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Superadiabatic flame for production of hydrogen rich gas from methane

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ABSTRACT

The hydrogen-rich gas for fuel cells is normally obtained by reforming hydrocarbon. Reforming inherently possesses problems such as catalyst deterioration, a system complication, and slow responses, which should be addressed by applying simplified and efficient processes to generate hydrogen from various feed-stocks. One solution is recently considered as utilization of the thermal partial oxidation of hydrocarbons by superadiabatic flame under rich and ultra rich conditions without catalyst. In this paper, we present the experimental results on the design of a perforated silicon carbide reformer employing superadiabatic flame and partial oxidation for fuel cells. The reformer (length: 100 mm, diameter: 40 mm) has 31 holes (diameter: 4 mm) separated by 2 mm thick silicon carbide walls. We investigated the effects of hydrogen and carbon monoxide yield for different equivalence ratios and inlet mixture gas velocities. It is found that a perforated silicon carbide reformer with superadiabatic flame plays role of reforming process well and the percent hydrogen yields increases with the equivalence ratio. Under rich equivalence ratio condition the synthesis gas yields varies from 7.47% to 10.20% (hydrogen) and 7.11%–9.20% (carbon monoxide).

Introduction

Hydrogen is considered the fuel of the future because it can provide more energy per unit mass than any other fuel and because it generates minimum emissions when burned and essentially no emissions when electro-chemically converted to electricity in fuel cell systems [1–5].

General reforming methods are classified into steam reforming, auto-thermal reforming, and partial oxidation reforming [6,7]. Steam reforming is an endothermic reaction in which a hydrocarbon fuel is combined with steam over a catalyst at high temperature; steam reforming of methane typically has the highest hydrogen yield on a dry basis. Partial oxidation reforming is an exothermic reaction in which a hydrocarbon fuel reacts with deficient oxygen leading to its partial oxidation into a mixture of carbon monoxide and hydrogen, usually in the presence of a catalyst. Auto-thermal reforming combines steam reforming, partial oxidation reforming, and water-gas shift reaction into a single process [8].

Recently it has become necessary to devise simplified and efficient processes to generate hydrogen rich gas from various feed-stock in order to meet demand for reliable and cost saving generation of hydrogen. One such process is the direct thermal partial oxidation of hydrocarbons by superadiabatic flame under rich and ultra-rich conditions without catalyst [9,10].

Weinberg was one of the first researchers to propose recirculation energy from hot products to unburned reactants to realize a “self-recuperating” reactor [11,12]. The peak

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temperature in these reactors appears to exceed the adiabatic equilibrium temperature, that is why superadiabatic combustion or excess enthalpy flame is called.

Research on superadiabatic flame for partial oxidation reforming, has focused on rich and ultra-rich conditions with high equivalence ratios for premixed combustion using porous media. Many different burner configurations, ranging from porous media burners to Swiss Roll combustors, have been proposed in order to form the superadiabatic flame [13–17]. In those porous combustor, it is known that the ratio of the surface to volume in combustor should be large enough for realizing sufficient heat transfer between the fluid and solid through porous media.

Dhamrat [18], Kennedy [19], and Dixon [20] developed a 2D numerical model to calculate the superadiabatic flame using reticulated ceramics, ceramic foam, or packed beds reformers. They revealed that the porosity of the porous media is an important factor, and higher porosities lead to higher combustion temperatures. In the porous combustor, a single piece of porous media can be used to stabilize a flame, but this is limited by flashback when firing at low rates. Adding a second piece of porous media with a smaller pore size upstream of the first piece is found to acts as a stabilizing holder for the flame and prevents flash-back [21].

Several experimental studies fabricated and investigated a superadiabatic flame reformer using packed beds, reticulated ceramics, ceramic foam of alumina ceramic for synthesis gas production. The experimental work focuses on the investigation of parameters that influence the oxidation behavior in the solid matrix. These parameters included inlet velocity, equivalence ratio, the thermal conductivity and the specific heat of the porous matrix [22,23].

Schoegl developed a reformer for flow channels using superadiabatic flame and partial oxidation [16,24,25]. From his results for channel flow, it is known that combustion in stationary flow channel occurs inside the voids of the solid walls and then energy generated from reaction is transferred to the solid walls by convection from the hot gases. Conduction and radiation through the solid walls, which has much higher thermal conductivity than the gas mixture and additionally significant radiation, distributes some of this energy to the region upstream of the flame. This in turn transfers energy via convection to the incoming reactants. The flow channel acts in essence as an integral preheater.

