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Combustion characteristics of a small-scale combustor with a percolated platinum emitter tube for thermophotovoltaics

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ABSTRACT

A small-scale combustor is one of the most important components in developing the small-scale thermophotovoltaic (TPV) power systems. In order to enhance the flame stabilization and to have a bright incandescent emitter, a platinum tube is used to serve as an emitter. However, a bright incandescent emitter is limited by the operating range of flow velocity and fuel concentration. In the present study, a novel combustion chamber design is proposed to overcome the critical heat loss and flame instability by using a percolated platinum tube as catalyst, emitter, and flame stabilizer. Besides, approaches of delivering fuel/air mixture inside and outside of the catalyst tube can meliorate the heat loss from the chamber wall. Experimental methodology is performed to verify the performance of the proposed percolated-platinum combustor as compared to a plain platinum combustor. In the plain platinum tube the flame only can be stabilized on the backward-facing step inside the tube, but in the percolated platinum tube the flame can be stabilized on the percolated hole inner and outer the tube. It appears that the catalytically induced combustion could be anchored on the percolated-platinum combustor in various conditions of fuel/air distribution and inlet flow velocity, and in the meantime could heat up the chamber wall to incandescent condition. Concept, design, and demonstration of the combustor are addressed and discussed in the paper.

1. Introduction

The concept of miniaturizing conventional power and energy generation systems for increasing demand of personal power is mainly motivated by the fact that hydrogen and most hydrocarbon fuels have much higher energy density than the most advanced lithium-ion batteries. Dunn-Rankin et al. [1] proposed the idea of personal power system, and suggested the human-compatible power density spanning from 10 to 1000 W/kg. Chia and Feng [2] summarized the promising miniaturized mechanical devices which have great opportunities for micropower generation. It included the micro gas turbine and rotary engine, the micro thermoelectric device, the micro fuel cell, the micro electromagnetic system, and the micro thermophotovoltaic power generator. For example, Whalen et al. [3] developed the P3 micro heat engine, and Khu et al. [4] proposed a thermodynamic model for determining the theoretical limit of power performance of micro heat engines. Kima et al. [5] implemented the Swiss-roll structure in a micro combustor to stabilize the flame, and utilized as heater. Vican et al. [6] designed the micro reactor and assembled in the microelectromechanical system.

Micro-scale combustion has been considered as the higher-density power supplies for the power demand. Nevertheless, combustion-driven thermophotovoltaic (TPV) power generator is one of promising approaches to simultaneously harvest electric power and heat output. Because it does not involve any moving parts, its fabrication and assembly are relatively simple and easy. Accordingly, research interest in combustion-driven TPV power generator has received intensive attention recently. Similar to the conventional TPV system, the small-scale TPV power system consists of a heat source, a small-scale emitter, namely a small-scale combustor, and a photovoltaic cell array. Li et al. attempted to convert flame radiation into electrical output via photovoltaic cells

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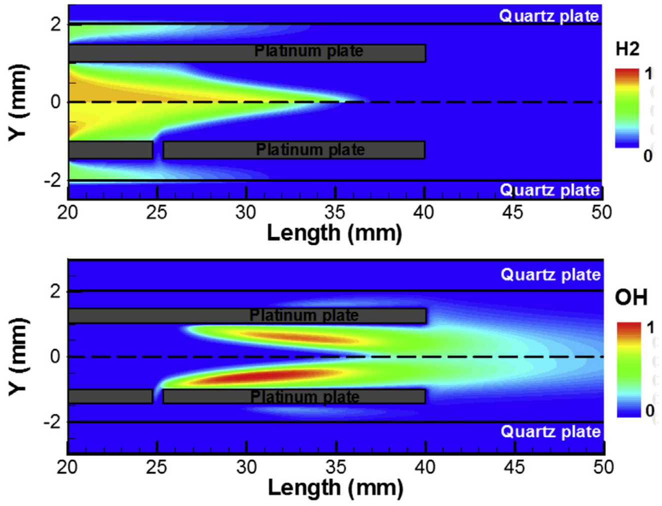
[7], to add iron pentacarbonyl into liquid hydrocarbon fuels for enhancing flame radiation [8] and to coat metal oxide layer on a quartz tube for improving radiant efficiency [9]. Li et al. [10] and Yang et al. [11] proposed a hydrogen-fueled micro-TPV combustor, and used backward facing step as flame stabilization mechanism. Besides, Yang et al. [12] tested different emitting materials for enhancing radiant efficiency. Park et al. [13] demonstrated a micro-TPV system with a heat-reciprocating and produced 2.4 W with an overall efficiency of 2.1%.

