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Research article

Numerical study on energy conversion performance of micro-thermophotovoltaic system adopting a heat recirculation micro-combustor

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ABSTRACT

In order to evaluate the energy conversion performance of micro-thermophotovoltaic system (MTPV) effectively, a novel calculation method combining Fluent with MATLAB program is proposed, which has considered the non-uniformity of temperature distribution of radiant surface, the angular coefficient between the emitter and the PV cell and its cooling efficiency. In this paper, numerical study on hydrogen/air premixed combustion in micro-combustors integrated with MTPV system to produce electricity has been adopted. Results show that the overall efficiency of heat recirculation combstor is almost twice as large as obtained in straight channel combustor. Furthermore, dimensionless baffle length, a key parameter in designing micro-combustor with heat recirculation, has been investigated. It is concluded that the subsystem efficiencies of MTPV system are increasing first and then descending with an increase in dimensionless baffle length. However, as the dimensionless baffle length reaches a certain point, the working performance of subsystems changes little. Meanwhile, it is demonstrated that increasing the dimensionless channel gap reasonably will improve the combustion process. Finally, the energy conversion performances as a function of hydrogen volume flow rate are calculated and compared. Results indicate that choosing a proper inlet velocity is of great pivotal to gain a better energy conversion performance of MTPV system. Of all the investigated cases, the maximum power generated with the MTPV is 1.4014 W and the overall efficiency is 0.7092%.

1. Introduction

The rapid development of micro-electro-mechanic systems has accelerated the research progress of micro-power systems [1–4]. These systems, such as micro-thermophotovoltaic (MTPV) system [1], micro-gas turbine [5] and micro-rotary engines [6] are mainly fuelled with hydrogen and hydrocarbon fuels due to the higher energy density. Since the MTPV system is free from frictional losses and clearance problems, this micro-power system is advantageous relative to other systems [7,8]. More importantly, the large heat losses from the emitter external wall can be beneficial to the system which includes micro-combustor (micro-emitter), optical filter, PV cell and cooler, as shown in Fig. 1. Although MTPV system possesses some advantages, short residence time and quenching phenomenon in the presence of micro-scale combustion will occur inevitably [9–11], and these deficiencies will reversely influence the working performance of the system.

It is obvious that the micro-combustor plays a crucial role in the whole system as it can supply the power and determine the whole efficiency of the system. Therefore, various researches have been carried out to enhance the thermal performance and flame stability of micro-combustor. The excess enthalpy combustion firstly proposed by Weinberg and Lloyd [12], also known as heat recirculation combustion, is an effective measurement to enhance micro-*meso* combustion. Three typical types are heat recirculation in reverse-flow micro-combustor [13,14], Swill-roll combustor [15–18] and internal heat recirculation combustor [19–23]. Fan et al. [17] explored the effect of bluff-body on flame stability, and found that the blow-off limit can be significantly extended by reducing the flame stretch effect. Vijayan and Gupta [18] and Taywade et al. [19] investigated the combustion characteristics of micro-combustor with heat recirculation using experimental and numerical method, while Tang et al. [22] compared the combustion characteristics of micro-combustor with and without heat recirculation adopting experimental way. All of their results indicated that both the flame stability and wall temperature of micro-combustor can be improved dramatically with a use of heat recirculation measurement.

Meanwhile, catalytic combustion [24–27] has been adopted to accelerate chemical reaction rate and thus enhance fuel/oxidizer combustion degree. For example, Ran et al. [26] numerically studied the catalyst combustion process, and they observed that catalyst method can effectively improve combustion process and promote complete

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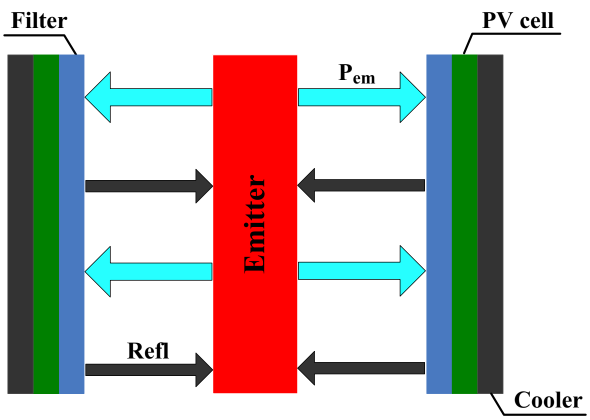

Fig. 1. Schematic diagram of the thermophotovoltaic (TPV) system.

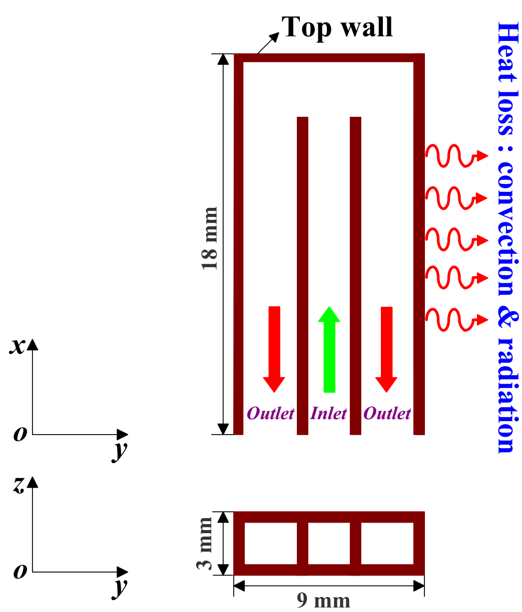

Fig. 2. Geometries of heat recirculation micro-combustor.

