Blue H_2 Production using Biowaste derived Combined Sorbent Catalyst Material

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Highlights

- Synthesized novel combined sorbent catalyst material (CSCM) using biowaste-derived CO_2 sorbent
- Synthesized sorbent exhibits CO_2 uptake of ~0.5g/g, which is almost double that of commercial CaO.
- CSCM tested for blue H_2 production through sorption enhanced reforming (SER) in fixed bed reactor.
- CSCM resulted in 98% CH_4 conversion with ~95% H_2 purity and CO_2 capture efficiency.

1. Introduction

According to the International Energy Agency (IEA) report, the global H_2 market demand stood at 92 million tonnes in 2022 and is expected to reach 130 million tonnes by 2032 at a cumulative annual growth rate (CAGR) of 3.58% [1]. Currently, 95% of the commercial H_2 production globally is achieved through conventional steam methane reforming (SMR) process (termed as grey H_2), emitting 12-15 kg of CO_2/kg of H_2. Although SMR is a well-established process, its carbon emission is predominantly attributed to its endothermic nature, severe operating conditions (high temperature, 800-1000◦C and pressure of 20-30 atm), the need for shift reactors and gas separation units such as pressure swing adsorption (PSA), thereby making the process highly energy and cost-intensive.

Sorption enhanced steam methane reforming (SESMR) offers an efficient, and eco-friendly process for high purity H_2 production with in-situ removal of CO_2 using sorbent material along with catalyst in the reformer, which tends to overcome the equilibrium limitations of reforming [2]. Further, the exothermicity of the CO_2 sorption can be utilized to fulfill the exothermicity of reforming. Continuous operation of SESMR requires two inter-connected fluidized bed reactors (FBRs) in a loop with the circulation of catalyst and sorbent materials between them as shown in Figure 1. Despite the significant promise of SESMR for H_2 production, there still exist no commercial technologies due to the challenges associated with the design and synthesis of combined sorbent catalyst material (CSCM) as a single grain which can offer sustained catalytic activity, sorbent capacity with thermal and mechanical stability [3]. Therefore, the present work explores the potential of SESMR to reduce the “3-E” *i.e.,* emission, energy, and expenditure incurred during H_2 production through SMR process. The work involves design, synthesis, characterization, and testing of novel CSCMs endowed with both catalytic and CO_2 sorption capabilities.

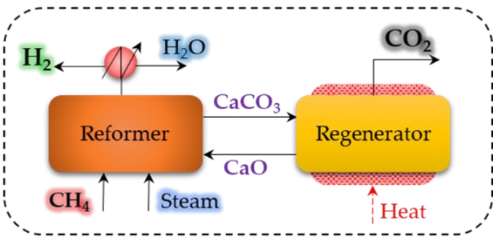

Figure 1. Schematic of SESMR for H_2 production with inherent CO_2 capture using commercial CaO as CO_2 sorbent.

2. Methods

The selection of suitable materials or precursors for catalyst, sorbent, support, and synthesis method is very crucial to develop a highly active CSCMs that is chemically, thermally, and mechanically stable. Several CSCMs were synthesized at IICT using the different CO_2 sorbent (derived from biowastes, naturally occurring limestone, dolomite, hydrotalcite etc.) supported on various materials in conjunction with a Ni-based catalyst derived from different precursors (such as Nickel Nitrate Hexahydrate or Nickle Acetate Tetrahydrate) using various methods (such as wet mixing, wet-impregnation, and sol-gel). The sorbents and CSCMs synthesized were initially tested in thermogravimetric analyzer (TGA) to CO_2 uptake followed by testing of CSCMs in fixed bed reactor of inner diameter ½" and length 40 cm.

