Performance of a miniature combustor applied in a portable TPV system

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1 Introduction

In view of the fact that traditional batteries fail to satisfy the rapidly growing trend towards miniaturization of both mechanical and electromechanical engineering devices, the need for micro or miniaturized power sources with significantly higher energy/power density becomes an emergent issue. A small-scale power system has been regarded as a liable solution and alternative power source. In the process of the miniaturization, however, with increasing surface-to-volume ratio (S/V) it inevitably leads to some apparent obstacles including incomplete combustion and flame instability [1-2]. Some logistical strategies have been developed to overcome these challenges. Among these novel and viable small-scale power source designs, the thermophotovoltaic (TPV) power system promises to be a very clean and quiet source of electrical power generation with no moving parts and yielding high power density, using a wide variety of fuels [3-6]. In general, the small-TPV power system mainly consists of a combustor with its wall served as an emitter and a PV array. The system is simple yet effective. However, the most obvious drawbacks of the TPV power devices are their low conversion efficiency and low throughput. The overall efficiency of a conventional thermophotovoltaic power system is the product of the efficiencies of the PV cells, and the radiation source, consisting of the combustor and the emitter. In particular, technological improvements in the fields of selective emitter and low band gap PV cells have opened up a renewed page in TPV generation of electricity [7-10]. Despite material limits on the PV cells, both combustor and emitter are key components in the design of a successful small-scale TPV power device. The emitter is usually the wall of the combustor and it functions to convert heat from the combustion into radiation by emitting photons. As regards to a small-scale combustor, it is highly constrained by inadequate residence time for complete combustion and high rates of heat loss from the combustor wall. Therefore, the major challenge in the small-scale combustor design is to keep an optimum balance between sustaining combustion and maximizing the specific electricity output. A high surface-to-volume ratio is very favorable to the surface power output per unit volume. On the contrary, a high heat loss through wall may influence the stable combustion in the small-scale combustor. This is because heat loss through the wall of the combustor increase drastically when miniaturized, which tends to suppress ignition and quench the reaction in high S/V ratio device. Therefore, the problems often encountered in the small-scale TPV combustors are those associated with incomplete combustion, flame instability and non-uniform emitter illumination. In the design of the miniaturized TPV, one should carefully consider the delicate coupling and balance among the fluid dynamics, heat transfer, and chemical kinetics [11]. In this paper, a novel design of the

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miniature TPV combustor with a reverse tube and a porous medium injector is proposed to remedy the above-mentioned obstacles. Consequently, the overall efficiencies of the miniature TPV system in different combustor configurations are tested and discussed.

2 Results and Discussion

Fig.1 shows the photograph of the experimental combustor assemblies and set-up. It consists of three parts, 1.the Infrared tube serves as an combustor wall, 2.the swirling inject and porous medium system and 3.the reverse tube.

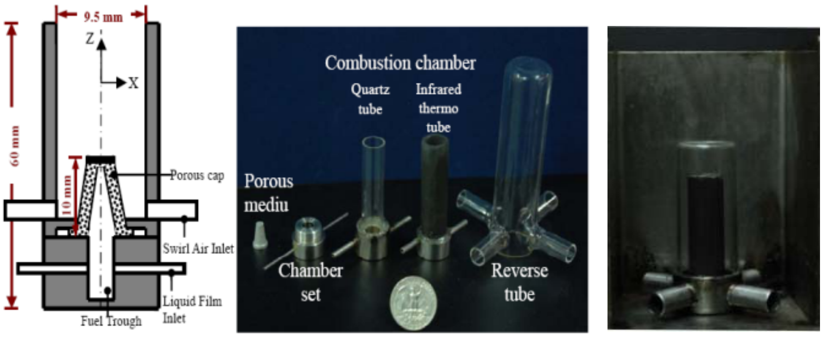

Figure 1. Schematic and photograph of the experimental combustor

Swirling air system and porous medium fuel injector are used to enhance flame stabilization in the miniature combustor by generating a recirculation zone, increasing residence time and enhancing fuel-air mixing. There are four exit tubes surrounding in the bottom of the reverse tube for exhausting product gas. Main function of a reverse tube is to redirect hot product gas to pass through the chamber and reheat the emitter again. Besides, existence of a reverse tube may squeeze the recirculation zone into the chamber, and further increase the residence time of the reactant inside the chamber. This approaching recirculation zone enforces the flame attaching to the combustion chamber. The emitter can attain thermal energy from the flame in means of heat transfer. In this manner, hot product gas can adequately heat up the emitter from both sides of the combustion chamber.

Figure 2.exhibits the intensity and uniformity of illumination on the emitter with and without reverse tube. The results show that the chamber wall with a reverse tube has much more uniform illumination and that the flame can be stabilized and confined inside the chamber. Apparently, an emitter with a reverse tube has higher illumination intensity and uniformity than that without a reverse tube.