Undoubtedly, the high surface-to-volume ratio of a small-scale combustor could lead to increasing heat loss to the surroundings and the possibility of radical termination on the wall. These effects may greatly reduce flame stability and fuel conversion efficiency in a small-scale combustor. In order to extend the stable operating range of a small-scale combustor, the utilization of quenching-resistant fuel, such as hydrogen [14], and catalytic materials, such as noble metals, in a small-scale TPV system has been considered as a promising manner to alleviate the above mentioned shortcomings. Since catalytic material is an important reaction enhancer for small-scale combustor, a novel concept is proposed here to use platinum, a noble metal, as the catalyst and the emitter for the small-scale TPV system. Besides, platinum is not only a catalytic material, but also a selective material [12]. The spectrum of illumination from platinum is prone to congregate in shorter wavelength region due to its larger emissivity in this region. Furthermore, it is much easier to manufacture a platinum emitter than the other selective emitters such as micro-machining tungsten and rare-earth oxide. For the quenching-resistant property, hydrogen is a promising fuel candidate for small-scale TPV power system due to its inherent large thermal diffusivity and high sticking coefficient to catalyst. Furthermore, hydrogen is a high-energy-density and quenching-resistant fuel. Therefore, hydrogen is a candidate for applying in micro-TPV power system. Platinum tubes [15] and channels [16] are often used as a catalyst for hydrogen-fueled small-scale combustors. Boyarko et al. [17] and Volchko et al. [18] applied a micro platinum tube in micro-propulsion. However, the low volumetric energy density of hydrogen leads to the small-scale combustor that has to be operated at high fuel mass flowrate. The high mass flowrate would further reduce the residence time for flame stability and complete combustion. Therefore, the flame-stabilizing mechanism is a pivotal consideration in small-scale combustor design. In general, a backward-facing step is employed in a small-scale combustor to enhance flame stabilization. Nonetheless, the flame anchoring position is strongly related to the flow structure and operating condition. It turns out that non-uniform illumination of the emitter and reduced overall efficiency are usually encountered in the small-scale combustor using backward-facing step as the flame stabilizer. Therefore, in the present study, a novel combustion chamber design is proposed by using a percolated platinum tube as catalyst, emitter, and flame stabilizer to overcome the critical heat loss and to improve the flame instability. Concept, design, and demonstration of the small-scale percolated-platinum combustor for future application in a small TPV power generation system are addressed and discussed in this paper.

2. Concept of the small-scale combustor

In the present study, a percolated platinum tube is proposed as the catalyst and flame stabilizer for hydrogen combustion in the small-scale combustor. The incandescent platinum tube can also serve as an emitter in a small TPV power generation system. In order to reduce the heat loss in a small-scale combustor, the well-premixed fuel/air mixture is delivered through the inner and outer surfaces of the platinum tube. It conjectured that a leaner mixture would induce heterogeneous reaction only, then preheats the platinum tube and prevents heat loss to the tube wall. While a richer mixture may induce heterogeneous reaction in the upstream, and also supports homogeneous reaction in the downstream, leading to an enhanced fuel conversion. Accordingly, the distribution of different equivalence ratios of fuel/air mixtures through the inner and outer surfaces of the platinum tube is an essential design and operation consideration in this system. Furthermore, the percolation around the platinum tube provides a low-velocity zone for flame stabilization along the inner and outer surfaces of the tube.



(Flow direction →)

Fig. 1. Comparison of the computed contours of H_2 and OH mass fractions for the platinum plate with and without a gap. The inner and outer equivalence ratios are 0.6 and 0.3, respectively, with the inlet velocity fixed at 10 m/s.

To demonstrate and verify the above mentioned concept that is feasible in a small-scale percolated-platinum combustor, a preliminary numerical simulation is performed prior to experiments. A commercial code, CFD-ACE+ [19], is modified to incorporate the detailed gas-phase and surface reaction mechanisms in CHEMKIN formats for the simulation. For simplicity, the small-scale combustor is modeled as a two-dimensional system. The platinum plate is 20 mm long with a gap of 0.5 mm placed at 5 mm downstream of the inlet. The inner and outer equivalence ratios of the hydrogen-air mixtures are 0.6 and 0.3, respectively. The inlet temperature is 300 K. A uniform velocity profile is specified at the inlet and the flow velocity is fixed at 10 m/s for the platinum plate with and without a gap. At the exit, pressure is specified with a constant ambient pressure of 101 kPa and an extrapolation scheme is used for species and temperature.

Chemical reaction mechanisms are used in the gas phase as well as on the catalyst surface. The homogeneous reaction mechanism of hydrogen-air combustion composes of 9 species and 19 reaction steps; these are adopted from the mechanism proposed by Miller and Bowman [20]. The surface reaction mechanism is compiled primarily from that proposed by Deutschmann et al. [21]. These reaction mechanisms have been used in previous studies [22] and the comparisons with experimental results are satisfactory [23].

Fig. 1 compares the calculated H_2 and OH mass fractions in both catalyst configurations. As to the plain platinum wall, hydrogen at the outer surface is initially reacted heterogeneously and provides catalytically induced exothermicity to assist hydrogen conversion at the inner surface, as seen in upper panel of Fig. 1. The catalytically induced combustion is anchored on the inner catalyst surface.

However, the anchoring position of gas-phase reaction is strongly related to the inlet condition in a plain platinum wall. As to the platinum wall with a gap, the distance for completion of hydrogen conversion is shorter than that in a plain platinum wall. The gas-phase reaction is anchored in the downstream of gap, as seen in the lower panel of Fig. 1. It appears that the gap on the catalyst surface can enhance the flame stabilization by means of providing a low-velocity zone as well as collecting heat and chemical radicals from both sides. Consequently, the distribution of different equivalence ratios of fuel/air mixtures along both sides of catalyst surface can mutually assist heterogeneous and homogeneous reactions in a confined space, and hence prevent heat loss to the tube wall. The preliminary computation confirms that the proposed concept is applicable to a small-scale percolated-platinum combustor.

