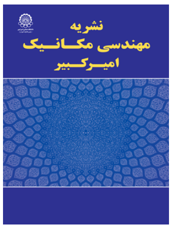

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Study of the Effective Parameters on the Performance of a Micro Thermophotovoltaic System with Micro Porous Combustion Chamber

M. Khosravi, S. A. Hashemi*

Department of Mechanical Engineering, University of Kashan, Kashan, Iran

ABSTRACT: The advantage of micro thermophotovoltaic systems is the direct conversion of heat energy into electrical energy without any moving parts. For an adequate performance of thermophotovoltaic systems, uniform and high temperature along the micro-chamber wall is required. In the present study, a laminar premixed combustion of hydrogen-air in a micro porous chamber is studied. Non-equilibrium thermal condition between gas and solid phases and radiative transport equation in solid phase is considered . Using numerical simulation, the effect of several parameters on the radiation efficiency of thermophotovoltaic system including equivalence ratio, porosity, porous thermal conductivity and inlet mixture velocity have been studied. The results show that increasing the equivalence ratio up to 1 increases the wall temperature and increasing the thermal conductivity of the porous medium, results in a more uniform temperature distribution. Also decreasing the inlet velocity, porosity and thermal conductivity of the porous medium increases the system's radiation efficiency. The convection heat transfer between the gas and solid phases inside the porous and the radiation and conduction heat transfer in the porous for the porosity of 0.4 and 0.8 were compared and it was shown that the role of radiation heat transfer inside the porous is negligible.

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1. Introduction

Nowadays, due to the improvement of the technology of manufacturing and machining of small scale components, Micro Electro Mechanical Systems (MEMS) has grown significantly, so the research on supplying suitable energy for these small equipment has been increased [1]. One of micro-scale power generation equipment is Micro ThermoPhotoVoltaic (MTPV) devices [2]. The general rule of MTPV systems is the direct conversion of heat energy into electrical energy without any moving parts. The system consists of four general components, including a heat source, a micro-chamber (the micro-chamber wall is an emitter), a simple dielectric filter and a photovoltaic cell arrangement. For proper MTPV application, uniform and high temperatures along the micro-chamber wall are required [2].

For years, the idea of flame propagation in dimensions smaller than one millimeter seemed impossible until Masel and Shannon succeeded in investigating the propagation of methane-air flame in dimensions less than one millimeter in 2001 [3]. With research on micro-combustion chambers, scientists have found that because of their high conductivity and heat capacity and high emissivity of solids, adding porous material is a good suggestion to increase the burning rate and so power and to decrease emission in porous media combustion compared to free combustion [4]. Yang et al. compared micro-combustion chamber with and without a SiC porous material for use in a TPV system. Using porous material improved heat transfer between the hot gas and the wall and eventually led to increase in wall temperature. This increase in temperature improves the radiation efficiency that is useful for TPV application [5]. Chua et al. investigated the effect of insertion porous medium in micro-combustion chambers numerically for use in MTPV and expressed the effect of equivalence ratio, thermal conductivity of porous material and flow rate on MTPV system performance. In their results, they stated that a high equivalence ratio leads to a high average wall temperature and a flame maximum temperature shift toward the inlet [6].

Considering the literature, it can be concluded that the effects of porous medium porous matrix parameters on the wall temperature distribution and radiation efficiency have not been comprehensively investigated with respect to the thermal non-equilibrium condition between the gas phase and the porous matrix.

2. Modeling

The geometrical model along with the boundary conditions, according to Fig. 1, is a channel with two parallel plates with a distance of 1 mm, a length of 15 mm and a wall thickness of 0.5 mm. The walls are made of 316L stainless steel. The hydrogen-air mixture enters the chamber at a rate of 0.8 equivalence at 300 K and 101.3 kPa, and the chamber is filled with stainless steel as the porous media. The equations of continuity, momentum, energy and species transport were simulated using a finite volume method and flow was

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*Corresponding author's email: hashemi@kashanu.ac.ir

