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A comparative study on combustion characteristics of methane, propane and hydrogen fuels in a micro-combustor

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ABSTRACT

The combustion characteristics of three hydrocarbon fuels are investigated so as to study the applicability of fuels in a micro-planar combustor. Experiments are performed to analyze the differences in flame stabilization, temperature distribution of external wall and flammable channel-heights. At different equivalence ratios, it is found that the mixture of hydrogen/air has a much wider and stable flammable range. The reaction positions of methane and propane cases will significantly move downstream along with the increase in mixture flow rate. Under the same chemical energy inputs, the external wall temperature distribution of methane case is most uniform, and the average wall temperature is also the highest among the three fuels. When hydrogen is selected as a fuel, the temperature gradient of the combustor wall becomes very large, which is caused by the flame position near the inlet. The flammable channel-heights of the three fuels in the micro-planar combustor are different. It is observed that stable combustion of methane/air cannot be achieved when the channel-height is less than 2.5 mm. However, the minimum flammable channel-height of propane/air case is 2 mm, and hydrogen/air can be ignited in a 1 mm height micro-combustor.[1]

Introduction

In recent years, micro-power generators, benefitting from the advantage of a long operating lifetime, non-moving parts and high energy density have caused wide public concern [1,2]. These devices directly convert chemical energy of hydrocarbon fuels into electricity or power, which is supplied for MEMS (such as micro pumps and micro robots), portable electronics, military devices and vehicles. A micro-power system consists of (1) a heat source (micro-combustor), (2) energy-conversion components, and (3) energy-input parts. However, the micro-combustor is the core component of every micro-power generator. Thus, realizing an efficient and stable combustion process has become the key to improving the performance of the whole system.

Various research works on the structure optimization of micro-combustors have been done within the past decades. In order to preheat the fresh incoming reactants with the outgoing combustion products, the reverse flow reactor designs are commonly employed for heat recirculation. Ahn et al. [3] have found that the reactive limits of propane over platinum

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are broad and cover the equivalence ratio range of 0.2–40 by using the Swiss-roll design. Yang et al. [4] compared the combustors with and without heat recuperation and found that a higher flow velocity and higher H_2/air equivalence ratio will increase the rate of entropy generation. While Federici and Vlachos [5] employed a heat recirculation combustor with two inner parallel plates to increase the blowout limit of propane/air mixture. Yang et al. [6] also proposed the SiC porous media form which was employed in the combustion channel to enhance heat transfer between the hot gas and the wall. Chou et al. [7] compared the performance of a micro cylindrical combustor with and without employing porous media. A micro combustor with a bluff body was developed by Fan et al. [8], which can extend the blow-off limit by 3–5 times. Tang et al. [9] found that compared to a single-passage combustor, the micro planar combustor with parallel separating plates can achieve a higher mean temperature of the radiation wall due to the enhancement of heat transfer. In addition, catalytic method was used to strengthen the micro combustion process. Boyarko et al. [10] tested combustion in platinum micro-tubes with an inner diameter of 0.4–0.8 mm. Chen et al. [11] addressed the combustion characteristics of multi-segment catalysts in a micro-reactor by numerical simulation with detailed heterogeneous and homogeneous chemistries. In addition, Fanaee and Esfahani [12–14] selected hydrogen-air or propane-oxygen as the mixture in a catalytic micro-channel and explored their combustion characteristics.

During the research of each micro-power generator, the authors usually chose different kinds of fuels and oxidants in the micro combustion process. Typically, for the micro-thermophotovoltaic (MTPV) system, Yang et al. [9] used H_2/air as the reactant in a micro-planar combustor, while Pan et al. [15] adopt the mixtures of hydrogen-oxygen. Choi et al. [16] selected methane and air as the mixtures. Park et al. [17] selected C_3H_8/air as the fuel and oxidizer in a heat-recirculation micro-emitter with an annular-type shield. However, different combustion characteristics will be presented when using different fuels and oxidants, but not many comparative studies have been conducted on this front. Demoulin et al. [18] investigated the catalytic combustion of methane, ethane and propane on a Pd/γ-Al_2O_3 catalyst and studied the influence of adding ethane or propane in the feed during the catalytic combustion of methane in a U-shape quartz micro-reactor. An experiment on the combustion of methane, methanol, and ethanol in three micro packed bed quartz tubes with the ZSM-5 zeolite supported nanometer-sized Pt as the catalyst was performed by Deng et al. [19]. In the condition of micro-scale, the combustion process of fuel may present very different characteristics compared with conventional scale combustion, which is subjected to the problems of short residence time and large heat loss. Obviously, most of the researches comparing micro-combustion characteristics among fuels are mainly focused on the catalytic reaction due to the advantages of catalytic combustion. However, the research on gas-phase reaction comparing fuels needs to be further improved, especially when it comes to the comparison on the flammable range, external wall temperature and flammable channel-height.

In order to contrast the micro-combustion characteristics of different fuels, a micro-planar combustor is designed. Methane, propane and hydrogen are selected as fuels, and air is chosen as the oxidant. The basic characteristics, combustion limit, and scale effect of different fuels are obtained by an experimental method, which can provide references for further fuel selecting processes of micro-power generators.

Experimental set up

Fig. 1 shows a schematic diagram of the experimental platform. It consists of a gas feed system, a mixing chamber, a micro-combustor, and the temperature measurement instruments. At first, the fuel (methane, propane and hydrogen) and oxidant (compressed air) will have their pressure reduced via the two valves and then flow into their respective micro flow meters. Purities of methane, propane and hydrogen in this study are 99.99%, 99.0% and 99.5%, respectively. Following this, the two gases will flow into a mixing chamber so as to realize a uniform mixing, and will then be injected into a micro-combustor. The mixture is ignited at the exit of the micro-combustor, and then the flame retreats into the micro-combustor and finally realizes a stable combustion state. The

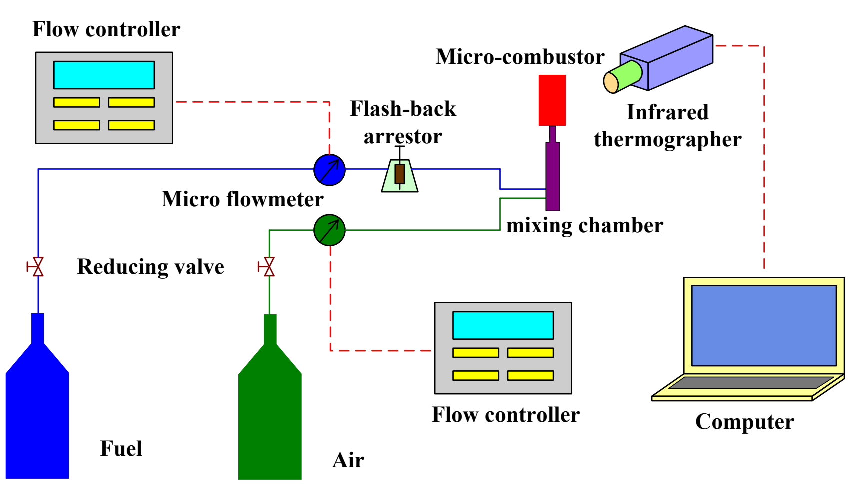

Fig. 1 – Schematic diagram of micro-combustion test platform.

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