3. Experimental apparatus

The small-scale percolated platinum tube used in this study is designed to extend stable flammability in a small-scale combustor and to enhance the radiant intensity of an emitter in a TPV power system. Fig. 2a shows the schematic diagram of the proposed percolated platinum combustion chamber and its corresponding pipes. The dimension of the platinum tube is 2 mm in ID, 2.9 mm in OD, and 20 mm in length with six percolated holes (0.5 mm in diameter) equidistantly placed around the tube at 5 mm away from the bottom of the platinum tube. The platinum tube is connected with a stainless steel tube with 1 mm in ID and 2 mm in OD. It makes a backward-facing step, which of length is 5 mm, in the connection section. The platinum tube is confined in the quartz tube, which has a diameter of 4 mm in ID and 6 mm in OD. A high purity of hydrogen (99.95%), utilized as fuel, and air were metered with electronic mass flowmeters (0–20 l/min; 5850E, Brooks Instrument), which had a linearity of over 97% in the range of 0–20 l/min. The mass flowmeter was calibrated with a dry-gas flow calibrator (0–30 l/min; DryCal Definer 220, Bios), and the uncertainty of the flowmeter was less than 1%. The pre-chamber filled with steel wool can provide a space to mix the fuel/air, as shown in the right hand-side of Fig. 2a. Well premixed fuel/air mixtures with different equivalence ratios are separately delivered to the inner and outer tubes. The Reynolds number ranges from 377 to1258 in the experiments. Therefore, the flow is assumed to be in laminar regime.

In this study, two different platinum tubes, a plain platinum tube and a percolated platinum tube, are employed in the experiments to investigate the effects of fuel/air distribution and inlet flow velocity on the performance of the small-scale combustor. Fig. 2b shows the experimental setup. A digital camera is used to record the combustion phenomenon in the combustor. The surface temperature was measured by an infrared thermal camera with a high temperature filter (Max. measuring Temperature: 2000 °C, TVS-200EX, AVIO) and the emissivity was referred to the emissivity table of materials and calibrated by the isothermal furnace. In the

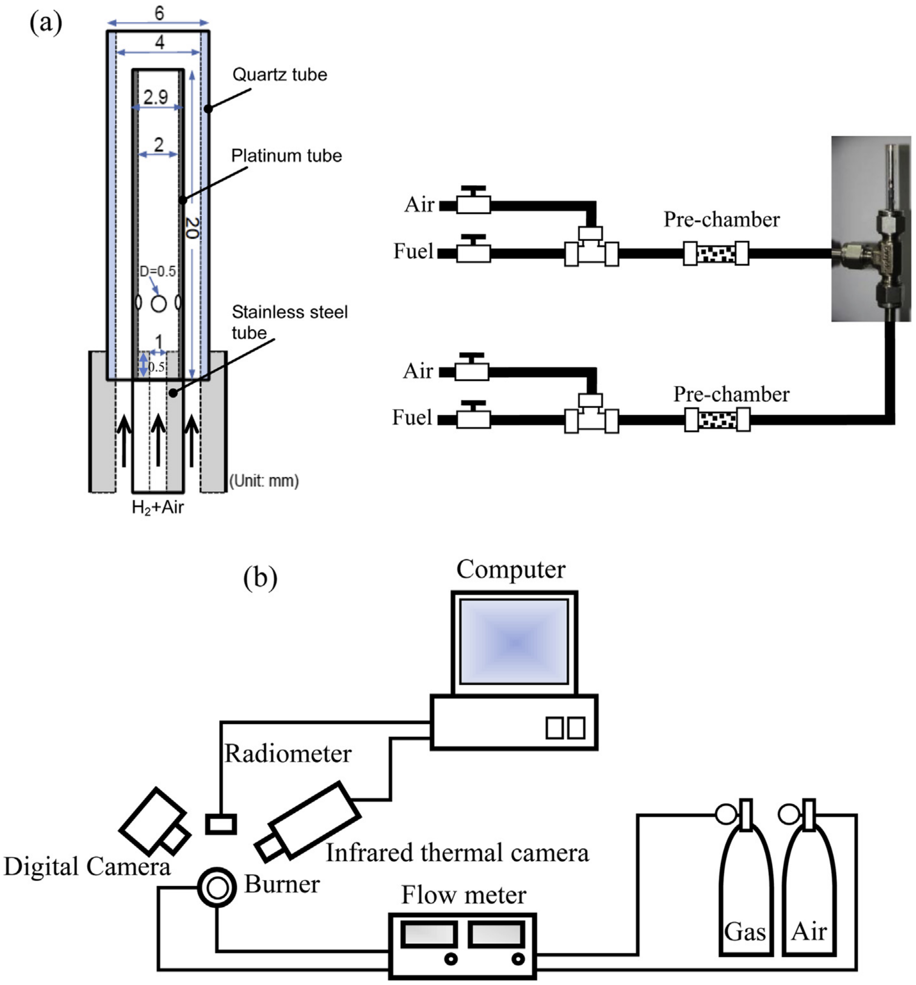


Fig. 2. Schematic diagram of (a) the percolated-platinum combustion chamber and the corresponding pipes (b) experimental setup.

