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# Numerical investigations on an improved micro-cylindrical combustor with rectangular rib for enhancing heat transfer

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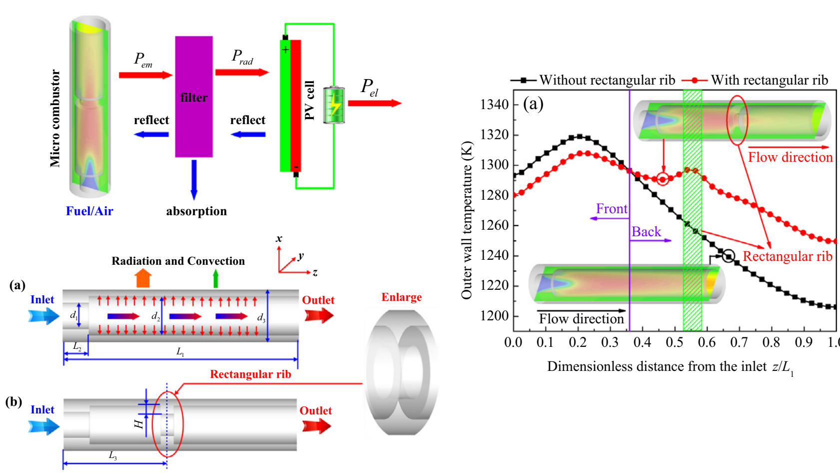
## HIGHLIGHTS

- An improved micro-cylindrical combustor with rectangular rib is developed.
- Wall temperature of combustors with and without rectangular rib are compared.
- Effects of rib positions and heights on wall temperature are investigated.
- Optimum rib position and height is obtained for high and uniform wall temperature.

## GRAPHICAL ABSTRACT

An improved micro-cylindrical combustor with rectangular rib for high and uniform wall temperature.

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## ABSTRACT

A high and uniform wall temperature on micro combustors is desirable for micro-thermophotovoltaic system application. In this work, an improved micro-cylindrical combustor with rectangular rib is developed. Numerical investigations on the combustors with and without rectangular rib are conducted under various $H_2$ mass flow rates and $H_2$/air equivalence ratios. Moreover, the effects of dimensionless rib positions and heights on the outer wall temperature of micro combustors are also widely investigated. Results suggest that the improved combustor has a higher and more uniform outer wall temperature distribution under the same inlet condition compared with that of the micro combustor without rectangular rib. It is concluded that the inserted rectangular rib makes a recirculation region, enhancing the heat transfer between the combustor inner wall and burned gas. In addition, among all the investigated geometrical models, the geometrical model with the dimensionless rib position of 5/9 and dimensionless rib height of 0.4 has the highest and most uniform outer wall temperature where the $H_2$ mass flow rate and $H_2$/air equivalence ratio are fixed at $5.25 \times 10^{-7}$ kg/s and 1.0, respectively. More importantly, the optimum dimensionless rib position is related with the inlet velocity of $H_2$/air mixture and it is increased with the inlet velocity of $H_2$/air mixture.

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## Nomenclature

| | |
|---|---|
| $A_{w,i}$ | surface area of grid cell $i$ on the outer wall ($m^2$) |
| $d_1$ | inner diameter of the micro combustor at the inlet (mm) |
| $d_2$ | inner diameter of the micro combustor at the outlet (mm) |
| $d_3$ | outer diameter of the micro combustor (mm) |
| $E_f$ | total fluid energy (J/kg) |
| $h_j$ | enthalpy of species $j$ (J/kg) |
| $h_0$ | natural convection heat transfer coefficient (W/($m^2$ K)) |
| $H$ | rib height (mm) |
| $\underline{I}$ | unit tensor |
| $\vec{J}_j$ | diffusion flux of species $j$ (kg/($m^2$ s)) |
| $k_{eff}$ | effective conductivity (W/(m K)) |
| $k_w$ | thermal conductivity of wall (W/(m K)) |
| $L_1$ | total length of the micro combustor (mm) |
| $L_2$ | step length of the micro combustor (mm) |
| $L_3$ | position of the rectangular rib (mm) |
| $l$ | dimensionless rib position, $l = L_3/L_1$ |
| $\dot{m}_{H_2}$ | mass flow rate of hydrogen at the inlet (kg/s) |
| $\dot{m}_{Air}$ | mass flow rate of air at the inlet (kg/s) |
| $p$ | gas absolute pressure (Pa) |
| $Q_{loss}$ | total heat loss (W) |
| $r$ | dimensionless rib height, $r = 2H/d_3$ |
| $R_j$ | net production rate of species $j$ by chemical reaction (kg/($m^3$ s)) |
| $S_f^h$ | fluid enthalpy source term (W/$m^3$) |
| $T$ | temperature (K) |
| $T_0$ | ambient temperature, 300 K |
| $T_{w,i}$ | temperature of grid cell $i$ on the outer wall (K) |
| $T_{w,max}$ | maximum temperature on the outer wall (K) |
| $T_{w,min}$ | minimum temperature on the outer wall (K) |
| $\overline{T}_w$ | mean outer wall temperature (K) |
| $\Delta T_w$ | outer wall temperature difference (K) |
| $\vec{u}$ | velocity vector (m/s) |
| $u$ | specific internal energy (J/kg) |
| $Y_j$ | mass fraction of species $j$ |
| $z$ | axial coordinate (mm) |

