Process simulation of biohydrogen production through sorption-enhanced steam reforming and conventional steam reforming processes

Elshaday Mulu Fetene [a], Maurizio Troiano [a], Roberto Solimene [b] & Piero Salatino [a]

[a] Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale (DICMaPI), Università degli Studi di Napoli Federico II, Naples, P.le V. Tecchio 80, 80125, Italy

[b] Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS), Consiglio Nazionale delle Ricerche, Naples, 80125, Italy

E-mail: elshadaymulu.fetene@unina.it

Abstract

Hydrogen has gained significant global attention for its potential in decarbonizing hard-to-abate sectors. Its production from biomass through thermochemical processes such as steam reforming of pyrolysis oil is emerging as a promising alternative to fossil energy sources. Though promising, biohydrogen production through steam reforming faces challenges such as high reaction temperatures, fast catalyst deactivation and high CO and CO_2 concentrations. Sorption-enhanced steam reforming enables integration of in-situ carbon capture with hydrogen production, thereby facilitating low carbon process and potentially net-negative CO_2 emission. This study investigates hydrogen production, energy demand and environmental impact of sorption-enhanced steam reforming of bio-oil derived from biomass pyrolysis. Moreover, a comparative analysis between sorption-enhanced steam reforming (SESR) and conventional steam reforming (SR) was conducted. Process simulations for both in-line and offline processes, as well as feedstock analysis were conducted using Aspen Plus V10. The process reaction temperatures in range from 300°C to 1000ºC and CaO/C molar ratios from 0 to 4 were studied. Moreover, in-line and offline steam reforming methods were investigated. The study further evaluated CO_2 equivalent (CO_2e) for hydrogen production for each feedstock and process configuration. The maximum products yield was achieved at a CaO/C ratio of 1. In this study, SESR improved the hydrogen yield of the aqueous bio-oil, whole bio-oil and pyrolytic vapour by 50%, 58% and 55% respectively compared to conventional steam reforming. In addition, CO_2 yield reduced significantly by more than 95%. The sorption-enhanced steam reforming process was found to offer energy savings ranging from approximately 40 to 65%, depending on the feedstock and the process used. Life cycle assessment (LCA) showed that the carbon footprint of the net product stream for SESR was in ranges from -0.77 to 0.25 kg_{CO2e}/kg_{H2}, while for the conventional SR process was from 5.1 to 7.6 kg_{CO2e}/kg_{H2}. These results highlight that a significant portion of CO_2 emissions is associated with indirect energy inputs, particularly utilities. The type of feedstock used strongly influences the decarbonisation potential. Overall, the findings underscore the critical role of the sorption-enhanced steam reforming process in enabling carbon free hydrogen production, aligning with global efforts to mitigate and combat climate change.

Keywords: *Hydrogen, Sorption-enhanced steam reforming, Bio-oil, Decarbonization*