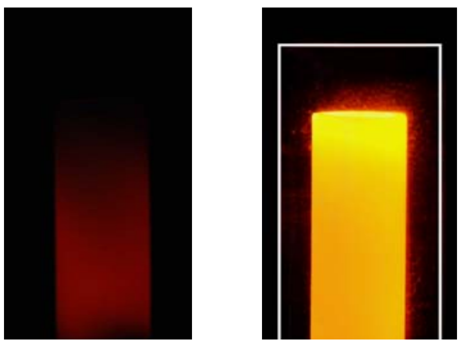

Figure 2. Photograph of combustion chamber operated without and with reverse tube.

For verifying the flame structure inside the chamber, the infrared thermal tube was taken place by a quartz tube. The flame structure can be monitored through a transparent reverse tube and a quartz tube. It is realized that the OH chemiluminescence images can represent the flame structure and its corresponding position, so the OH chemiluminescence images with and without a reverse tube were taken and transformed by Abel deconvolution, as shown in Fig.3. In the case without a reverse tube, the flame structure is trapped in the central line of the combustion chamber. On the contrary, the flame structure in the case with a reverse tube is flung to the combustion chamber. Consequently, the flame burns along the combustion chamber with a reverse tube, and it is optimum to heat transfer the energy to the emitter. This is realized that the emitter with a reverse tube performs high and uniform illumination.

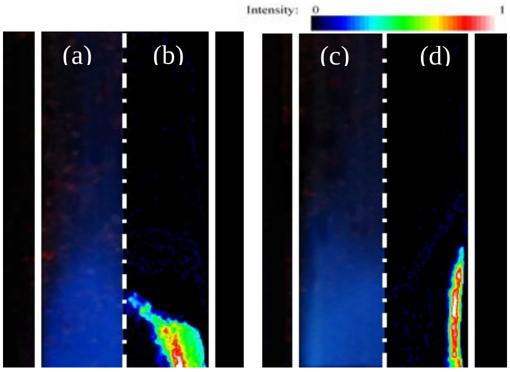

Figure 3. Chemiluminescence images of excited OH^* in the combustor wall

In order to evaluate the efficiency of the combustion-driven TPV system, GaSb PV cells are employed to collect illumination emission and convert it into electricity. The prototype TPV system consists of the miniature combustor with necessary assemblies surrounded by four pieces of PV cell modules. Each cell array has an area of 18 cm^2 and contains two strings of 6 series connected cells in parallel. The electrical power output of the prototype mesoscale TPV system incorporating GaSb cell modules is then measured for various equivalence ratios and different combustor configurations as shown in Fig. 4. Considering identical thermal input, maximum electrical power output of the conventional burner increases depending upon the equivalence ratio. Perhaps, as the fuel/air ratio approaches stoichiometric condition, power output increases correspondingly due to more stable and complete combustion. With a reverse tube, the electric power output increases 3.16 times. With an increase in the ER and air flow rate, the electric power output correspondingly enhances. The maximum power output may reach to 6.27 W when the ER equals to 1.05, and its overall thermal to electric efficiency is approximately 1.02%, which is higher than that obtained by Yang [6]. The open-circuit voltage and short-circuit current are 1.81 V and 6.6 A. The fill factor reaches 0.695. Besides, the exhaust product gas possesses a large amount of energy dissipated to the environment. Further extracting energy from the exhaust product gas by using thermoelectric material is the other approach to improve the overall efficiency.

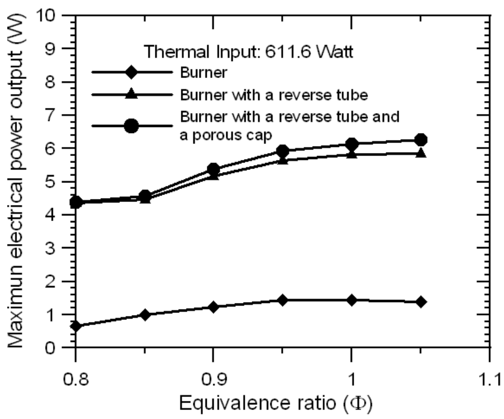

Figure 4. Electrical power output at different equivalence ratio

3 Conclusion

Methods to improve a mesoscale combustion-driven TPV system are proposed and demonstrated. Swirling air system with porous medium injector is shown to enhance flame stabilization in the miniature combustor by generating a recirculation zone, increasing residence time and enhancing fuel-air mixing. The illumination of the conventional combustor and emitter design, however, has non-uniform and low intensity due to low and concentrated heat transfer from flame. In order to ameliorate this situation, a reverse tube is proposed and demonstrated to effectively redirect hot product to reheat the emitter. The results show that the chamber wall has much more uniform illumination and that the flame can be stabilized and confined inside the chamber. In the process of improvement, the overall efficiency can be increased from 0.24% to 1.02%, which is superior than that reported in the literature.

4 References

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