3. Results and discussion

The comparison of CO_2 uptake of the sorbent materials and CSCMs is shown in Figure 2.a. The biowaste derived sorbent showed impressive uptake and stability of ~0.50 g of CO_2/g of material over ten cycles, a substantial improvement compared to naturally occurring or commercially available materials (0.25-0.30 g of CO_2/g of material). The TGA results of the CSCMs synthesized using biowaste derived CO_2 sorbent, also revealed superior CO_2 uptake, compared to the ones reported in literature. Further the performance of these CSCMs were tested for SESMR process in a fixed bed reactor at 10g scale, at 650ºC. The results obtained demonstrate the improved performance of the hybrid materials compared to the existing ones in literature, in terms of 98% CH_4 conversion and 95% H_2 purity (Figure 2.b) with ~97% carbon capture. This innovation represents a significant advancement in the field of CO_2 sorbent materials and H_2 production technologies, fostering efficient CO_2 capture and high-purity H_2 generation. The utilization of biowaste derived "CO_2 sorbent and CSCMs" introduces new dimensions to sustainable energy processes, with potential applications across diverse industrial and environmental domains.

The study also highlights the challenges encountered in the synthesis and testing of CSCMs such as catalyst deactivation or decline in sorption capacity arising from prolonged exposure to elevated temperatures, causing both physical and chemical alterations. However, these issues were mitigated by carefully choosing the ideal composition and type of active metal, sorbent, and support, ensuring the uniform dispersion of the active metal and sorbent across the support material.

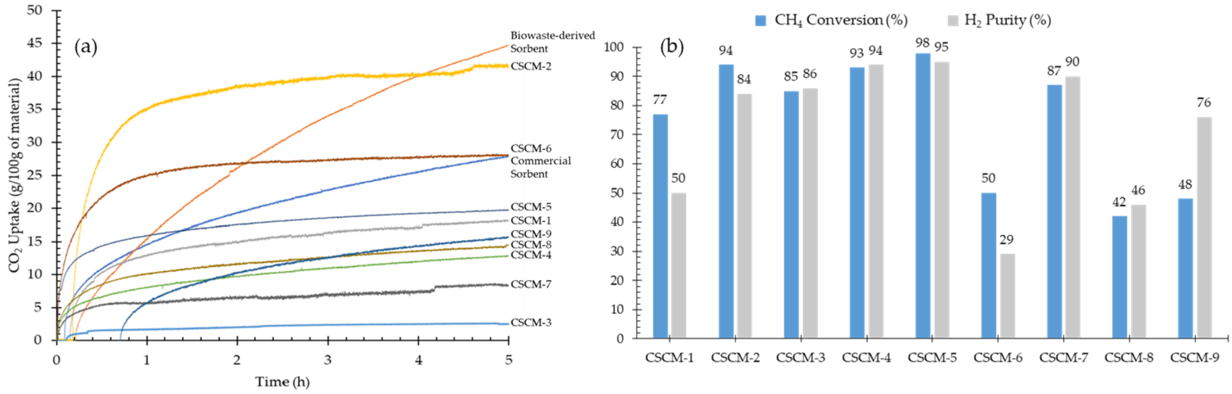

Figure 2. Comparison of (a) CO_2 uptake and (b) performance in fixed bed SESMR process, of different materials

4. Conclusions

The results, challenges, and recommendations presented in this study play a vital role in advancing the synthesis of novel dual functional materials as a single grain that can offer both catalytic and CO_2 capture capability suitable for high-purity H_2 with inherent CO_2 capture through SESMR process.

References

[1] IEA, "Global Hydrogen Review," Glob. Hydrog. Rev. 2023, 2023, doi: 10.1787/cb2635f6-en.

[2] S. Alam, J. P. Kumar, K. Y. Rani, and C. Sumana, "Comparative assessment of performances of different oxygen carriers in a chemical looping combustion coupled intensified reforming process through simulation study," J. Clean. Prod., vol. 262, p. 121146, 2020.

[3] A. Di Giuliano, K. Gallucci, A. Di Carlo, S. Stendardo, C. Courson, and P. U. Foscolo, "Sorption enhanced steam methane reforming by Ni/CaO/mayenite combined systems: Overview of experimental results from European research project ASCENT," Can. J. Chem. Eng., vol. 98, no. 9, pp. 1907–1923, 2020,

Keywords

Blue H_2; CO_2 Sorbent; Reforming