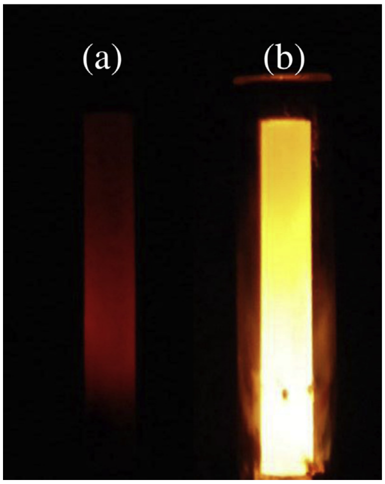


Fig. 3. Photograph of combustion phenomenon for the cases: (a) a plain platinum tube and (b) a platinum tube with holes under the condition of $ER_{in} = 0$ and $ER_{out} = 0.6$ and $V = 10$ m/s. (the exposure time of photograph is fixed in 1/200 s.).

calibration, the platinum tube is placed in an isothermal furnace and the temperature of the platinum tube and furnace are measured simultaneously by infrared thermometer and thermocouple with different emissivity values. The operating temperature spans from 500 to 1000 °C for IR temperature calibration with an accuracy of 95%. The radiant intensity is measured by the radiometer (UP19K-VM, Gentec-eo), which has a uniform quantum efficiency ranging from ultraviolet (190 nm) to near-infrared (2500 nm) wavelength region. The measurable power ranges from 1 mW to 15 W. Therefore, various fuel/air mixtures are separately deployed and delivered to outside and inside of the tube, and the combustion phenomena of two platinum tubes are individually recorded via a digital camera (D80, Nikon) with an F-mount lens (18–135 mm; f/3.5–5.6, Nikon). Owing to the radiant efficiency of the emitter related to the overall efficiency of TPV power system, the issue of illumination uniformity and brightness on the emitter is imperative in the procedure of designing a micro-TPV system. Accordingly, the surface temperature of the emitter provides a good indicator to examine the uniformity of the illumination on the emitter. The radiant intensity measurement of the emitter is aimed to examine the illuminating strength of the emitter. For monitoring temperature distribution and radiant intensity of two platinum tubes, an infrared thermal camera and a radiometer are used and recorded via a computer.

4. Results and discussion

In order to identify the effect of fuel/air distribution on the performance of the small-scale combustor, various fuel/air distributions are systematically investigated in the proposed combustor. Firstly, the fuel/air mixture is delivered inside the platinum tube with equivalence ratio (ER_{in}) of 0.6 and only air is delivered outside the platinum tube ($ER_{out} = 0$) under the condition of inlet velocity of 10 m/s. It is found that the gas-phase reaction cannot be stabilized inside the tube for both combustor cases. This is due to that the flowing air on the outer surface of the tube takes the thermal energy away from the tube and results in thermal quenching. On the contrary, when the fuel/air mixture is only delivered outside the tube ($ER_{out} = 0.6$ and $ER_{in} = 0$), there is only heterogeneous reaction on the plain platinum tube with dim red illumination, as shown in Fig. 3a. This is because that no flame stabilizing mechanism exists on the platinum tube. Nonetheless, for the percolated platinum tube, both of heterogeneous and homogeneous reactions occur on the tube with bright illumination (see Fig. 3b). It appears that flame can be stabilized on the percolated holes around the platinum tube. This is because that the larger contact surface allows hydrogen to react along the outer surface of the platinum tube and to release heat for supporting homogeneous reaction on the percolated holes.

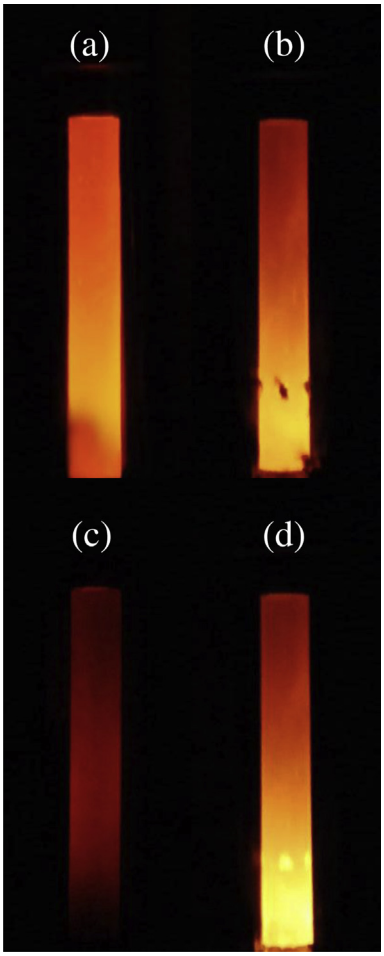


Fig. 4. Photograph of combustion phenomenon for the cases: (a) a plain platinum tube and (b) a percolated platinum tube under the condition of $ER_{in} = 0.6$ and $ER_{out} = 0.3$ and $V = 5$ m/s, (c) a plain platinum tube and (d) a percolated platinum tube under the condition of $ER_{in} = 0.3$ and $ER_{out} = 0.6$ and $V = 5$ m/s. (the exposure time of photograph is fixed in 1/200 s.).

