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M1Or2C-02: Performance analysis of insulation materials for LH2 tanks

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Hydrogen is expected to be one of the most promising energy options for future energy generation as it is renewable, is environmentally friendly, and has high gravimetric energy density. Hydrogen can be stored in the form of compressed gas, in materials such as metal hydrides, and in liquid phase. The most efficient way to transport and store hydrogen is in the liquid phase. Moreover, compared to other storage methods, liquid hydrogen (LH2) has significant advantages in terms of energy density and safety. However, owing to the extremely large temperature gradient between LH2 and the environment, heat ingress into the LH2 tanks inevitably occurs, causing evaporation loss. Thus, a special type of insulation system is required to reduce the evaporation loss and the properties of insulation materials for cost-effective insulation systems for stationary applications and offshore transportation need to be analyzed. Although the design code requires the testing of various material properties for the intended service temperature, the performance analysis of insulation materials is performed between the normal boiling temperature of liquid nitrogen (77 K) and ambient temperature (298 K), which is the minimum temperature range in the design code. To evaluate the insulation performance, a thermally guarded horizontal cylinder is developed that advantageously comprises a demountable outer cylinder to easily adapt various types of insulation materials. The main components of the test bed are as follows: (1) inner cylinder (testing cylinder), for which insulation materials are installed and evaluated, (2) guard cylinders, which minimize the heat ingress from both sides of the inner cylinder, (3) vacuum pump system, which can control the degree of vacuum in the annular space up to 10−5 torr, and (4) sensors (temperature, vacuum, and mass flow) and DAQ. The heat flux, temperature distribution, and effective thermal conductivity from the mass flow rate of liquid nitrogen are measured using the boil-off calorimeter method. The results are compared to the effective thermal conductivity data obtained by NASA to prove the reliability of the proposed test bed. To evaluate the mechanical properties of the insulation materials, special types of jigs are fabricated considering the type (bulk, mat, and powder) of insulation material. A custom-built cryogenic chamber with a universal testing machine is used to maintain the temperature during the mechanical test, and the internal temperature is maintained using liquid nitrogen, which can reduce the temperature to 77 K. The materials tested include multi-layer insulation, powder insulation (glass bubble), aerogel blanket, and spray-on foam insulation, which are candidate materials for LH2 tanks. To consider transient effects, such as the sudden loss of vacuum in a vacuum-jacketed annular space, thermal performance data are obtained for the full cold vacuum pressure range (from 5 × 10−6 torr to 760 torr). Furthermore, the thermal performance of different combinations, such as spray-on foam/multi-layer insulation and aerogel blanket/multi-layer insulation, is measured to compare the theoretically and experimentally obtained values.

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