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Hydrogen generation in spatially coupled cross-flow microreactors

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HIGHLIGHTS

- A spatially coupled *cross-flow* microreactor is explored for H_2 generation for fuel cells.
- Design guidelines are provided through operating diagrams for both microreactors.
- Cross-flow microreactors showed more stability for lower H_2 throughput.
- Co-current microreactors showed higher operating efficiency at higher H_2 throughput.
- Higher wall thermal conductivity materials are recommended for better stability.

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ABSTRACT

Thermal management of microreactors is very important for process intensification to achieve higher efficiency and for maximum heat utilization. In this work, a cross-flow spatial coupling between endothermic ammonia decomposition reaction and exothermic propane combustion in a microreactor is explored. Unlike the conventional co-current or counter-current reactors, the combustion channels in the cross-flow microreactor are aligned in transverse direction, perpendicular to the ammonia flow direction. The cross-flow coupling mode is parametrically analyzed to delineate the operating region and efficiency of the microreactor. The effect of inlet flow rates of propane and ammonia, reactor wall thermal conductivity on the performance of cross-flow microreactor are studied in detailed, and design guidelines are depicted through operating diagrams, which are quantitatively valid for the reactor dimensions and flow rates simulated in this work. The performance of the cross-flow coupling is compared with co-current coupling in terms of energy efficiency and the range of feasible operating conditions. The results show that energy efficiency of co-current coupled microreactor is higher than that of cross-flow coupled microreactor, whereas cross-flow coupled microreactors show advantages when operating at lower ammonia flow rates (i.e., lower hydrogen throughput).

1. Introduction

Thermal coupling between endothermic and exothermic reactions in a heat exchanger like arrangement is an important route for reducing costs and increasing efficiency through process intensification. Microreactors (with diameter or critical dimension less than 1 mm) are very effective for such applications due to fast heat and mass transfer rates. Hydrogen generation via thermal decomposition of ammonia on Ruthenium catalyst is taken as a representative system in this work [1–3]. The energy requirement for this endothermic reaction is supplied by exothermic reaction. This thermal coupling between endothermic ammonia decomposition and exothermic propane catalytic combustion is investigated in this work. This system has generated significant interest in recent years as CO-free source of hydrogen for portable power generation [1–3].

Various ways of coupling endothermic and exothermic reactions include direct coupling, temporal coupling, and spatially segregated coupling [4]. In direct coupling, both the endothermic and exothermic feeds are mixed and the reactions happen simultaneously on the same catalyst; in temporal coupling the two reactions are separated in time; whereas in spatially segregated coupling, the reactions are separated through a wall. Kolios et al. [5] recently reviewed the merits and demerits of each coupling mode. Not all reaction systems are conducive to the direct and temporal coupling since the same flow channel and catalyst is used for both endo- and exothermic reactions. The other problem is damage of the catalyst and the reactor material due to the hot spot formation from exothermic reaction [6].

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