Assessment of Net Equivalent Hydrogen Delivered by Selected Hydrogen Carriers

Federica Restelli [a], Elvira Spatolisano [a] & Laura A. Pellegrini [a]

[a] GASP - Group on Advanced Separation Processes & GAS Processing, Dipartimento di Chimica, Materiali e Ingegneria Chimica "G. Natta", Politecnico di Milano, Milano, Italy

E-mail: *federica.restelli@polimi.it*

The expanding global market for hydrogen, driven by the push for cleaner energy alternatives, poses technical challenges regarding its effective and low-cost storage and transport because, under standard conditions, hydrogen has a low volumetric density (0.09 kg/m^3). Hydrogen carriers, such as liquefied hydrogen (LH_2), ammonia (NH_3) and liquid organic hydrogen carriers (LOHCs), have emerged as promising solutions to increase the volumetric hydrogen density through physical or chemical transformations.

An energy assessment is conducted for LH_2, NH_3, and LOHCs as hydrogen carriers. The toluene/methylcyclohexane system is selected as representative of LOHCs. At their typical storage conditions, the volumetric hydrogen density is 71 kg/m^3 for LH_2, 121 kg/m^3 for NH_3, and 48 kg/m^3 for methylcyclohexane. The "equivalent hydrogen" method is applied to convert energy consumptions into equivalent amounts of hydrogen that would need to be burned to power the relevant processes. The net equivalent hydrogen delivered is then calculated by subtracting the equivalent hydrogen consumed from the total hydrogen initially available. This approach allows for a consistent and fair comparison across different carrier systems.

A case study is analysed in which 20000 Nm^3/h of hydrogen have to be stored and transported. Each hydrogen carrier is obtained from hydrogen through a "conversion" process and, after storage and transport, the hydrogen is released through a "reconversion" process. The conversion and reconversion processes correspond to liquefaction and regasification for LH_2, synthesis and cracking for NH_3, and hydrogenation and dehydrogenation for LOHCs. These processes are modelled using Aspen Plus® simulation software to obtain material and energy balances, which serve as inputs for the equivalent hydrogen analysis.

The results show that the net equivalent hydrogen delivered is 11890 Nm^3/h for LH_2, 14190 Nm^3/h for NH_3, and 9960 Nm^3/h for LOHCs. Among the selected hydrogen carriers, NH_3 proves to be the most energy-efficient option for the considered case study. Ammonia cracking is identified as the main energy-consuming process, suggesting that ammonia should be used directly as a fuel or feedstock, when possible, to bypass this step. LH_2 ranks second in energy efficiency, with the liquefaction process being the main source of inefficiency due to the high energy demand for compression within the liquefaction cycles. LOHCs are found to be the least efficient method to store hydrogen for this case, due to the high energy demand for dehydrogenation and product losses caused by the formation of by-products during hydrogenation.

Keywords: *hydrogen carriers, liquefied hydrogen, ammonia, liquid organic hydrogen carriers, energy assessment, hydrogen transport.*