Case Study

Better management of boil-off in LNG, ammonia and liquid hydrogen storage

BoilFAST is a software tool recently developed by the FEnEx CRC, designed initially to predict and manage the boil-off gases generated during LNG storage and transport. It has now been extended to similarly quantify boil-off gases generated by other cryogenic liquids central to the export of renewable energy, such as liquid hydrogen and ammonia.

The Challenge

Natural gas is commonly cooled to cryogenic temperatures forming liquified natural gas (LNG), reducing its volume to make its storage and transport economically viable. Although tanks containing LNG are highly insulated, it is inevitable that heat will leak in over time, particularly during transfers between storage facilities. Heating causes the most volatile components of LNG such as methane and nitrogen to evaporate, increasing pressure in the storage tank. This collective evaporation is called boil-off gas (BOG) and it is either vented, reliquefied or used as fuel where it is generated. Boil-off gas can account for up to six per cent of the total LNG cargo during ocean LNG transport, depending on the voyage duration and conditions.

The composition of the remaining LNG is also affected by BOG generation, with the proportion of heavy hydrocarbons such as ethane and propane in the liquid increasing. This has significant industrial, safety and economic implications, and can compromise the marketability of the final LNG product after storage or transport.

There has been no accurate way to predict exactly how much BOG will be generated, or the resulting change in LNG composition, because the process is very dependent on the specific geometry and condition of storage tanks, the pressure and the liquid volume level. However, expensive physical infrastructure such as re-liquefaction systems are needed to handle the BOG, and these must be sized appropriately: too small means they won't cope with BOG production, but if they are sized too large the cost can become prohibitive. Until now, the builders of ships used to transport LNG had to rely on wasteful over-design to deal with this uncertainty.

Growing interest in the production and export of zero-carbon fuels, such as ammonia and liquid hydrogen (LH2), is further increasing the need for reliable prediction of BOG. Ammonia is stored at temperatures around –30°C, which is warmer than LNG but no venting can be tolerated given its potential toxicity. Liquid hydrogen is stored at –253°C, 90 degrees below LNG conditions, which makes accurately predicting the amount of BOG to be generated even more important.

The Solution

Current methods for estimating BOG rates for large-scale tanks are entirely empirical and based on limited data, and existing models have only been developed for very specific LNG mixtures and scenarios.

To create a reliable BOG modelling tool, it was essential to first get reliable measurements from real boil-off processes.

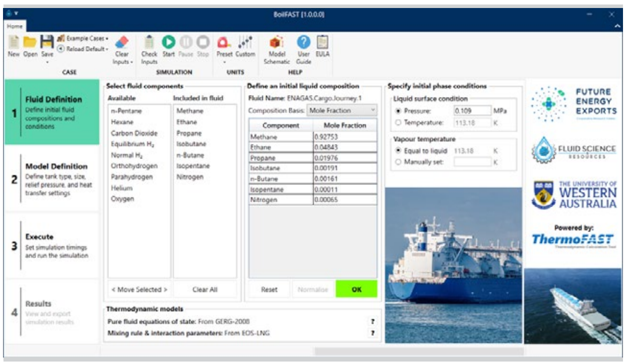
A custom-designed, highly-instrumented apparatus was constructed to explore the effect of heating rate, liquid volume and LNG composition on BOG production and the resultant pressure changes that occur under a wide range of industrially-relevant conditions.

The data generated and understanding gained of the phenomena occurring during boil-off allowed the development of a non-equilibrium heat and mass transfer model, implemented in the new software package developed by FEnEx CRC called 'BoilFAST'.

Predictions of BOG generation and pressure build-up from the dynamic BoilFAST model were in excellent agreement with data obtained from additional laboratory boil-off testing, the limited data available in the literature, and real-world industrial-scale data acquired by Samsung Heavy Industries, the leading manufacturer of LNG bulk carrier vessels.

BoilFAST uses reference equations of state for its thermodynamic property calculations, with heat transfer parameters underpinned by high-quality experimental data obtained for pure fluids. This meant it could then be extended to other liquids including hydrogen and ammonia.

BoilFAST's predictions for LH2 storage in a variety of scenarios were recently tested successfully against laboratory and industrial-scale data acquired at NASA's Kennedy Space Centre.



The BoilFAST Graphical User Interface (GUI) which is used to set up and run simulations using the SHV model.

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Outcomes, Impact and Future Horizons

The BoilFAST software model is freely available at www.fsr.ecm.uwa.edu.au/software/boilfast/.

