A Circular Bunkering Process for Hydrogen-Fuelled Marine Vessels

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ABSTRACT

As the demand for sustainable and alternative fuels grows, hydrogen has emerged as a fuel for marine vessels. However, due to its low gravimetric and volumetric energy density, the use of compressed and liquefied hydrogen is limited to smaller vessels with relatively short trips. More potential is seen with solid hydrogen carriers such as sodium borohydride, as these carriers show advantageous gravimetric and volumetric energy densities, as well as being safer to store and handle. When using solid hydrogen carriers, in the form of granules or powder, as fuel for marine vessels, a 'spent fuel' forms, which has to be stored on the vessel for the remainder of the voyage. To achieve a circular process, this spent fuel will be transported from the vessel's storage tanks to the port's regeneration facility, where it is regenerated to sodium borohydride.

From an operational perspective, both the fuel and the spent fuel have to be stored for at least the duration of one vessel trip. A key challenge lies in the design of the required storage and handling equipment to realize a circular bunkering process, as this highly depends on the (mechanical) behaviour of the fuel and spent fuel. To determine the different material characteristics required to design storage and handling equipment, numerous experiments are being conducted. It is also important to consider the effect of operational conditions, such as relative humidity and temperature, as well as the stress history of the materials, as these conditions can affect the behaviour of the material, leading to malfunctioning of the equipment if not properly taken into account.

Another challenge is related to the hydroscopic nature of solid hydrogen carriers, meaning that they attract moisture from ambient air if the relative humidity is above a certain threshold. If enough moisture is attracted, the fuel starts to react into their spent fuels, producing hydrogen in the process. Therefore, equipment must be designed such that either the equipment is ventilated, the ambient air is sufficiently dry, or the air is replaced by a (dry) inert gas. Also, as the rate of moisture absorption depends on the specific ambient conditions (temperature and relative humidity), equipment designs may vary between different ports.

Aside from the equipment itself, the logistical process compared to single use fuels is more complex. Due to the creation of a spent fuel that is generated an additional flow of spent fuel aside of the fuel has to be accommodated, as not only the solid hydrogen carriers have to be stored and handled on the port and the vessel, but also their respective spent fuels. This results in the need for an infrastructure that enables the supply of fuel and the retrieval of spent fuel from multiple vessels in the port simultaneously. Even more, the infrastructure should incorporate transport of the fuels, spent fuels, or both, between ports, such that fluctuations in demand and supply can be managed.

Consequently, this work addresses the main challenges that arise when using solid hydrogen carriers as a fuel for maritime vessels: unknown characteristics and required capacities of the carriers and their spent fuels, and the infrastructure to manage the fuel and spent fuel streams, both at and between ports. Therefore, a multi-scale approach is required where experimental data, simulations, and logistical analysis are used to provide guidelines for the design of storage and handling equipment and the logistics and infrastructure.

Met opmerkingen [DS1]: circularity of een circulair process

Met opmerkingen [DS2]: consider? (anders heb je in 1 zin 2x 'take into account')

Met opmerkingen [DS3]: and capacities

Met opmerkingen [MB4]: Ik weet niet of dit in de scope past, maar enigzins kijken naar de benodige fuel streams in ports en of er tussen ports transport nodig gaat zijn kan wellicht ook al gezien worden als 'logistical analysis'