Fig. 4 shows the photograph of combustion phenomenon for two combustor cases under various fuel/air equivalence ratios and fixed inlet velocity ($V = 5$ m/s). Two equivalence ratios are selected for clarifying the relationship of chemical reaction occurring on the inner and outer surfaces of the catalyst. The stream of $ER = 0.6$ mixtures is prone to induce both heterogeneous and homogeneous reactions, while the $ER = 0.3$ stream induces only heterogeneous reaction. When $ER_{in} = 0.6$ and $ER_{out} = 0.3$, the flame can be stabilized inside the tube for both combustors. It seems that the existence of the backward-facing step and percolated holes can offer adequate mechanism for flame stabilization in the combustor, as shown in Fig. 4a and b. Nevertheless, as $ER_{in} = 0.3$ and $ER_{out} = 0.6$, there is only heterogeneous reaction on the conventional plain platinum tube due to heat loss and the lack of flame stabilization mechanism, as shown in Fig. 4c. With the percolated holes, the catalytically holding combustion can be seen on the tube (Fig. 4d).

When the inlet velocity is increased to 10 m/s, no significant change of the flame stabilization position in both combustors under

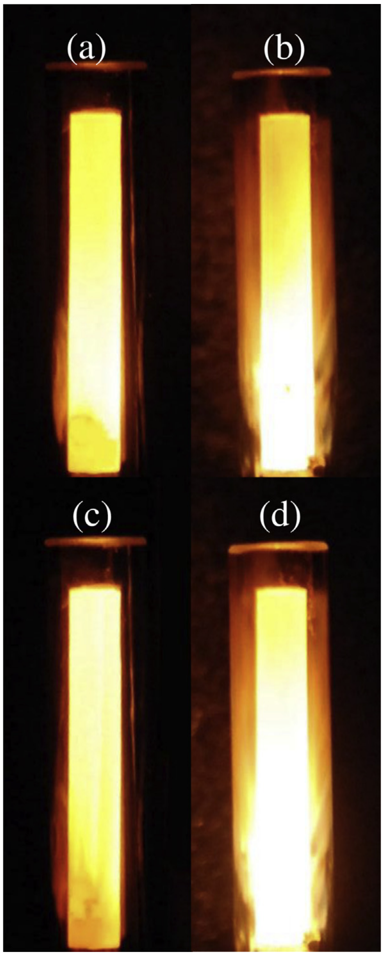


Fig. 5. Photograph of combustion phenomenon for the cases: (a) a plain platinum tube and (b) a percolated platinum tube under the condition of $ER_{in} = 0.6$ and $ER_{out} = 0.3$ and $V = 10$ m/s, (c) a plain platinum tube and (d) a percolated platinum tube under the condition of $ER_{in} = 0.3$ and $ER_{out} = 0.6$ and $V = 10$ m/s. (the exposure time of photograph is fixed in 1/200 s.).

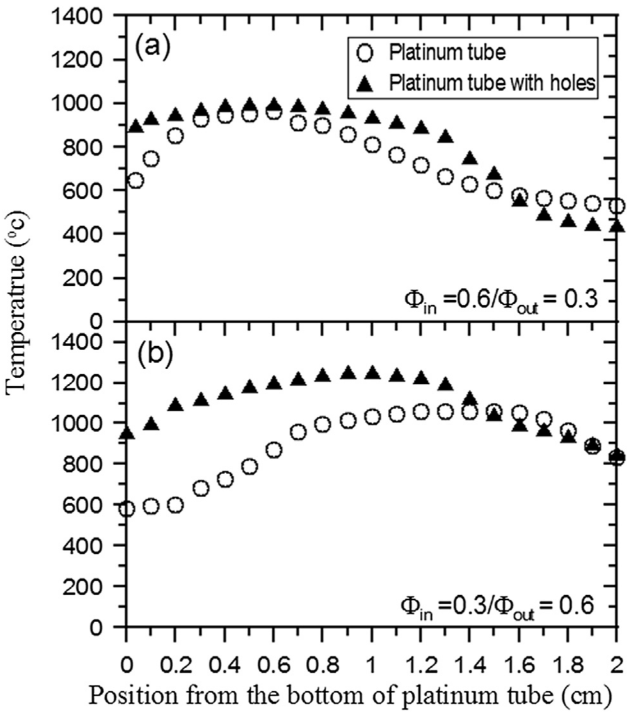


Fig. 6. Measured surface temperatures along the axial direction of the platinum tube without and with percolated holes under the condition of (a) $ER_{in} = 0.6$, $ER_{out} = 0.3$ and $V = 10$ m/s, (b) $ER_{in} = 0.3$, $ER_{out} = 0.6$ and $V = 10$ m/s.

the condition of $ER_{in} = 0.6$ and $ER_{out} = 0.3$ (see Fig. 5a and b). However, the radiation from the two tubes becomes much brighter than the previous cases (Fig. 4a and b). This is due to that catalytically holding combustion can be induced and stabilized inside the tube under the flammable fuel/air condition. The presence of heterogeneous reaction on the outer surface of platinum tube contributes to preheat the tube and prevent the heat loss from the tube. It is noted that there are bright illumination regions congregated in the downstream part of the conventional plain platinum tube under the condition of $ER_{in} = 0.3$ and $ER_{out} = 0.6$ (Fig. 5c). In principal, extensive hydrogen reaction on the outer surface of the catalyst can release large amount of catalytically induced exothermicity, which can sufficiently compensate the heat losses. Besides, when the inlet flowrate is further increased, the residual hydrogen can induce gas-phase reaction in the downstream of the platinum tube. As to the percolated platinum tube, it can be seen from Fig. 5e that flame is anchored on the percolated holes of the platinum tube. The presence of flame not only accelerates fuel conversion, but also heats up the platinum tube to become a bright emitter.