BoilFAST can simulate boil-off from cryogenic liquids in a storage tank, reliably predicting pressurisation, compositional change and BOG losses. A range of fluid compositions, tank geometries and heat transfer settings can be specified, allowing for the simulation of a wide range of cryogenic storage scenarios, including for LNG, LH2 and ammonia.

Version 1.0 of BoilFAST was released in Q3 2021, and is being tested by industrial participants of the FEnEx CRC. While the model has already been validated against industrial-scale data from Samsung Heavy Industries for LNG transport by ship, testing against industrial-scale data for LH2 and ammonia is ongoing as real-world data becomes available.

Additional capabilities will be added to the BoilFAST software in 2022, including automatic estimations of heat transfer coefficients based on specified tank geometry and insulation.

BoilFAST already accounts for temperature gradients in the vapour phase, and will be extended to also include temperature gradients in the liquid phase (thermal stratification). This is not expected to cause significant differences for small and pilot-scale tanks, but may further improve predictions of the dangerous phenomenon of roll-over in large LNG storage tanks. Simulating cryogenic liquid filling and draining operations is another planned extension.

These improvements to BoilFAST are scheduled to be ready by 30 June 2022 as part of the FEnEx CRC's Commonwealth Grant Milestones.

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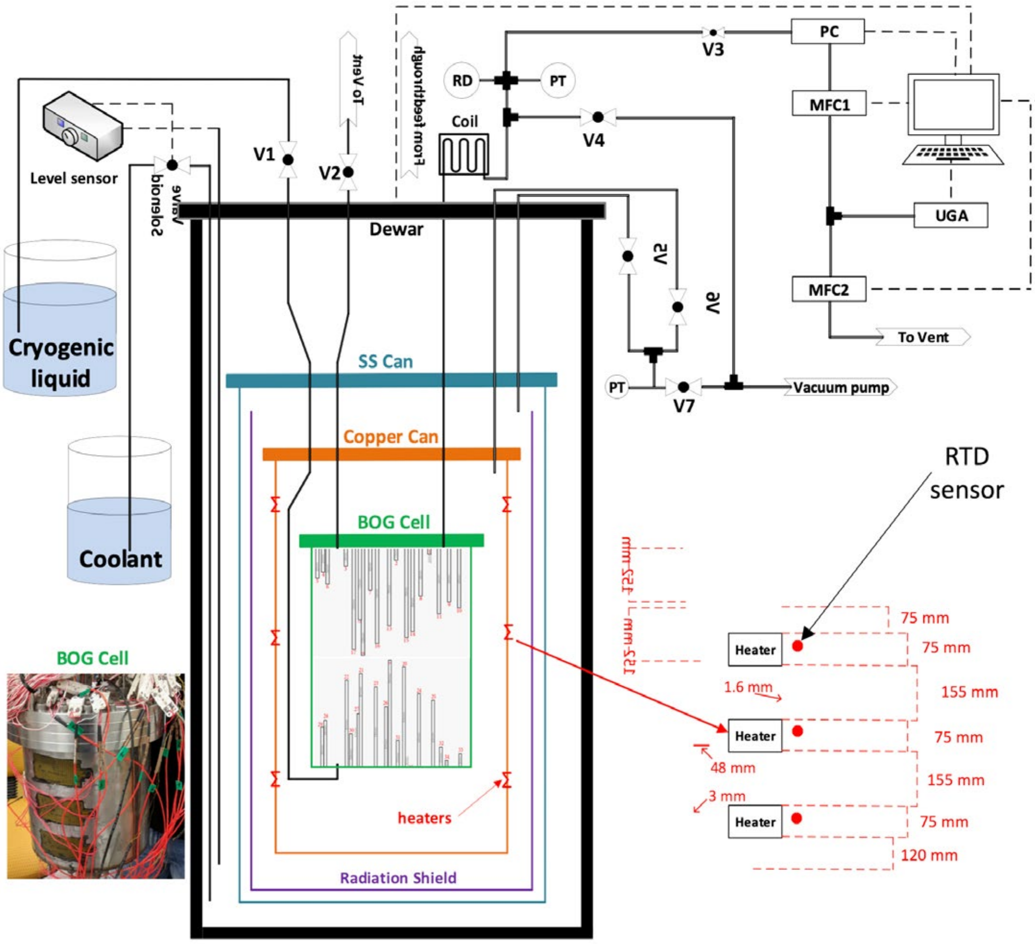

Schematic diagram of the BOG apparatus. MFC: mass flow controller; PC: pressure controller; PT: pressure transducer; RD: rupture disk; UGA: universal gas analyzer.