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Modelling heat ingress in LH2 containment systems –benchmarking improved thermal resistance network models against the finite element method

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Hydrogen is projected to play an important role in the decarbonization of industries that are not readily electrifiable, such as aviation, shipping, and high-energy process industries [1]. To this end, effective solutions for hydrogen transport and storage are needed at a scale far exceeding current capacity. As the hydrogen value chain expands, a wide range of computational modelling tools are required to ensure that the deployed technology is satisfactory in terms of thermo-dynamic efficiency, economic profitability, and safety. In the present work, we discuss and compare two modelling tools designed to predict heat ingress and boil-off generation in liquid hydrogen containment systems.

In the first tool, the finite element method (FEM) is used to solve the steady heat equation on a tetrahedral mesh that accurately represents the geometry of the containment system. This tool, which we have implemented using the open-source NGSolve library [2], provides high predictive accuracy, but it is also computationally intensive. These characteristics imply that the tool is most suited for detailed assessments of the containment system in isolation, as computational cost is then not a critical concern.

For more comprehensive studies, where several value chain components are considered simultaneously, the computational cost of modelling each component must be kept at a minimum. Then, an alternative to the FEM-based tool is desirable. This motivates the second modelling tool we consider: a state-based thermal network model that exploits the analogy between electrical and thermal conduction [3]. In this model, the various components of the containment system are represented by nodes connected by thermal resistances that are computed, e.g., using exact solutions of the heat equation for simple geometries, such as spherical shells and cylinders. With this approach, some local information about the temperature field within the system is lost, but high-level performance indicators such as total heat ingress can still be predicted with reasonable accuracy.

In this work, we present novel augmentations of the network model that significantly improve the model's predictive accuracy without any adverse increase in model complexity. One such augmentation is a semi-analytic estimate of the temperature field surrounding the cold spot at the intersection between the support structure and the outer tank. We also discuss how to handle geometrically complex support structure components such as a connection between a support skirt and the inner tank. The FEM tool is used to provide empirical error bounds for the network model across a range of material choices and support structure geometries. Based on these bounds, we establish that the augmented network model is sufficiently accurate for use in more comprehensive studies of liquid hydrogen carrier ships, including optimization of ship design and reliquefaction capacity. Results from a case study on 40 000 m3 capacity LH2 tanks –conducted in the LH2 Pioneer project (Research Council of Norway grant 320233) –will be presented in order to demonstrate the efficacy of the modelling tools discussed.

References
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