Producing Clean Hydrogen Using a Modular Two-Stage Intensified Membrane-Enhanced Catalytic Gasifier

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The paper presents the development and demonstration of a process intensified two-stage bubbling fluidized bed (BFB) gasifier integrated with a hydrogen separation membrane for the production of exclusively clean hydrogen from biomass. A large portion of the syngas is recycled to the gasifier through a highly selective solid-sorbent based CO_2 capture process that produces a sequestration-ready CO_2 stream. By leveraging multi-functional catalysts and highly selective separation technologies for H_2 and CO_2 production synergistically coupled with considerable mass- and heat-integration, the gasifier maximizes utilization of biomass for H_2 production. Our process intensification includes biomass gasification, tar cracking and reforming, water gas shift (WGS) reaction and hydrogen membrane integrated in a single unit operation. By integrating high and low temperature WGS reactions inside the gasifier by leveraging two bubbling catalyst beds arranged in series, H_2 partial pressure is considerably increased thus enhancing the efficiency of hydrogen membrane separation. Furthermore, the in-reactor separation of H_2 shifts the equilibrium of reforming of recycled hydrocarbon towards hydrogen formation. Optimization of the proposed intensified process by developing rigorous and well-validated unit-level and plant-level models plays an instrumental role in enhancing the economics of the process.

In particular, the advantages include: (i) a multi-functional catalyst bed to enhance the gas yield and H_2 concentration in the gasification of biomass using a BFB gasifier, (ii) a two-stage BFB reactor that can produce H_2-rich syngas free of particulate matter and other contaminants, (iii) a highly selective membrane for producing fuel-cell grade H_2, (iv) a selective solid-sorbent based CO_2 capture process that can produce sequestration-ready CO_2, (v) an integrated process with syngas recycle and heat integration that can produce the desired steam and maximize H_2 production, (vi) validated rigorous unit-level and plant-level process models that are used for design and optimization of the modular scaled-up process, (vii) preliminary TEA with quantified uncertainty that can be instrumental in identifying opportunities for future improvement for reducing the cost of clean H_2 production.

The **outcomes** of the resulting engineering innovations include: (a) **>99.9%** purity hydrogen, (b) a sequestration-ready CO_2-rich stream with **>96.5%** CO_2 purity, (c) a process that can generate the entire quantity of steam required for gasification, and regeneration in the CO_2 capture process, (d) a modular and highly intensified system with far fewer equipment items than traditional gasification systems.