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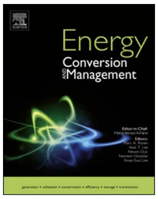

Investigation on the effects of wall thickness and porous media on the thermal performance of a non-premixed hydrogen fueled cylindrical micro combustor

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ABSTRACT

An investigation on non-premixed H_2/air combustion in a cylindrical micro combustor has been carried out. The effects of porous media and outer wall thickness on the combustion characteristics, flame location, thermal performance and energy conversion efficiency of the thermo photovoltaic (TPV) system were investigated. For the application of micro TPV system, a high and uniform outer wall temperature distribution is indispensable for the sustaining output, and the high energy efficiency is desirable. The results indicate that the setting of porous media or the increase of outer wall thickness can enhance the heat transfer in micro combustor and affects the flame stability, and the micro combustor with porous media and outer wall thickness $b = 0.2$ mm obtains the lowest flame location. They are also conducive to the improvement of outer wall temperature and energy efficiency, the outer wall temperature of the micro combustor with a thicker outer wall and porous media is relatively uniform and the energy conversion efficiency of micro TPV system is also improved, the micro combustor with $b = 0.6$ mm and porous media is more suitable for the application of micro TPV system. Additionally, the external thermal environment also can improve the outer wall temperature profile and the working performance of the micro combustor.

1. Introduction

As a relatively new technology, the micro-power system is developing rapidly with the development of Micro Electro Mechanical Systems (MEMS) and micro-fabrication technologies, which have accelerated dramatically the small devices and systems successively appearing in human life, while they require a compact, long lifetime, and instantly rechargeable power supplies capable of providing power from several milliwatts to hundreds watts [1–3]. As the critical component of micro power-system, micro combustion is an area of research focus [4,5]. Many prototypes of micro power devices have been built such as micro thermo photovoltaic (TPV) systems, micro fuel cells, micro gas turbines and others [6–8].

The heat loss of micro combustor is extremely high [9], which reduce its flame stability [10], as Wang et al. [11] found that the warm external thermal helps stabilize the flame. Taking advantage of the heat transfer from the flame can improve the combustion stability [12,13], such as heat recirculation[14] and local reflow in micro combustor, which are the flame-anchoring mechanisms of flame[15]. Furthermore, heat recirculation is of significant influence to micro combustion [16]. Yang et al. [17] found that the micro combustor with heat recuperator obtains a more uniform and higher outer wall temperature, in addition, equivalence ratio and inlet temperature also have significant effects on the heat recirculation of micro combustor [18].

Recently, researches of micro TPV system are more focus on the thermal performance and combustion characteristics of micro combustor [19]. The combustor's size and outer wall thickness [20,21] affect micro TPV energy conversion, as Li et al. [22,23] found that the effective way to elevate the system efficiency is to improve the wall temperature distribution, which needs to make full use of energy of combustion. Combustion characteristic is one of the important areas of micro combustion [24,25]. Lee et al. [26] investigated the effects of a low Peclet number and Lewis number on premixed microflames. While Tang et al. [27] investigated combustion characteristics of three hydrocarbon fuels as to study the applicability of fuels in a micro-planar combustor. Non-premixed fuel/air combustion has significant impact

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Nomenclature

c	the inertial resistance factor
D_p	the average diameter of particles, m
$D_{m,l}$	the diffusion coefficient of species l
d_{in}	the inner diameter of micro combustor, mm
h_w	the natural convection heat transfer coefficient, W/(m^2·K)
$\dot{m}_{H_2}$	the mass flow rate of inlet hydrogen, kg/s
Q_{Lhv}	the hydrogen lower heating value, MJ/kg
Q_o	the heat dissipating capacity of the outer wall, W
Q_R	the reaction heat rate, W
R_0	the universal gas constant, J/(mol·K)
R_l	the net production rate of species l, kmol/(m^3·s)
S_h	the combination of heat chemical reactant and every other heat resource
S_i	the source term of pressure loss, Pa
S_T	the standard deviation, K
T_g	the temperature of gaseous mixture and the solid matrix, K
$T_{w,i}$	the temperature of wall, K
$\overline{T}_{w,o}$	the mean outer wall temperature, K
T_∞	the ambient temperature, K
u_i	the velocity component of x_i ($i = 1, 2, 3$) direction, m/s
W_l	the molecular weight
Y_l	the mass fraction

