A Mesoscale Syngas-Burning Multilayer Catalytic-Mesh Combustor

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1 Introduction

Technologies such as integrated gasification combined cycle (IGCC) enable combustion of coal, biomass, and other solid or liquid fuels while still maintaining high conversion efficiencies and low pollution emissions. With sufficient and steady supplying sources, synthetic gas (syngas) derived from coal are particularly promising in this regard. Syngas fuels are typically composed primarily of H_2 and CO, with ratios usually in the range of 0.5 to 2, and may contain N_2, CO_2, H_2O, CH_4, and other higher-order hydrocarbons [1, 2]. Nevertheless, different CO/H_2 compositions in syngas have apparent different flame speeds, flammability, and combustion characteristics [3, 4]. In general, syngas combustion has inherent low energy density so that the flame is usually associated with the problems of low flame temperature, narrow stability limits as well as low combustion efficiencies. Catalytic combustion is a well-known technique to enhance the combustion stability in the fuel-lean conditions, and to extend flammability limit of the low-heating-value combustion.

As regards to the catalyst configurations, wire-mesh catalysts combine both merits of excellent mass and heat transfer performance of a pellet-type catalyst and low pressure drop of a monolith. The effects of pore diffusion during combustion are relatively small due to the shell-like design of the catalyst layer. Thus the catalyst efficiency is considerably improved compared with pellet or monolith catalysts [5, 6]. Besides, effects of catalyst clogging and fouling can easily be handled as wire-mesh catalyst are easy to disassemble and to clean. Wire-mesh catalysts also offer a great flexibility with respect to dimensions which makes retrofit installations easier.

In this study, a multilayer catalytic-mesh combustor is designed and tested. The main objective is to ignite the syngas by minimum energy input leading to stable combustion in fuel-lean conditions. In addition, catalytic configurations (honeycomb and wire-mesh) are compared and characteristic parameters are also examined such as number of layers and distance D between catalytic meshes. Conceptual design and preliminary results are addressed in the following sections.

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2 Concept and Design

In order to ignite the syngas by minimum energy input (conventional spark), the wire-mesh catalyst is utilized in the miniature combustor due to its excellent heat transfer performance. Experimental test indicates that a spark plug can induce a flame in the condition of 6%CO+6%H_2. Once a flame induced by the spark attaches to the catalytic mesh, the catalytic mesh will be heated up quickly and uniformly, and start to react the syngas independently. Figure 1 displays the picture and the schematic diagram of a multilayer catalytic-mesh combustor and its experimental setup. The quartz combustor chamber is made of two pieces of quartz of 25mm in inner diameter, and 10 and 30 mm in length respectively. The catalytic mesh is placed within the flange, and clipped between a flange and a quartz tube. The commercial wire mesh is coated with platinum and its blockage ratio is 48%. Air is supplied from a compressor system whereas, hydrogen and carbon monoxide are supplied from cylinders in order to simulate the main compositions of syngas. Fuel and air are rectified and mixed before entering the combustor. The gas analyzer is used to measure the gas emission and examine the CO conversion, and K type thermocouple is used to measure the temperature distribution near the combustor exit and along the distance between catalytic meshes.

3 Preliminary Results

In order to examine the feasibility of the multilayer catalytic-mesh combustor, different catalytic configurations are examined. Figure 2 indicates the variation of CO conversion with respect to inlet velocity in different catalyst configurations of honeycomb, one layer and two layers catalytic mesh. Results reveal that the catalytic honeycomb has relatively high CO conversion ratio in high velocity conditions, but one layer catalytic mesh has opposite effect. In principle, catalytic honeycomb has relatively high specific heat so that it needs more fuels to offer sufficient energy and to increase its support material's temperature in finite distance of the combustor. On the contrary, high velocity may cool down the wire-mesh temperature so that its CO conversion ratio will apparently reduce. Nevertheless, adding the second catalytic mesh will effectively increase CO conversion ratio. The reason is that hydrogen will be ignited and reacted in the first catalytic mesh, but most carbon monoxide does not. The high-temperature resultant gases from the first mesh heat up the second catalytic mesh, and trigger the catalytic combustion of the second mesh. Two layers catalytic mesh has excellent CO conversion ratio (up to 90%) in both low and high velocity conditions compared to catalytic honeycomb.

Figure 3 indicates the CO conversion ratios of one and two meshes catalyst in different fuel compositions. Two meshes catalyst can enhance the CO conversion ratio in both 4%CO+4%H_2 and 5%CO+5%H_2 conditions, but not in 3%CO+3%H_2 condition due to its low heating value.Besides, the 3%CO+3%H_2 condition is out of fuel-lean limit (4 vol. % for hydrogen and 21 vol. % for carbon monoxide). High temperature can extend fuel-lean limit, but 3%CO+3%H_2 condition cannot provide sufficient heat to maintain stable catalytic reaction of syngas. Furthermore, the distance D between two catalytic meshes is a vital parameter in designing a multilayer catalytic-mesh combustor. Two distances (D=1 and 3 cm) are considered in Fig. 4. Results show that the CO conversion ratio in D=1 cm condition is better than that in D=3 cm. There are apparent differences of CO conversion ratio between two distance Ds in low velocity condition, especially for the 4%CO+4%H_2 case. Low velocity means low rate of fuel supply, and in the meantime has low heat release rate. Sufficient distance D plays an important role to design a high efficiency syngas-burning combustor.

