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Exergy and environmental impact assessment of solar photoreactors for catalytic hydrogen production

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HIGHLIGHTS

- ▶ We studied the performance of a new photo-catalytic energy conversion system to produce hydrogen.
- ▶ Two methods of photo-catalytic water splitting and solar methanol steam reforming are investigated.
- ▶ An optimum water flow rate exists for maximum exergy efficiency.
- ▶ A trade-off exists in terms of exergy efficiency improvement and CO_2 emissions of the photo catalytic system.
- ▶ A light intensity range of 530 W m^{-2} < J < 600 W m^{-2} is found to be the optimum light intensity criteria.

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ABSTRACT

In this paper, a new photo-catalytic energy conversion system is analyzed for continuous production of hydrogen at a pilot-plant scale. Two methods of photo-catalytic water splitting and solar methanol steam reforming are investigated as two potential solar-based methods of catalytic hydrogen production. The exergy efficiency, exergy destruction, environmental impact and sustainability index are investigated for these systems, as well as exergoenvironmental analyses. A Compound Parabolic Concentrator (CPC) is presented for the sunlight-driven hydrogen production system. This study shows that an optimum water flow rate exists, where the exergy efficiency of the photo-catalytic hydrogen production is maximized. The amount of CO_2 emissions that are reduced by this process increases at higher flow rates. The light intensity is one of the key parameters in design optimization of the photo-reactors, in conjunction with light absorptivity of the catalyst. The results show that a trade-off exists in terms of exergy efficiency improvement and CO_2 emissions of the photo catalytic hydrogen production system. The optimal working condition of solar methanol reforming to satisfy the exergy–environmental considerations is found to be light intensity range of 530 W m^{-2} < J < 600 W m^{-2} and water–methanol mole ratio of 1.5–2. An optimum methanol feeding rate associated with CO_2 emissions of methanol steam reforming is determined in order to establish the required solar flux for photo-catalytic conversion of methanol to hydrogen.

1. Introduction

The development of new types of photocatalysts for water splitting and hydrogen production by incident visible light has been studied extensively over the past decade [1,2]. Hydrogen is an environmentally benign carrier of energy and has many applications in different sectors of industry. Traditionally, water splitting by photocatalysts in a powder form produces a mixture of H_2 and O_2. Efficient devices are needed for the use of heterogeneous or homogenous photocatalysts to separate H_2 and O_2 in water photo-splitting processes [3].

Yan et al. [4] designed a dual-bed system to produce hydrogen through photocatalytic water splitting. The system was comprised of a photocatalytic reaction bed and a regeneration bed. Aqueous KI solution and Pt-loaded TiO_2 constituted the photocatalytic reaction bed where hydrogen was produced. The hole scavenger iodide ion was oxidized into I_2. The effluent containing I_2 from the photocatalytic bed entered the regeneration bed and passed through a Cu_2O layer where I_2 was reduced to I^-. The regeneration bed effluent was then recycled to the photocatalytic reaction bed.

Solar thermochemical hydrogen production systems based on concentrated solar radiation drive an endothermic chemical transformation by thermal energy input. This process has the advantages of low greenhouse gas and other emissions in comparison with conventional systems such as natural gas steam reforming.

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