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Production of hydrogen-rich syngas from methane reforming by steam microwave plasma

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ABSTRACT

Steam-methane reforming (SMR) is most commonly carried out in a catalytic reactor at temperatures from 700 to 1000 °C. During the reforming reaction, the catalyst agglomerates under the high temperatures, showing degradation of catalytic performance with carbon deposition on the catalyst surface. Here, we report methane reforming in a steam plasma generated by microwaves at atmospheric pressure without the use of catalysts. The plasma reforming system is mainly composed of a 2.45 GHz microwave plasma torch and a plasma nozzle. Methane gas is introduced into the steam microwave plasma, which is stabilized by a swirl flow. The steam microwave plasma provides highly active species and a high-temperature plasma flame, enhancing the chemical reaction rate and eliminating the need for catalysts. We investigated the dependence of the hydrogen concentration on the steam to carbon ratio at a given plasma power. Using a specially designed plasma nozzle, we achieved high hydrogen concentrations (>70 vol.%) in the effluent streams.

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Introduction

Hydrogen is one of the most promising alternative fuels for the future. The high-energy conversion efficiency, zero CO_2 and NO_x emissions, wide range of primary sources, and diversity of production methods are the main arguments promoting hydrogen as a potentially important player in the future energy scene [1–4]. However, hydrogen storage is problematic because a very large vessel volume is required. Despite intensive research activities in the field of hydrogen storage, the available technologies (e.g., compressed gas, liquid hydrogen, materials-based) still require improved efficiency [2]. Nevertheless, hydrogen production and purification processes remain essential for the use of hydrogen energy [1,2].

Hydrogen can be produced from a variety of feedstocks. These include fossil fuel resources as well as renewable resources (e.g., biomass, water) with input from renewable energy sources (e.g., sunlight, wind, wave, or hydropower). A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic, and thermochemical. Each technology offers unique opportunities, benefits, and challenges, although each is in a different stage of development. Several technologies are already available in the marketplace for the industrial production of hydrogen [1,5,7].

Currently, hydrogen is mainly produced from natural gas by three different chemical processes: steam reforming, partial oxidation, and autothermal reforming [1–7]. Steam reforming involves the endothermic conversion of methane and water vapor into hydrogen and carbon monoxide. The high temperature requirement (700 to 1000 °C) is often achieved by the combustion of some of the methane feed gas. Partial oxidation of natural gas, on the other hand, is the process whereby partial combustion of methane with oxygen gas yields carbon monoxide and hydrogen. Heat is produced in an exothermic reaction; therefore, a more compact design is possible because external heating of the reactor is not required. Finally, autothermal reforming is a combination of both steam reforming and partial oxidation. The total reaction is exothermic; hence, heat is released. The outlet temperature of the reactor is in the range of 600 to 900 °C [3].

Table 1 summarizes the advantages and disadvantages of the technologies used for hydrogen production from natural gas [3]. Of the three methods, steam reforming shows the highest hydrogen yield because air is not used as an oxidant. On the other hand, it requires careful thermal management and only works on certain fuels. Partial oxidation has an advantage of quick dynamic response with less careful thermal management because the

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Table 1
Advantages and disadvantages of the different technologies used for H_2 production from natural gas [3].

	Advantages	Disadvantages
Steam Reforming	Highest H_2 yield	Requires careful thermal management Only works on certain fuels (sensitive to natural gas qualities)
Partial Oxidation	Quick dynamic response Less careful thermal management	Lowest H_2 yield
Autothermal Reforming	Quick to start Compact due to reduction in heat exchangers	Low H_2 yield Requires careful control system design to balance exothermic and endothermic processes

reaction is exothermic. However, this method displays the lowest hydrogen yield of the three. Finally, the autothermal reforming approach, which combines steam reforming with partial oxidation, achieves both benefits of simple heat management and quick response [1–6]. However, autothermal reforming requires the design of a careful control system to balance exothermic and endothermic processes during changes in the flow rate, as well as during start-up [5], thus, the control system is very delicate.