*Greek letters*

| | |
|---|---|
| $\varepsilon$ | wall emissivity |
| $\mu$ | molecular viscosity (Pa s) |
| $\mu_j$ | chemical potential of species $j$ (J/kg) |
| $\rho$ | density of gas (kg/$m^3$) |
| $\sigma$ | Stephan-Boltzmann constant, $5.67 \times 10^{-8}$ W/($m^2$ $K^4$) |
| $\varphi$ | $H_2$/air equivalence ratio |

## 1. Introduction

Combustion is an important energy conversion way in energy supporting systems [1–3]. However, with the rapid development of the society and technology, people propose higher requirements for these systems. Therefore, the micro combustion as an advanced energy usage technique is well developed and investigated. It is due to that micro power generation systems (MPGS) based on micro combustion have merits of high energy density, small volume and long working time [4–7]. As one of the most important MPGS, the micro-thermophotovoltaic (MTPV) system has the advantage of simple structure and no moving components [8], which is shown in Fig. 1 [9,10]. In a typical MTPV system, the micro combustor is the most important component, which directly affects the output power and the total energy conversion efficiency of the system.

In order to improve the energy conversion efficiency of the MTPV system, many scholars have adopted various methods and built novel micro combustors for obtaining high and uniform wall

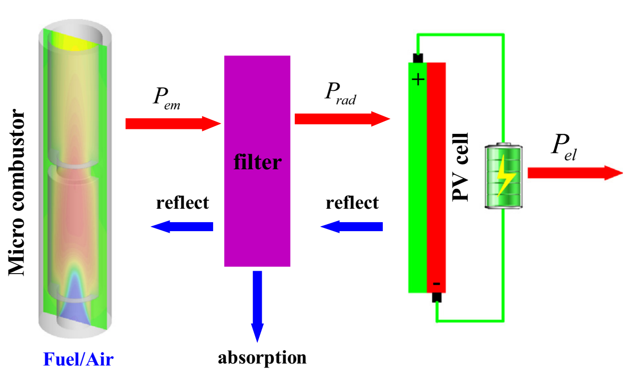


**Fig. 1.** Energy conversion process of a MTPV system.

temperature. For example, the porous media has been successfully used by Chou et al. [11], Pan et al. [12] and Li et al. [13–15] to enhance heat transfer and improve flame stabilities in micro channels. Catalytic combustion [16–21] was another advanced technique for improving fuel conversion efficiency. As adding hydrogen to methane plays a pivotal role in modification processes of combustion phenomena in a micro combustor [22,23], Yan et al. [24,25] and Chen et al. [26] investigated hydrogen assisted catalytic combustion of methane in micro-channels. Results indicated that hydrogen successfully caused catalytic self-ignition of methane-air mixtures. Moreover, micro combustors with recirculation structure were developed. Yang et al. [9] employed a heat recuperator to improve the wall temperature of the micro combustor. Vijayan and Gupta [27,28], Shirsat and Gupta [29], and Wierzbicki et al. [30] widely investigated the combustion characteristics of Swiss-roll combustors. Results indicated that the Swiss-roll combustors greatly enhanced combustion stability and extended extinction limits. Bagheri and Hosseini [31] investigated and compared flame stability and thermal performance of two different heat recirculation micro-combustors (inner reactor heat recirculation (IHR) and outer reactor heat recirculation (OHR)). It was suggested that IHR micro-combustor profoundly affected flame characteristic and stability, while OHR presented a higher range of emitter efficiency. Yan et al. [32] analyzed the effects of the baffle length, baffle angle $\theta$, inlet temperature and inlet velocity on the methane conversion rate and heat transfer effect on heat recuperation micro-combustor with plate structure. Results indicated that the baffle angle $\theta$ of burner significantly affected the flow and temperature field. In addition, bluff bodies were applied to extend the blow-off limit [33–35]. Hosseini and Wahid [36] investigated characteristics of lean premixed conventional micro-combustion and lean non-premixed flameless regime of methane/air. Results showed that the micro-flameless combustion was more stable when a bluff-body was used. Bagheri et al. [37] investigated effects of different shapes of bluff body on combustion characteristics and flame stability in a micro combustor. Results illustrated that the

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