In the present study, we focused on possibility of the production of hydrogen-rich gas from methane in a perforated silicon carbide reformer. The reformer is 100 mm long, and has a 40 mm diameter with 31 holes, each of diameter 4 mm, separated by 2 mm thick silicon carbide walls. Experimental investigations and the effects of the inlet velocity of premixed gas and the equivalence ratio on the wall temperature, yield of hydrogen and carbon monoxide, and conversion efficiency are experimentally analyzed and also compared to previous calculated numerical analyses results.

Experimental apparatus and method

A diagram of the experimental apparatus used in this study is shown in Fig. 1. The apparatus consists of a perforated silicon

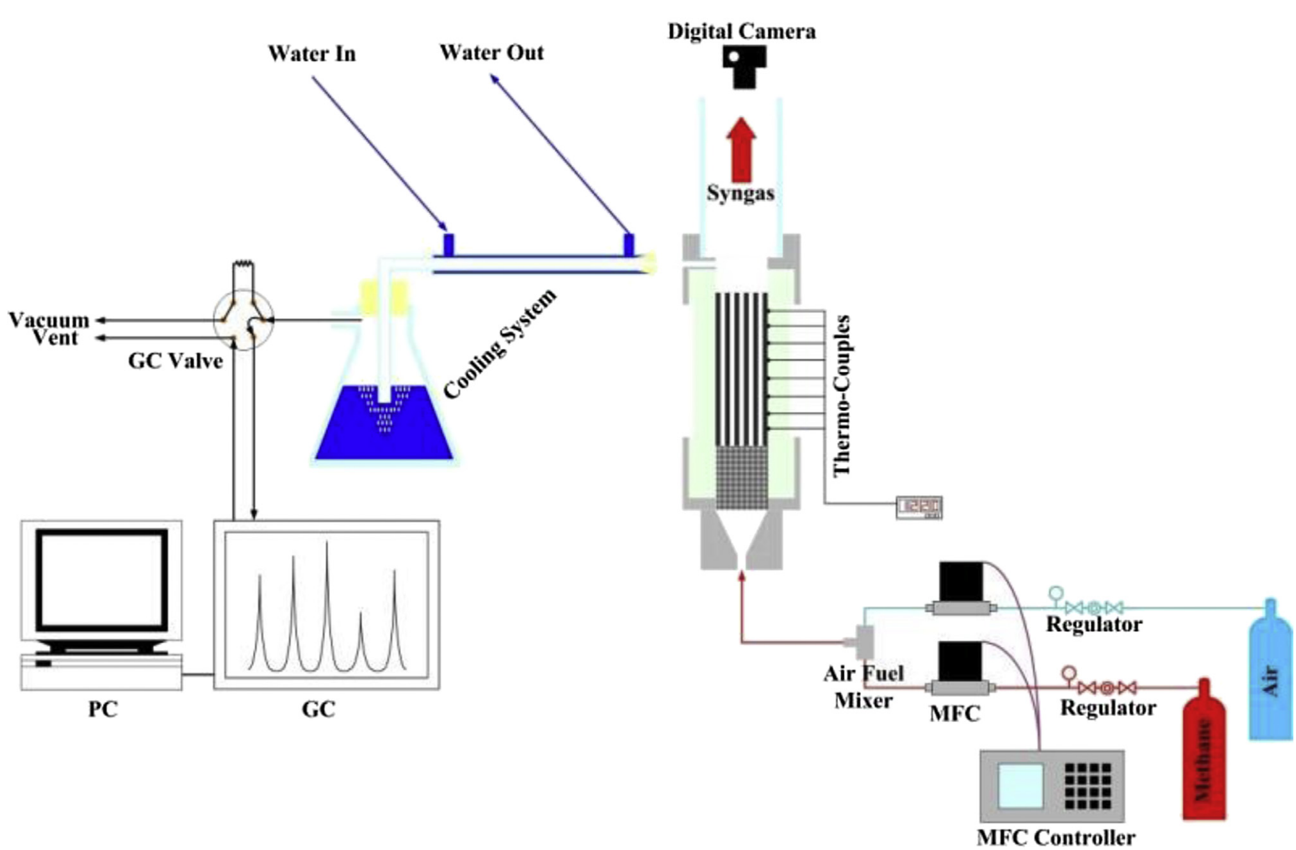

Fig. 1 – Schematic diagram of perforated silicon carbide reformer experimental system.