Fig. 6 displays the measured surface temperatures along the platinum tubes under various fuel/air distributions. For the case of $ER_{in} = 0.6$, $ER_{out} = 0.3$ and $V = 10$ m/s, the measured temperatures along two different platinum tubes are similar due to the presence of catalytically holding combustion inside the tube. For the case of $ER_{in} = 0.3$, $ER_{out} = 0.6$ and $V = 10$ m/s, the surface temperatures of the percolated platinum tube are much higher than those of the conventional plain platinum tube. This is because that both heterogeneous and homogeneous reactions occur in the percolated platinum tube, but only heterogeneous reaction takes place in the plain platinum tube. Comparison the measured temperatures for the percolated platinum tube (Fig. 6a and b) indicates that a richer outer stream ($ER_{out} = 0.6$) results in a higher surface temperature than that of a richer inner stream ($ER_{in} = 0.6$). It is conjectured that heating the tube from inside is prone to heat loss to surrounding, but heating from outside of the tube could enhance reaction in the platinum tube. This fact suggests that the illumination of the platinum tube may be enhanced with proper thermal management.

Figs. 7 and 8 show the operating range of the plain and the percolated platinum tubes, respectively, with various fuel–air distributions under $V = 5$ and 10 m/s. Four distinct combustion phenomena, i.e., no illumination, heterogeneous reaction with dim red illumination, hetero- and homogeneous reaction with moderate illumination, and hetero- and homogeneous reaction with bright illumination, are identified by image observations and wall temperature measurements. For the plain platinum tube, conditions for bright incandescent illumination congregate in the higher inner and outer equivalence ratios (see Fig. 7a). When the inlet velocity is increased to 10 m/s, the bright incandescent region is remarkably extended to lower inner and outer equivalence ratios, such as 0.3 and 0.2, as shown in Fig. 7b. It can be delineated that the presence of backward-facing step can stabilize the flame inside the tube in higher inner equivalence ratio conditions, and heat loss from the tube can be reduced by means of heat release from catalytic induced exothermicity on outer surface. Nevertheless, no significant improvement is found for the conditions of higher outer equivalence ratios when the inlet velocity is increased. The flame would recede to the exit of the combustion chamber due to the lack

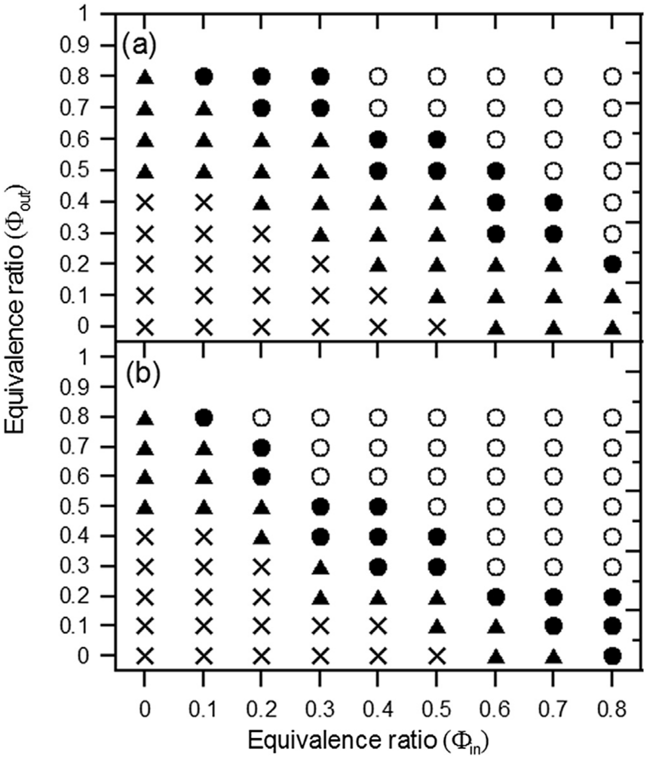


Fig. 7. Operating range of a plain platinum tube under the condition of inlet flow velocity of (a) 5 m/s and (b) 10 m/s. Symbols: (×) no illumination, (▲) heterogeneous reaction with dim red illumination, (●) hetero- and homogeneous reaction with illumination, and (○) hetero- and homogeneous reaction with bright illumination.

