Hydrogen powered propulsion for an offshore crane vessel

A technical and economical evaluation by Gilles Hagen - 2021

The International Maritime Organisation (IMO) has set the goal to reduce the total annual greenhouse gas emissions from international shipping by at least 50% by 2050 compared to 2008. For this reason, shipowners will have to innovate on vessel drive trains and energy systems to reduce harmful emissions.

Hydrogen is considered as a promising solution for this. Gaseous hydrogen poses a tremendous technical challenge however, as it requires a large volume to be stored. To overcome this barrier, hydrogen can be stored in dense hydrogen carriers (DHCs). This thesis performs a technical and economical feasibility study of dense hydrogen carriers as a fuel to power the largest semi-submersible offshore crane vessel in the world – Heerema's Sleipnir.

Liquid hydrogen, ammonia and methanol are identified as feasible dense hydrogen carriers in a 6.5MW drive train on board Sleipnir. The resulting configurations for each carrier are evaluated on technical and economic feasibility, as well as on health, safety, and environmental impact.

First, a technical concept design was made of a possible drive train for each carrier. For the liquid hydrogen, a proton exchange membrane fuel cell was chosen because this configuration emits no harmful emissions and has a high conversion efficiency. Ammonia and methanol can not be directly used in a PEM fuel cell and will therefore be used in an internal combustion engine. Since ammonia has a slow flame speed and bad combustion characteristics, it was decided to combust it in a spark ignite 4 stroke internal combustion engine. In addition, 30% volume hydrogen will be added as pilot fuel to improve combustion in the combustion chamber. Methanol has better combustion characteristics than ammonia and can therefore be burned in a compression ignite 4-stroke internal combustion engine. It still needs to be mixed with hydrogen at a ratio of 10% volume to get a full combustion.

With this design and the efficiencies of the separate components, a heat and mass balance was made to calculate the on-board efficiency and required volume of the fuel tanks for each configuration. While on-board efficiency was similar for all hydrogen carriers (ranging from 43%-44%), the volume of the liquid hydrogen tank must be at least twice that of the ammonia and the methanol tanks in order to store enough energy to comply with the operational profile of the Sleipnir. The required storage volume for the carriers can therefore limit technical feasibility of the system.

Given fuel consumption for each carrier, an economic evaluation was executed and compared with the current LNG system. Ammonia is considered as the cheapest option with a levelized cost of energy in the range of 0.152 €/kwh, which is in the same order of magnitude as the current system. Liquid hydrogen has a levelized cost of 0.195 €/kwh and methanol is the most expensive option at 0.209 €/kwh.

From a health, safety and environmental perspective, liquid hydrogen performs best. Unlike ammonia and methanol, it is not a toxic substance, minimizing safety risks when handling the fuels. In addition, it emits no CO2 and, when used in a fuel cell, no NOx either. Hydrogen does have a higher flammability compared to the other dense hydrogen carrier, but this risk can be mitigated with good ventilation systems installed.

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