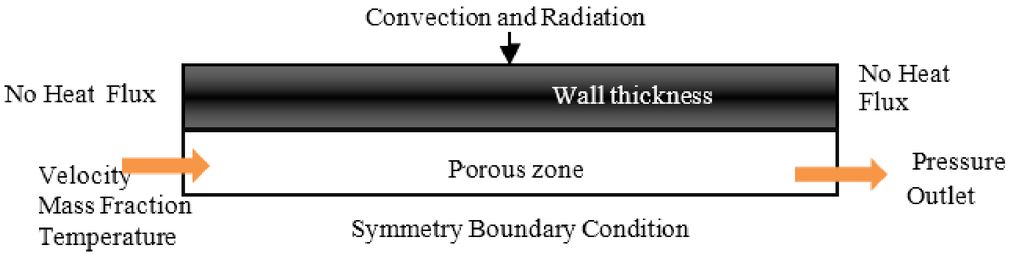

Fig. 1. The model with boundary conditions

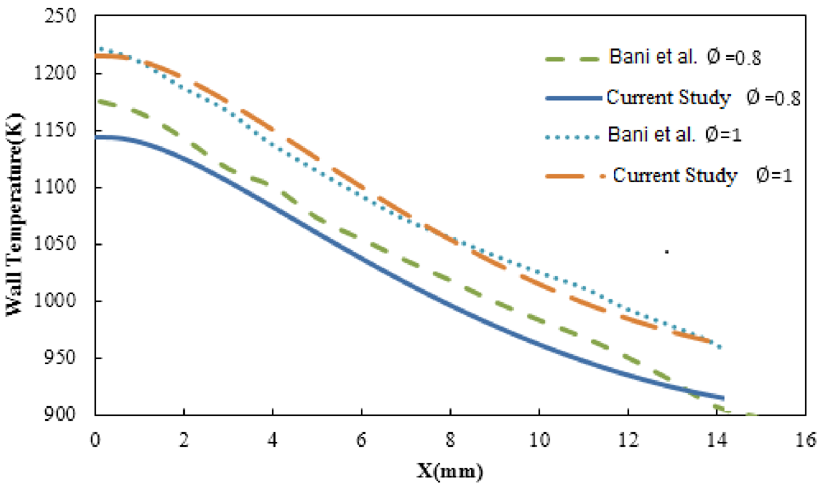

Fig. 2. A Comparison of wall temperature results in the present study with [9]

considered as a steady and laminar flow of a Newtonian fluid. The thermal non-equilibrium condition is also applied as a UDF code. For modeling the combustion chemistry, a detailed mechanism is used with 19-step reversible kinetics [7].

The following assumptions are used in numerical modeling: (1) The porous medium is considered as a gray homogeneous medium. (2) The reactants and products of combustion are considered as ideal gases. (3) The porous medium has not catalytic effect. (4) The buoyancy effects of gases and the Dufour and Soret effects are neglected. (5) Radiative gray and no-slip conditions are considered for the walls. (6) Due to the high dispersion of the porous medium in the combustion compared to the gas, the radiation in the gas has been neglected. (7) The assumption of thermal non-equilibrium between the gas phase and the porous material is considered by the UDF. (8) Reynolds number of the porous medium flow is less than 150 and therefore the flow inside the chamber is laminar.

Also, the radiation efficiency, which represents the ratio of the radiated energy emitted by the wall to the input fuel energy, is defined in [8].

3. Results and Discussion

The results of the present modeling are validated using the results presented in [9]. Fig. 2 shows the temperature distribution along the chamber wall for the present work and the results of Bani et al. in the equivalence ratio of 0.8 and 1, inlet velocity of 1 m/s, porosity ratio of 0.9 and thermal conductivity of 16.27 W/(m.K). As can be seen, there is a good agreement between the present work and the results.

According to the dependence of the reaction on the fuel concentration, the equivalence ratio of the hydrogen and air mixture is considered an important parameter. The highest wall temperature occurs in the equivalence ratio 1, and the wall temperature decreases as the equivalence ratio decreases and with increasing the equivalence ratio, the radiation efficiency also increases (Fig. 3).

Temperature distribution has become more uniform with increasing thermal conductivity and the radiation efficiency decreases slightly (Fig. 4).

Part of the combustion reaction heat is transferred by convection heat transfer to the porous medium, which increases the solid temperature in the flame region and this heat, transfers through the solid network from the high-temperature zone to the low-temperature zone. The heat transfer mechanisms inside the porous medium are conduction and radiation. In the region before the flame, heat transfer between the high temperature solid and the inlet gas mixture is via convection, which preheats the inlet gas mixture. This mechanism is called heat recirculation and plays an important role in flame stability. A comparison between the maximum value of radiation and conduction heat transfer shows that the role of radiation heat transfer inside of the porous medium in a micro combustor is negligible. Fig. 5 shows that the radiation efficiency is higher at the lower porosity coefficient.