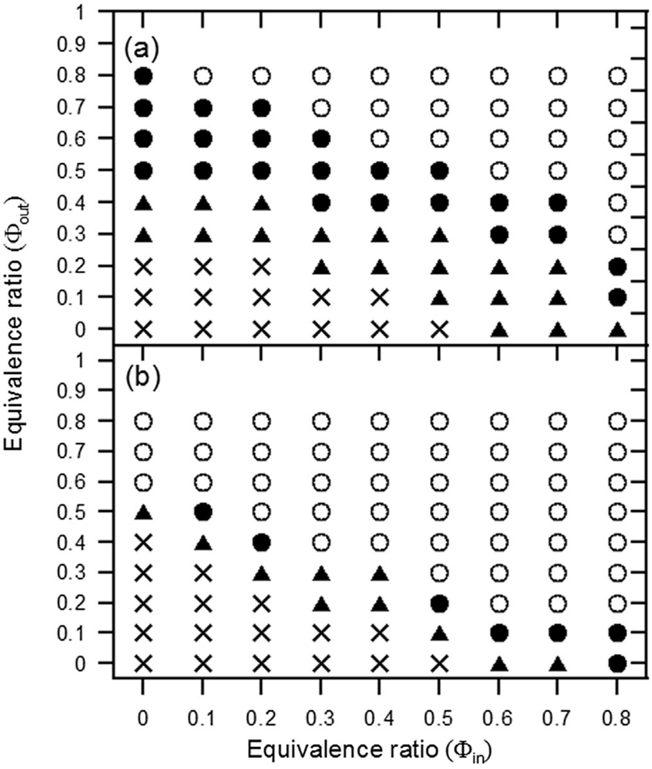


Fig. 8. Operating range of a percolated platinum tube under the condition of inlet flow velocity of (a) 5 m/s and (b) 10 m/s. Symbols: (×) no illumination, (▲) heterogeneous reaction with dark red illumination, (●) hetero- and homogeneous reaction with illumination, and (○) hetero- and homogeneous reaction with bright illumination.

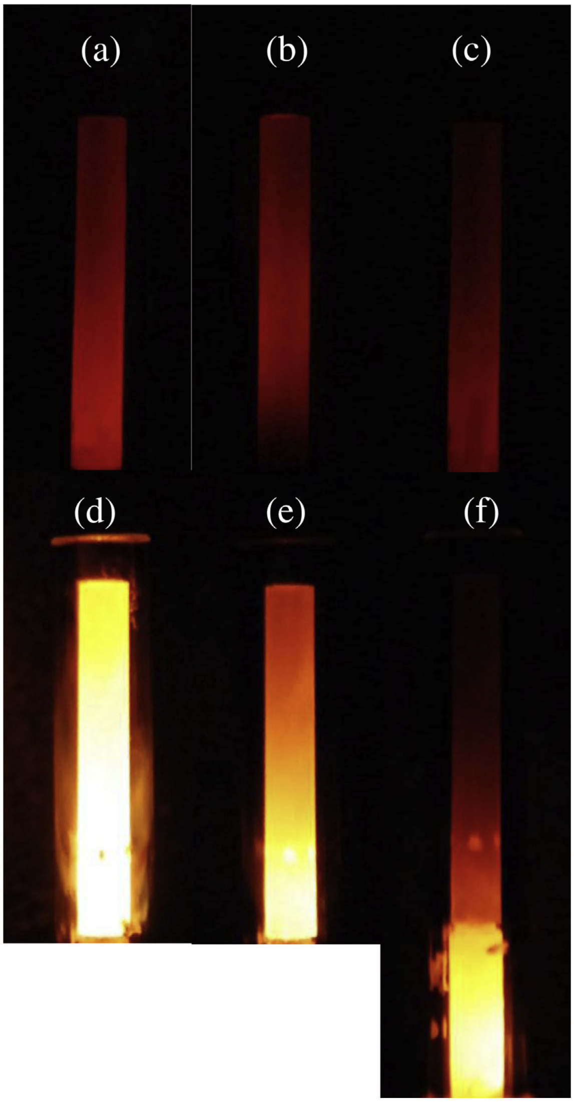


Fig. 9. Photographs of combustion chamber operation for a plain platinum tube (a,b,c) and a percolated platinum tube (d,e,f) under the condition of fixed inner and outer equivalence ratio of 0.6 and (a,d) $V_{in} = 3$ m/s and $V_{out} = 6$ m/s, and (b,e) $V_{in} = 5$ m/s and $V_{out} = 5$ m/s, and (c,f) $V_{in} = 7.5$ m/s and $V_{out} = 3.75$ m/s fuel velocity and stoichiometric conditions.

of flame stabilizer in the outer stream. Comparison of Figs. 7a and 8a indicates that the operating range with bright incandescent illumination for the percolated tube is much larger than that for the plain tube under the conditions of larger outer equivalence ratio. This is attributed to the presence of percolated holes for flame stabilization. When the inlet velocity is increased to 10 m/s, the operating range of bright incandescent illumination (Fig. 8b) is, again, remarkably extended, especially for lower inner equivalence ratios.

