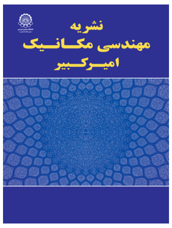

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Numerical Investigation of Channel Cross-section Effect on the Performance of Integrated Thermoelectric Power Generator

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ABSTRACT: Thermoelectric generators are a sustainable and environmentally friendly technology that can recover wasted heat energy and convert it to electricity. Meanwhile, integrated thermoelectric generators have been able to significantly increase the performance of thermoelectric generators. In this paper, the effect of flow channel cross-sections on integrated thermoelectric power generator performance is investigated numerically using the finite volume method. In this regard, various flow channel configurations including circles, trapezoids, squares, and rectangles have been taken into account and the effect of cross-sectional area ratio, semiconductor length, and Reynolds number on the performance of the device has been evaluated. In this study, the top and bottom of conductor surfaces are exposed to a cold temperature and a hot fluid with a constant velocity and temperature enters the channel. The results show that the power output, voltage, and thermal efficiency of 36 rectangular configurations are higher than other flow channels. Also, the heat input, power output, and thermal efficiency at a cross-sectional area ratio of 0.28 are respectively found to be 1.68, 1.77, and 1.52 times higher than at a cross-sectional area ratio of 0.68. In addition, an optimal length for a semiconductor is determined, in which the maximum output power is achieved.

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1- Introduction

Thermoelectric devices are a viable and suitable technology that can be used to recover waste heat energy, convert it to electricity and reduce the harmful effects of fossil fuels [1, 2]. In order to increase the performance of conventional thermoelectric generators, an integrated thermoelectric device that uses an internal conductive connector between n-type and p-type materials has been used. A channel is created in the internal connector of the integrated thermoelectric and serves as a fluid flow passage [3, 4]. In recent years various studies have been conducted on thermoelectric devices. Chen et al. [5] investigated the performance of a single-stage thermoelectric device. They found that increasing the Reynolds number and hot fluid inlet temperature improves the performance of the device. Reddy et al. [6] by changing the configuration of the flow channel of an integrated thermoelectric generator with a constant coefficient, improved the heat transfer rate and the performance of the device. Garmjani and Hosseinpour [7] investigated the performance of thermoelectric generators by considering the objective functions of power, cost, and the second law of efficiency. They concluded that the counter-flow pattern can lead to higher power output than the co-flow pattern. According to the literature survey, it can be concluded that the flow channel configuration is one of the most effective parameters in the performance improvement of integrated thermoelectric devices. In this study, different flow channel structures of an integrated thermoelectric generator including rectangle, 18 circles, 18 squares, 18 trapezoids, and 36 rectangles are investigated. In addition, finding the optimal length of the semiconductor to achieve the maximum power is another point that is addressed in this research It should be noted that the properties of thermoelectric materials (thermal conductivity, specific resistance and Seebeck coefficient) are also considered as a polynomial function of temperature.

2- System Description and Governing Equations

Fig. 1 shows the schematic view of an integrated thermoelectric generator. According to this figure, a channel is created between the terminals of the thermoelectric material in order to pass the hot fluid inside it and this channel acts like a heat exchanger. Fig. 2 shows the types of flow channel configurations including rectangle, 18 circles, 18 squares, 18 trapezoids, and 36 rectangles. It should be noted that the cross-sectional area ratio (defined as the ratio of flow cross-sectional areas of an integrated fluid flow channels $\left(A_c\right)$ and the main flow channel $\left(A\right)$ is kept constant [6]:

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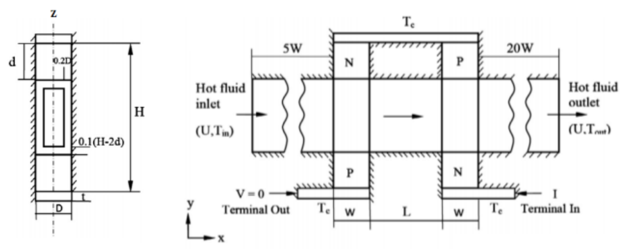

Fig. 1. Schematic view of an integrated thermoelectric generator [4].

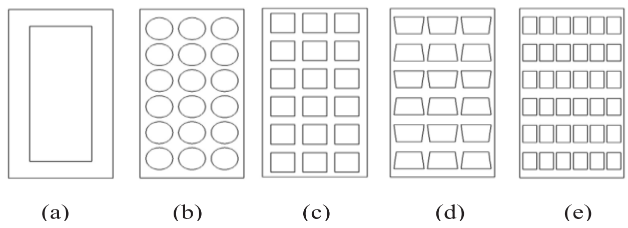

Fig. 2. Types of flow channel configurations (a) rectangle, (b) 18 circles, (c) 18 squares, (d) 18 trapezoids, and (e) 36 rectangles.