Steam reforming is therefore the most common and economical method for hydrogen production because of the high hydrogen yield [1,3]. However, this reaction is performed in a catalyst-packed vessel and shows limitations that include containing the

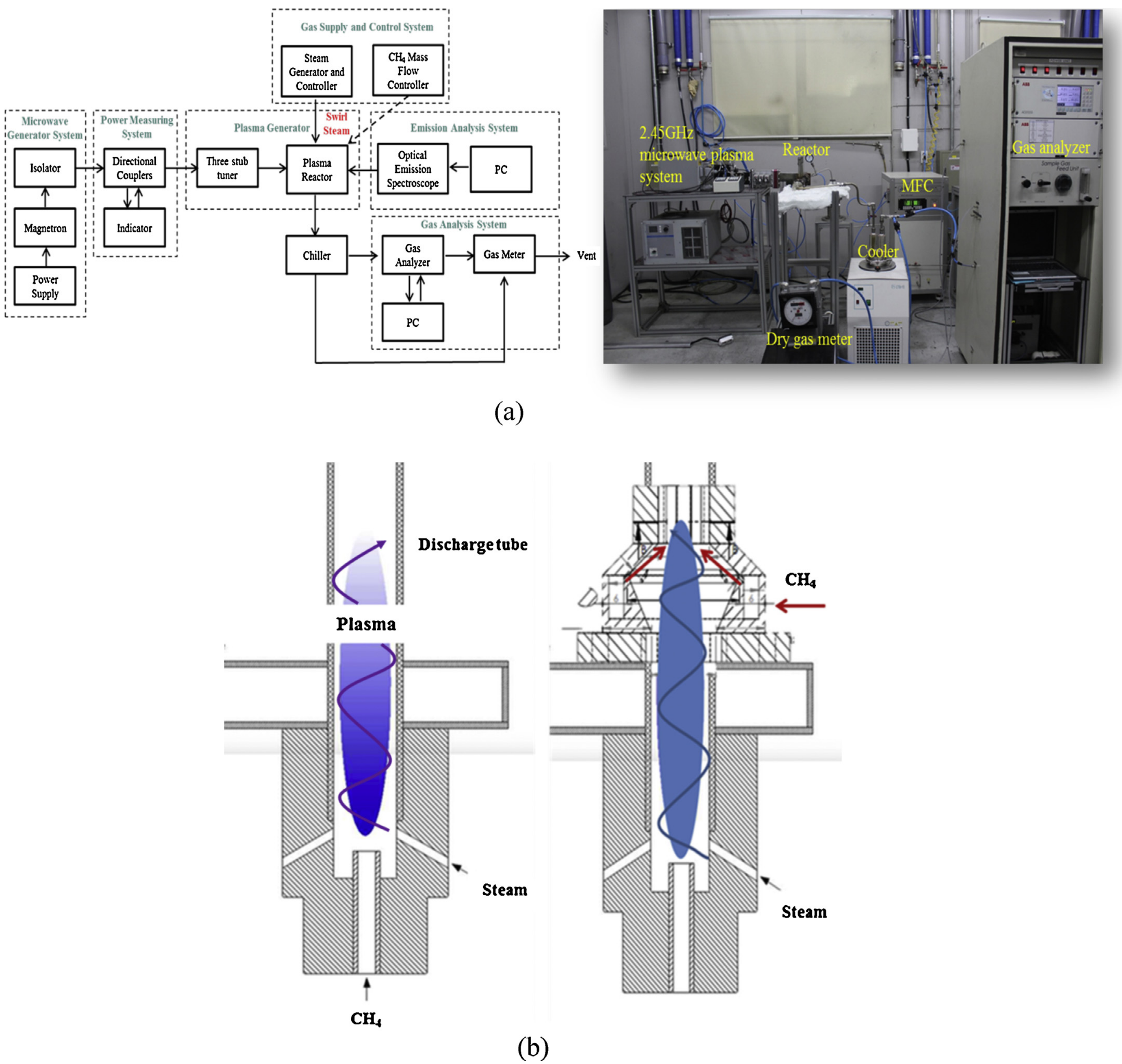

Fig. 1. (a) Steam-methane reforming (SMR) system using microwave steam plasma, and (b) cylinder-type (left) and shoppe-type (right) nozzles used for the SMR reaction.

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