Fig. 6 shows a comparison of radiation efficiency for different inlet velocities. As the input velocity increases, the

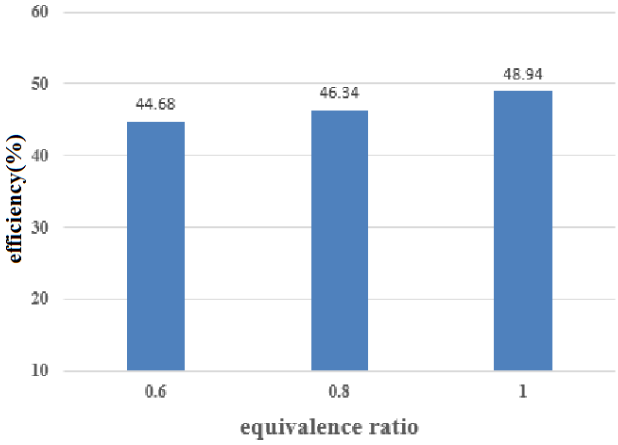

Fig. 3. Comparison of radiation efficiency for different equivalence ratio

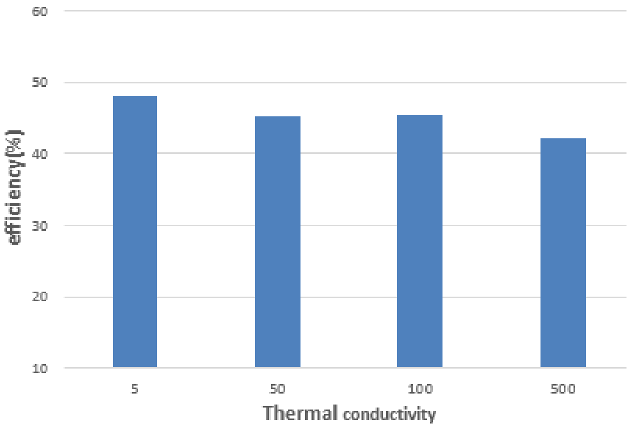

Fig. 4. Comparison of radiation efficiency for different thermal conductivity of porous

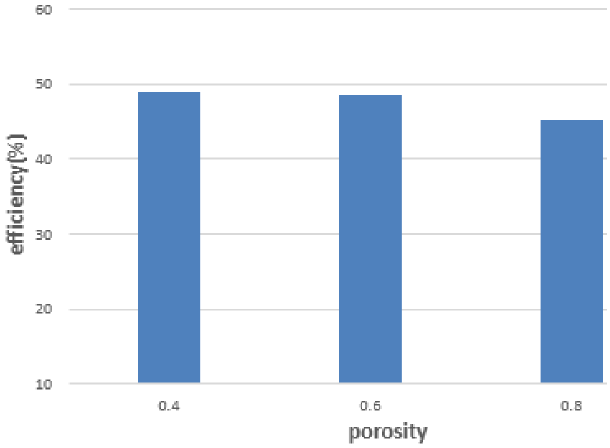

Fig. 5. Comparison of radiation efficiency for different porosity

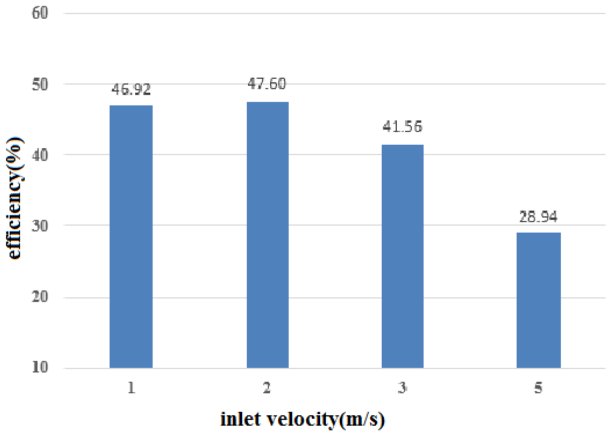

Fig. 6. Comparison of radiation efficiency for different inlet velocity

amount of input energy also increases and despite the increase in wall temperature, the radiation efficiency decreases for velocities higher than 2 m/s.

4. Conclusions

In the present work, the following results are obtained.

1. The higher thermal conductivity of the porous material results in a more uniform wall temperature distribution and reduces radiation efficiency.
2. Different mechanisms of heat transfer inside the porous media were presented and the effect of each in the different porosity coefficients was determined and it was found that the convection heat transfer between the gas and the porous solid has a significant effect on the preheating of the incoming gas mixture.
3. The effect of radiation heat transfer inside the porous material is very low.
4. Lower porosity coefficient improves heat transfer and increases radiation efficiency.

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