$$\phi = \frac{A_c}{A} \tag{1}$$

The equations of continuity, momentum, and energy in the fluid region are shown as Eqs. (2) to (4), respectively [3, 4]:

$$\nabla .u = 0 \tag{2}$$

$$\rho_f \left(u.\nabla u \right) = -\nabla p + \mu \nabla^2 u \tag{3}$$

$$\left(\rho_f c_{p,f} \right)\left(u.\nabla T \right) = \nabla .\left(k_f \nabla T \right) \tag{4}$$

where u, T and P are velocity vector, temperature, and pressure of the fluid, respectively. Also ρ_f, k_f, μ and $C_{p,f}$ are density, thermal conductivity, dynamic viscosity, and specific heat of fluid, respectively. For conductors and semiconductors, the current density continuity equation $\left(J \right)$ is determined from Eq. (5) [3, 4]:

$$\nabla .J = 0 \tag{5}$$

The energy equation in the conductor and semiconductor are shown in Eqs. (6) and (7), respectively [3, 4, 8]:

$$\vec{\nabla}.\left(k_s \nabla T \right) + \rho J^2 = 0 \tag{6}$$

$$\vec{\nabla}.\left(k_s \nabla T \right) + \rho J^2 - TJ.\left[\left(\nabla \alpha \right)_T + \left(\frac{\partial \alpha}{\partial T} \right) \nabla T \right] = 0 \tag{7}$$

Also, the electrical potential in thermoelectric devices consists of Ohmic potential $\left(V_O \right)$ and Seebeck potential $\left(V_s \right)$ [4]. In this study, governing equations are solved with ANSYS-FLUENT software based on finite volume method discretization.

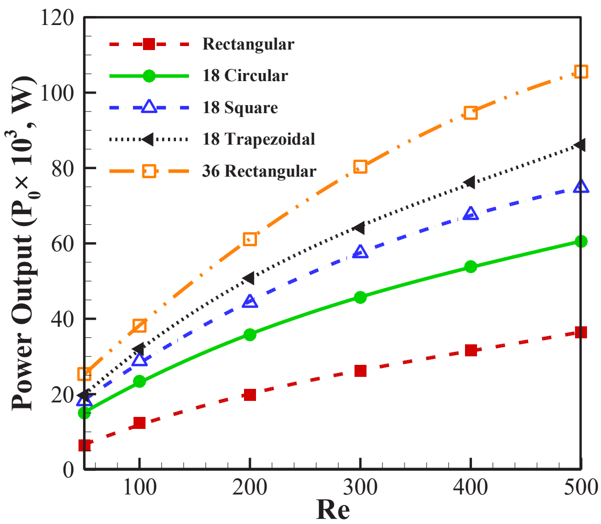

Fig. 3. The effect of Reynolds number on the power output of a thermoelectric generator with different flow channels.

3- Results and Discussion

Fig. 3 shows the effect of the Reynolds number on the power output of the thermoelectric generator. As the Reynolds number increases from 50 to 500, the rate of heat transfer between thermoelectric materials increases, and as a result more Seebeck voltage is generated. Therefore, the power output of this device increases with the increase of the Reynolds number. In addition, regardless of the value of the Reynolds number, the flow channel with the 36-rectangular configuration has a higher power output than other configurations. The variation of power output and heat input with the cross-sectional area ratio are shown in Fig. 4. According to this figure, by increasing the cross-sectional area ratio from 0.28 to 0.88, it has been observed that the power output and heat input decrease exponentially and linearly, respectively. This is due to the fact that as the temperature increases, the average velocity and rate of heat transfer between the fluid and the internal conductor decreases.

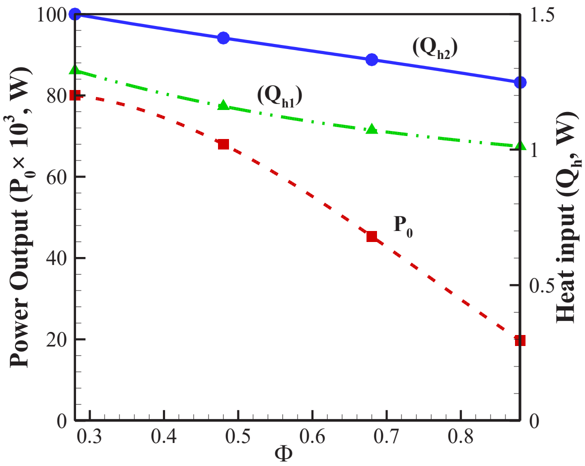

Fig. 4. The effect of different cross-sectional area ratios on power output and heat input.

4- Conclusion

In this research, the effect of the cross-section of the flow channel on the performance of an integrated thermoelectric device was studied using the finite volume method. According to the results, the structure of the flow channel has an impressive effect on the performance of the integrated thermoelectric device. The results showed that increasing the Reynolds number leads to an improvement in the power output. Also, the flow channel with the configuration of 36 rectangles has a higher power output compared to other configurations. In addition, due to the reduction of heat transfer surface area, as the cross-sectional area ratio increases, the power output, and heat input decrease. Moreover, at an optimal length of the semiconductor, the power output of the thermoelectric device reaches its maximum value and then reduces.

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