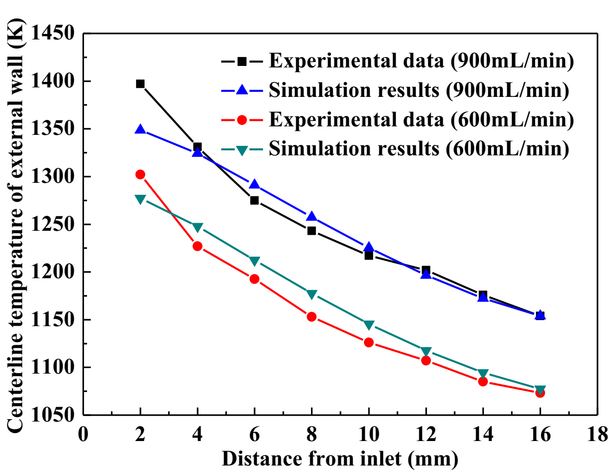

Fig. 3. Comparison of experimental data and simulation results in straight channel combustor.

combustion. Besides, porous media combustion [28–32] has been proved to be a feasible approach to anchor flame and improve the uniformity of temperature distribution of the external wall.

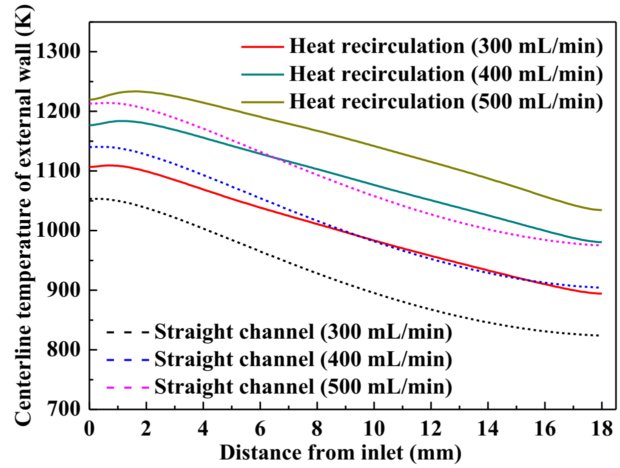

Fig. 4. The centerline temperature profiles of external wall along flow direction.

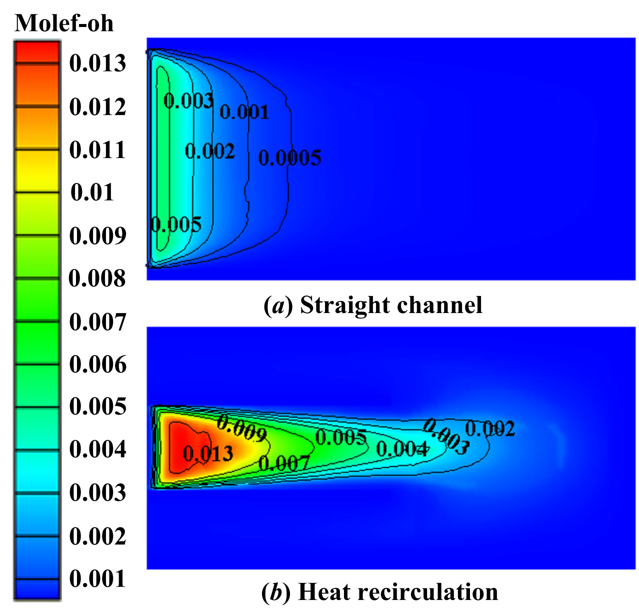

Fig. 5. Comparison of mole fractions of oh on cross section.

Experimental study was carried out by Yang et al. [28] to reveal the effect of porous media combustion, and they found that as SiC porous media was inserted into micro-combustor, the peak temperature of external wall increased by 90–120 K. Li et al. [30] and E et al. [31] demonstrated that the porous can drastically affect the flame locate and thus improve the uniform rate of external wall. Moreover, blended combustion measurement [33–37] has also been adopted by some scholars. Chen et al. [37] pointed out that for a stable combustion in a micro-planar catalytic combustor with channel-height 0.8 mm, the minimum hydrogen mole fraction should be larger than 3.2%. What is more, micro-combustor with special structure [38–44] has been fabricated for the purpose of stabilizing combustion and enhancing the degree of fuel/air mixing.

In view of the above works, they were mainly focused on the thermal performance and flame stability of the combustor. To the best of authors' knowledge, little attention has been paid to the energy conversion performance of MTPV system. Even if some works [31,44] studied the overall efficiency of the system, the non-uniformity of temperature distribution of radiant surface and the angular coefficient between the emitter and the PV cell had not been considered and given enough attention, which may result in the low accuracy of calculation