Development of Micro Catalytic Combustors

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Abstract

With the growing trend in miniaturization of mechanical systems by using micro-electro-mechanical (MEMS) technology, high energy density (small size, low weight) power generators are required[1]. Miniature mechanical system such as micro air vehicles and micro robots are limited by the weight of the available power system. Currently, most of the power systems used in the micro systems, are batteries[2]. Top batteries available (Lithium) have an energy density about 1.2 MJ/kg. However, typical liquid hydrocarbons have an energy density about 45 MJ/kg. It means a micro combustor with a only 3% system efficiency can compete with top batteries [2]. In this paper, MEMS-scale combustion was studied experimentally using a micro catalytic combustor to examine the feasibility and possible benefits of microscale combustion. The micro catalytic combustion chambers, 1mm wide with 1mm deep, 20mm long and coated with platinum (Pt) catalyst and micro temperature sensor array, were fabricated by using MEMS technology. The 1.0 mm height of the micro catalytic combustion chambers was chosen because this size is smaller than the quenching diameter of gas-phase hydrogen-air combustion [3] and because it is comparable to sizes proposed in many microscale combustor designs. In a typical experiment, the catalyst wall temperature is preheated to either176^{o}C or

260^{o}C, while the inlet composition and mass flow rates of H_2 and air were kept constant. Various air/H_2 ratio (including fuel rich, stoichiometric and fuel lean conditions) with air mass flow rate fixed at 75, 125 and 188 SCCM were investigated by measuring wall temperature distribution along the micro catalytic combustor during testing. Figure 1 shows the photograph of the micro catalytic combustor. In Figure 1, there are total 8 temperature sensors located from the inlet to the outlet on the wall of the micro catalytic combustor. Microscale catalytic reaction was studied as function of preheated wall temperature, total mass flow rate (resident time) and inlet compositions in the micro catalytic combustor. Figure 2 shows the catalyst wall temperature distribution as the preheated wall temperatures is increased from 176^{o}C to 260^{o}C, while the inlet composition and mass flow rate of H_2 and air were kept at. 75 SCCM and 188 SCCM (stoichiometric) conditions. The wall temperature increases dramatically indicating that the heat generation during catalytic hydrogen oxidation is increasing at increasing preheated temperature. The maximum wall temperature occurring at the inlet of the micro catalytic combustor can reaches above 1000^{o}K. Figure 3 shows Pt-catalyzed H_2 oxidation reaction generates huge amount of energy and heats the wall of the micro catalytic combustor to red when wall temperature is fixed at 260^{o}C and the mass of flow rates of H_2 and Air are 75 SCCM and 188 SCCM (stoichiometric condition) respectively. Micro catalytic combustion was further studied as a function of the mass flow rates, while the preheated wall temperature, and inlet compositions in the micro catalytic combustor are kept constant. Figure 4 shows the wall temperature distributions as the total mass flow rate (sum of the mass flow rate of H_2 and Air) is increased from 105 SCCM to 263 SCCM, while the preheated wall temperature and inlet air/H_2 mass flow rate ratio are fixed at 260^{o}C and 2.5 respectively. As the mass flow rate increased (resident time decreased), the average wall temperature distribution of micro catalytic combustor increases, indicating that the reaction time is much shorter than the resident time. The reactants react and generate heat energy in a very short time (<resident time ~ 4.8msec at total mass flow rate 263 SCCM). Figure 5 shows the wall temperature distributions as the H_2 mass flow rate is increased from 37.6 SCCM to 94 SCCM, while the preheated wall temperature and air mass flow rate are fixed at 260^{o}C and 188 SCCM respectively. In Figure 5, the wall temperature distribution does not change between fuel rich (H_2 mass flow rate 94 SCCM) and stoichiometric (H_2 mass flow rate 75 SCCM) conditions, but decreases at fuel lean (H_2 mass flow rate 37.6 SCCM) situation. It indicates that the reaction is reaction-limited. A large fraction of the hydrogen complete the oxidation reaction at total flow rate 282 SCCM (resident time ~ 4.5msec). In the current experimental results, larger heat loss rate relative to heat generation rate resulting in the decrease of the wall temperature from inlet to outlet of the micro catalytic combustor is also noticed. The heat loss problem becomes significant as devices are scale down [3]. Therefore, combustion in micro-scale is possible with optimal thermal and chemical management conditions.

Reference

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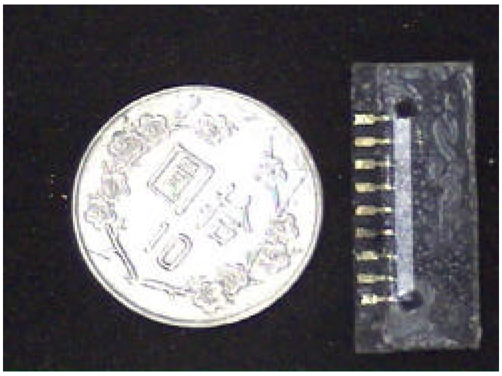

Figure 1 the photograph of the micro catalytic combustor.

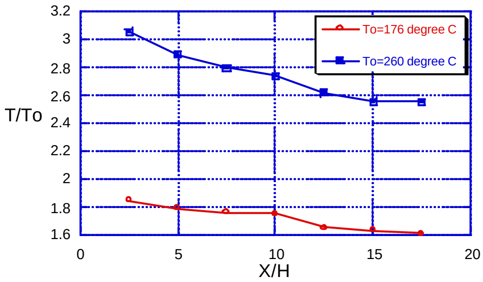

Figure 2 Wall temperature distribution as the preheated wall temperatures is increased from 176°C to 260°C, while the inlet composition and mass flow rate of H_2 and air were kept at. 75 SCCM and 188 SCCM (stoichiometric) conditions.

Figure 3 the photograph of the micro catalytic combustor when wall temperature is fixed at 260°C and the mass of flow rates of H_2 and Air are 75 SCCM and 188 SCCM (stoichiometric condition).

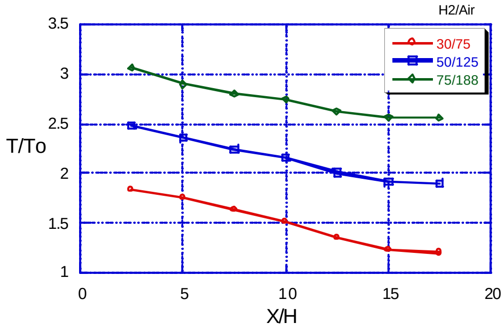

Figure 4 Wall temperature distributions as the total mass flow rate (sum of the mass flow rate of H_2 and Air) is increased from 105 SCCM to 263 SCCM, while the preheated wall temperature and inlet air/H_2 mass flow rate ratio are fixed at 260°C and 2.5 respectively.

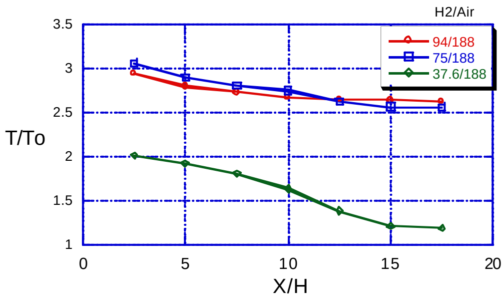

Figure 5 Wall temperature distributions as the H_2 mass flow rate is increased from 37.6 SCCM to 94 SCCM, while the preheated wall temperature and air mass flow rate are fixed at 260°C and 188 SCCM.