In order to investigate the effect of velocity differences on combustion characteristics, three different inner and outer stream velocity ratios are considered under the condition of $ER_{in} = ER_{out} = 0.6$. The inner stream to outer stream velocity ratios are 0.5, 1, and 2. To have equally fuel inputs in the inner and outer streams, the inner and outer inflow velocities are adjusted to 3 and 6 m/s, 5 and 5 m/s, and 7.5 and 3.75 m/s, respectively. Fig. 9 shows the photographs of combustion phenomena in the plain and percolated platinum tubes. It can be seen that only heterogeneous reaction occurs on the surface of the plain platinum tube (Fig. 9c)

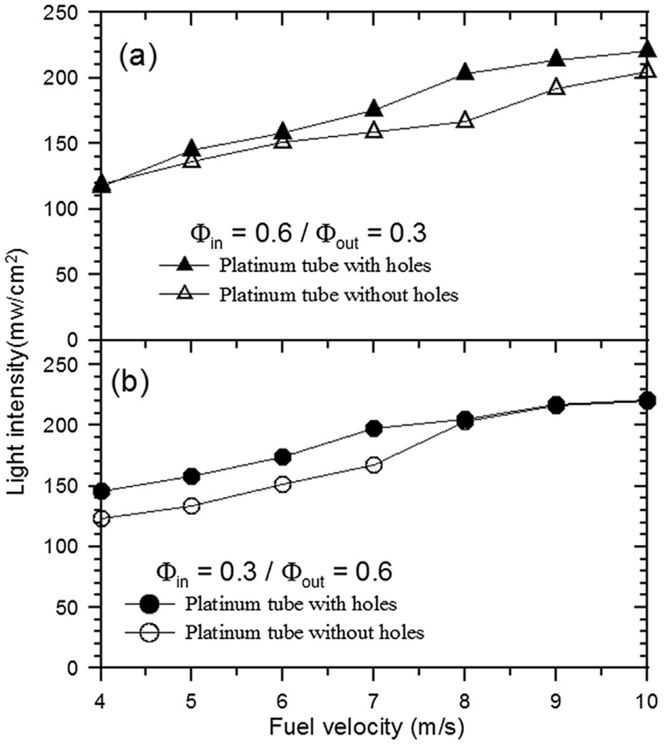


Fig. 10. Radiant intensity from the platinum emitter with and without percolated holes under various inlet velocities and (a) $ER_{in} = 0.6/ER_{out} = 0.3$ and $ER_{in} = 0.3/ER_{out} = 0.6$.

when the inlet velocity ratio is 2. It seems that the backward-facing step becomes ineffective in this condition. For the percolated platinum tube, the catalytically induced combustion occurs with the flame anchoring in the upstream under the inlet velocity ratio of 0.5 and 1, as shown in Fig. 9d and e. However, for the inlet velocity ratio of 2, the flame is flash-back and stabilized in the upstream stainless steel section (Fig. 9f). To alleviate the flash-back problem, the outer inlet velocity must be greater than 3.75 m/s. In addition, the percolated holes on the platinum tube provide a stabilization mechanism for the wider operating range and brighter incandescent radiation as compared to the plain platinum tube.

Fig. 10 compares the measured radiant intensity, taken by the radiometer, from two platinum tubes under various inlet velocities. For the case of $ER_{in} = 0.6$ and $ER_{out} = 0.3$, the radiant intensity from the plain platinum tube is about the same as that from the percolated platinum tube under low inlet velocity conditions. When the inlet velocity is increased, the differences in radiant intensity for the two platinum tubes become significant, as shown in Fig. 10a. This is due to that the shift of flame anchoring position inside the plain platinum tube would reduce the incandescent feature of the tube. For the case of $ER_{in} = 0.3$ and $ER_{out} = 0.6$, the radiant intensity from the plain platinum tube is much lower than that from the percolated case due to lack of flame stabilization at the outer surface under low inlet velocity conditions. When the inlet velocity is increased, sufficient hydrogen could enhance the heterogeneous reaction on the surface of the plain platinum tube, and the residual hydrogen would induce gas-phase reaction anchoring at the exit of the combustion chamber. The platinum tube absorbs heat from the flame and results in increasing radiant intensity on the tube. This is the reason why the radiant intensity from the plain platinum tube is comparable to that from the percolated platinum tube, if fuel is completely consumed inside the tube with sufficient flame stabilization mechanism and heat loss prevention.

5. Conclusions

The result of a simplified simulation supports the concept of sustaining catalytic combustion on a platinum wall with a gap, and flames anchoring on the wall can contribute to efficiently heat up the wall temperature. For testifying the concept of our proposed micro-TPV combustor, an experimental study on the performance of the proposed percolated-platinum combustion chamber is made under various equivalence ratios, fuel/air mixture distributions, and inlet velocities. Results demonstrate that the percolated-platinum combustor can sustain the heterogeneous and homogeneous reactions, extend the operating range of the combustor, and enhance the incandescent illumination of the platinum tube. Besides, delivering fuel/air mixtures into two sides of platinum tube can reduce the heat loss from the chamber wall, and a percolated-hole can sustain flames anchoring on the wall in various experimental conditions. These two novel approaches consolidate the accomplishment of simultaneously flame stability in a small-scale system and high illumination on the chamber wall. Therefore, the percolated-platinum tube can serve as an effective emitter for the small-scale TPV power generation system as compared to the plain platinum tube. These facts suggest that future application of the proposed concept and design of the percolated-platinum combustor to a small-scale TPV power system is feasible.

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