Materials for Liquid Hydrogen Storage and transportation: Current status and future challenges

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Due to the increasing demand for a sustainable green economy with low emissions, hydrogen (H_2) is anticipated to play a significant role in the forthcoming years. It is a clean and sustainable energy source, that is now considered one of the best possible alternatives for fossil fuels, allowing for decarbonization in energy-intensive sectors including long-distance transportation, chemical industry, and mineral processing, while it can be combined with renewable sources for energy storage and addressing inadequacy challenges. The storage and transportation of hydrogen constitutes a critical stage. The main storage methods include compressed and liquid hydrogen (LH_2). LH_2 storage is carried out under cryogenic conditions at -253°C (20K) at atmospheric pressure.

The storage and transportation of LH_2 significantly engages the maritime sector, both as cargo and as fuel using fuel cells. Many feasibility studies have been published in the past for LH_2-operated ships as well as LH_2 tanks. However, as of 2023, the only LH_2 vessel in operation is the Suiso Frontier. It is an LH_2 transport tanker with a storage capacity of 1250 m^3.

Due to the extremely low temperature of LH_2 (20 K), specific materials are required for the construction of storage and transportation tanks. The essential characteristics of materials include resistance to H_2 penetration and superior mechanical and thermophysical properties at cryogenic temperatures. Austenitic stainless steels (304L/316L) are principally the first choice for the construction of the primary barrier in LH_2 tanks due to their reliable performance at cryogenic temperatures.

The use of LH_2 in the maritime sector is accompanied by significant challenges. Environmental issues must be carefully examined, including emissions throughout the entire life cycle of hydrogen. BOG (Boil-Off Gas formation), management of electrical energy on the ship, and the use of cryogenic equipment are among the challenges. Material selection for cryogenic applications, safety issues, and the lack of infrastructure are recognized as critical obstacles to the introduction of LH_2 in shipping. Hydrogen embrittlement is a critical issue concerning the metallic primary barrier and refers to the degradation of material toughness and ductility due to hydrogen penetration. This arises mainly because of the corrugated shape and welding of the austenitic stainless-steel sheets, which leads to phase transformations, resulting in degradation of H_2 permeability. Additionally, cryogenic embrittlement has to be taken into account. These issues must be addressed through research, development, and investment in innovative technologies and infrastructure to ensure the safe and efficient integration of LH_2 into the maritime industry, thus facilitating the transition towards a greener and more sustainable future.