4 Conclusions

In order to design a high efficiency syngas-burning combustor, the concept of a multilayer catalytic-mesh combustor is proposed and tested. It is successful to utilize a minimum energy spark igniter to ignite syngas and to stabilize high-CO-conversion-ratio reaction in different velocities and fuel compositions. Hydrogen is believed to be catalytically reacted in first catalytic mesh and release sufficient chemical energy to trigger the catalytic combustion of CO in the second catalytic mesh. Therefore, carbon monoxide can be stably and sufficiently reacted in the second catalytic mesh. Moreover, effects of different fuel compositions and distance Ds between meshes on the stable catalytic reaction of syngas are also demonstrated.

References

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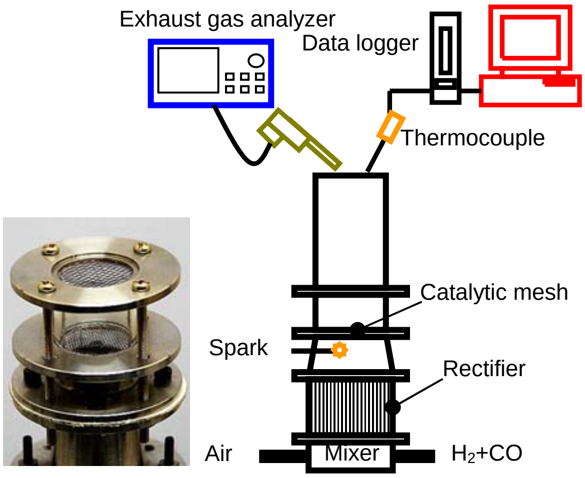

Figure 1. Photograph and sketched diagram of the multilayer catalytic-mesh combustor and experimental setup.

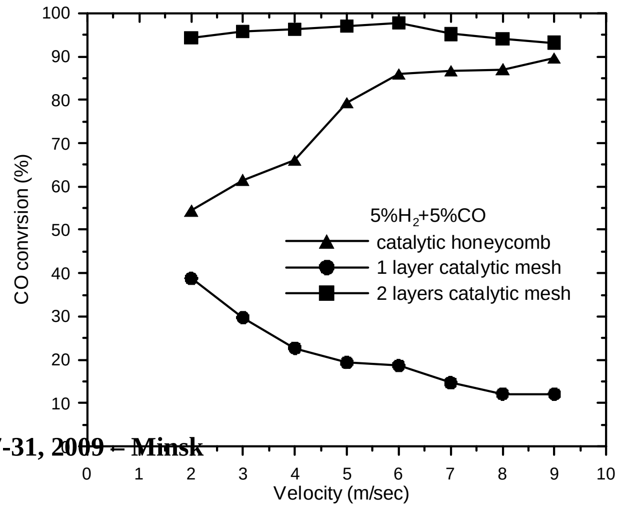

Figure 2. CO conversion ratio in different fuel catalyst configurations.

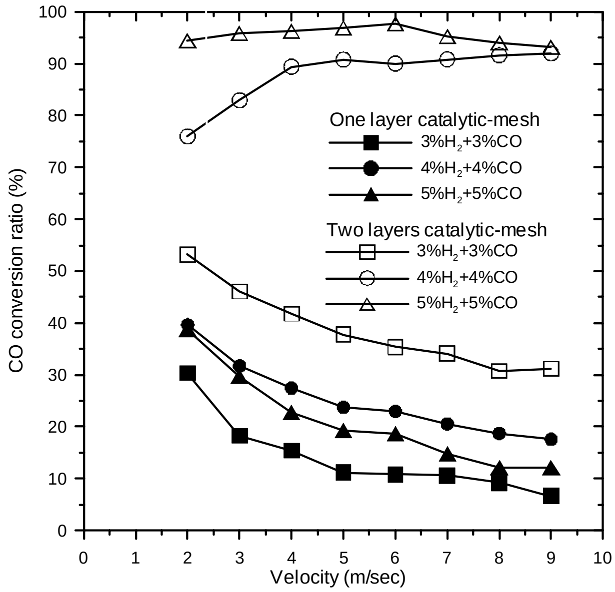

Figure 3. CO conversion ratio in different fuel compositions.

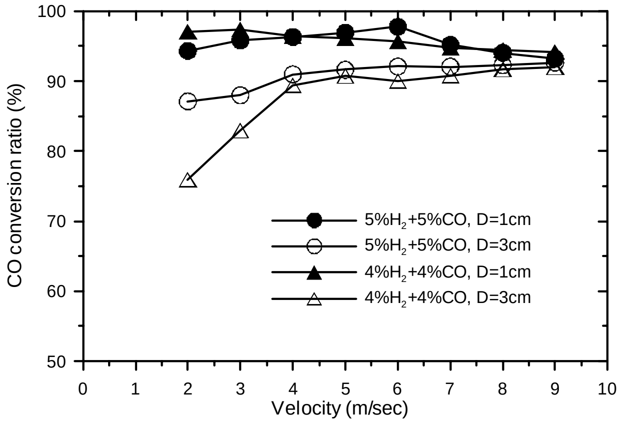

Figure 4. CO conversion ratio in different distance Ds.