainable. LNG used as a transport fuel is relatively new for the Netherlands; there is almost no infrastructure for LNG supply in smaller quantities for the use of LNG as a transport fuel. TNO helps to get the small scale LNG supply chain off the ground by transfer of technology, investigating the environmental and economic effects and its safety.

As an independent party and in collaboration with the industry, TNO offers the possibility of removing the current obstacles to establishing the chain, such as lack of legislation, unknown permit conditions and absence of a knowledge base for safety and LNG technology. Different cooperation initiatives have already been started. While LNG is in the picture as a transport fuel among both suppliers and end users in the chain, there is yet to be a breakthrough.

LEGAL AND SAFETY ASSESSMENT

In order to consider LNG as a viable option, a number of legal obstacles will have to be overcome. To remove these barriers, governmental authorities are supporting local experimental initiatives to apply LNG as fuel for transport. Although the support of several single projects works out to be very practical, it does not cover legal issues. And, solving legal barriers is a prerequisite to justify investments in LNG supply infrastructure.

In February 2011 TNO started a joint industry project called LESAS with the objective to develop a roadmap towards an optimal small scale LNG supply chain for the Rotterdam area from a safety, commercial, technical and legal point of view based on the long term vision of relevant stakeholders. At the same time possible legal barriers for LNG in the international guidelines, governmental legislation and technology will be outlined. Recommendations will be presented to overcome these barriers. The project partners DNV, NEN and TNO (leading partner) facilitate the process and perform the actual assessment, in part based on input from the participating stakeholders.

ENVIRONMENTAL AND ECONOMIC ASPECTS

A study was conducted to investigate the environmental aspects, and to a lesser extent economic aspects, of using LNG as a fuel for different types of ships. The study was supported by the Dutch Maritime Innovation Program (MIP) and 12 industrial stakeholders.

The investigation focused on case studies for three different types of ships (container feeder, harbour tug and inland ship) which operate from Rotterdam, the Netherlands. The environmental aspects studied greenhouse gas (GHG) and air pollutant emissions. The GHG emission comparison included three LNG chains and three diesel fuel chains (HFO, MDO/MGO and EN590). In addition a limited economic analysis was done, comparing the potential fuel cost savings of LNG with the additional costs of LNG powered vessels.