Greek letters

α	the permeability
ε	the emissivity of the wall
η_m	the efficiency of the micro combustor
η_{TPV}	the energy conversion efficiency for TPV cells
η_t	the total energy conversion efficiency for the micro TPV system
λ_e	the thermal conductivity, W/(m·K)
λ_w	the wall thermal conductivity, W/(m·K)
μ	the dynamic viscosity, N·s/m^2
ρ_g	the gas density, kg/m^3
σ	the Stephan-Boltzman constant, W·m^2·K^{-4}
τ_{ij}	the stress tensor, N
φ	the porosity of porous media

on researches of conventional combustion, but few studies were conducted with micro combustor. Liu et al. [28] investigated the non-premixed methane/oxygen combustion in Y-shaped mesoscale combustors with and without porous media, and Ziani et al. [29] found that the increase of ambient pressure reduces the axial and radial expansion of flame and leads to a slight increase of the flame temperature, while Kim et al. [30] investigated the reacting flows in a non non-premixed methane/air micro can combustor with a baffle plate of seven holes and discussed the combustion efficiency by the conversion rate and heat loss.

For the application of micro TPV system, a high and uniform outer wall temperature distribution is desirable [17,31,32]. The fluctuation of wall temperature has a negative effect on the application of micro TPV system and reduces the lifetime of micro combustor [33]. In order to obtain a high and uniform wall temperature distribution some structural designs were introduced to the micro combustor [34,35]. Using a step in micro combustor [36–38], a counterflow and coflow double-channel micro combustor [39], a micro elliptical tube combustor [40] and a novel micro-combustor with a nozzle [41] are some useful measures to reduce the flow velocity and affect the heat transfer. Yan et al. [42] found that temperature distribution of a heat recuperation micro combustor with baffle is more uniform, while Wan et al. [43] and Su et al. [44] developed micro cavity-combustor to obtain stabilized flame and improve its performance. Furthermore, Choi et al. [45] and Park et al. [46] developed low output micro TPV device to study the performance of micro combustor. On the other hand, Jejurkar and Mishra [47] designed a hydrogen-fuelled micro combustor and Jiang et al. [48] also investigated micro combustion with a micro planar combustor to obtain a high micro TPV efficiency.

Porous media is regarded as one solid matrix which can be promising and is widely used in the combustor, due to the high conductivity, high heat capacity and high emissivity. Scholars have found that combustor with porous media can provide high burning rate, increased power and extend the lean flammability [49,50]. Adding porous media to a free flame micro combustor can enhance thermal energy transport and flame stabilities, the micro combustor with porous media will give a higher wall temperature and a lower flame temperature than that of free flame micro combustor [51,52]. Moreover,

Table 1
Comprehensive overview of investigations done with simple geometries in micro combustion.

Authors	Fuel/oxidizer	Combustor geometry	Combustor size	Reaction mechanism
Yang [1,7]	H_2/air	Cylindrical tube	L = 16 mm d_{in} = 3 mm b = 0.4,0.6,0.8 mm	Experimental research
Pan [21]	H_2/air	Cylindrical tube	L = 18,20 mm d_{in} = 1,3mm b = 1 mm	Experimental research
Wan [13,39]	CH_4/air	Parallel plate	L = 15 mm d_{in} = 1 mm b = 2 mm	Detailed gas-phase reactions
Li [22,23]	H_2/air	Cylindrical tube	L = 10,15,20 mm d_{in} = 2,3,4mm b = 0.5 mm	Experimental research
Tang [55] Su [56]	H_2/air	Parallel plate & cylindrical tubes	L = 18,20 mm d_{in} = 2 mm b = 0.2,0.5 mm	Experimental research & detailed gas-phase reactions
Chen[57]	C_3H_8/air (platinum catalyst)	Cylindrical tube	L = 4,8mm d_{in} = 0.4,0.8,1.6 mm b = 0.2,0.4,0.6 mm	One-step global reaction
Mayi [58]	CH_4/air	Cylindrical tube	L = 10 mm d_{in} = 0.6 mm b = 0.2 mm	One-step global reaction

Note: L is the combustion chamber length; d_{in} is the inner diameter of micro combustor; b is the wall thickness.

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