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IMPROVED POWER GENERATION OF MICRO THERMOELECTRIC GENERATOR USING MICROFLUIDIC HEAT TRANSFER SYSTEM

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ABSTRACT

In these paper microfluidic properties is applied to a micro thermoelectric generation device (μTEG) and compared it with a micro thermoelectric generator where the microfluidics property is not used. By computationally applying a constant temperature difference between the hot side and cold side of the micro thermoelectric generator where the fluid parameters are considered as a laminar flow and the micro thermoelectric generator efficiency is calculated. Furthermore using the same temperature difference between the hot side and the cold side of the same dimension micro thermoelectric generator efficiency is calculated. In this paper it shows that using microfluidics properties the generated power is more. Experimental studies have done for a 50μm×50μm cross sectional area and 700K temperature distribution of a μTEG where the output power is 380 mv which 16% more than the previous.

Keywords: micro thermoelectric generator, laminar flow, flow rate.

1. INTRODUCTION

Due to the awareness of energy harvesting and global warming issues the demand of the clean energy system is increasing. Micro thermoelectric generators which utilizes waste heat energy and acts as a clean energy source. Micro thermoelectric generators works on the principle of the seebeck effect. When there is a difference in temperature exist across the material, an electric potential is developed and when a load is connected electrical power output is obtained. The micro thermoelectric generators have no moving part, so the device is robust and maintenance free [1, 2]. The lack of moving parts offers silent reliable operation [2]. Like that from hot gas streams the electrical power generated using micro machined radial thermoelectric modules [2]. This is applicable for biomass furnaces with thermoelectric generators [3]. This thermoelectric module made by Bismuth-Telluride and can provide a nominal power of 200w [3]. This power generation also applicable for waste heat energy which utilizes the body heat [4]. This proposed micro thermoelectric generator (μTEG) also made by thermoelectric material bismuth-telluride and makes the body heat from person's wrist. This proposed system also can generate electric potential and used to power up wrist watch of 1μw with a driving voltage of 1.5v [5]. In micro thermoelectric generator output power is increased Bv microfluidic property which is interfaced with the heat transfer module of thermoelectric property. Using microfluidic property the thermal contact resistance goes to very small range to enhance the output power of the micro thermoelectric generator. Stacked micro thermoelectric generator using oil and water as a heat exchanger media and can produce 170w of power with a temperature gradient 130K [6]. Furthermore a 6 stacked thermoelectric module can produce 500w power with an inlet temperature difference of 205K [6]. The heat exchanger media can change for applications. This thermal coupling of micro thermoelectric devices will create an effect on the temperature gradient between the heat source and the heat sink and can produce improved output power.

2. MATHEMATICAL MODELLING

The single-phase fluid flow (laminar flow) interface is based on the Navier-Strokes equation. From the equation it shows

$$\frac{\partial\rho}{\partial t} + \nabla.(\rho.u) = 0 \quad (1)$$

From the equation after partial differntiation

$$\rho c_p(\frac{\partial T}{\partial t}+(u.\nabla)T)=-(\nabla.q) + \tau.s - \frac{T}{\rho}\frac{\partial\rho}{\partial T}\Big|p\,(\frac{\partial\rho}{\partial t} + (u.\nabla)p) \quad (2)$$

Where the density $(\rho)$of the microfluidic material is 1kg/m^3.

In the velocity vector (u), the initial inlet velocity (v) = 0.01m/s and at the outlet the atmospheric pressure (p) = 0. The absolute temperature (T) is 293.13k. In that temperature the heat capacity at constant pressure is 4.1818J/(kg-k). Where as in the above equation the heat flux (q), the heat source (Q) and the strain-rate tensor are taking from the material properties.

For evaluating the electric potential (V) from the thermoelectric module with the corresponding applied temperature from the following mathematical equation. With whole computational domain D

$$\int_D(\nabla.q)V_T=\int_D QV_T \quad (3)$$

$$-\int_D J.\nabla\, v_v+\int_D n.J\, v_V=0 \quad (4)$$

After partial integration

$$-\int_D q.\nabla V_T + \int_B n.qV_T=\int_D QV_T \quad (5)$$

$$-\int_D\ J.\nabla v_V\ +\int_B n.v_V=0 \quad (6)$$

In the above, assuming there are known value for the heat flux q=q_0 and the current flux $J = J_0$and rewrite the equation

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$$\int_D q.\nabla v_T + \int_B q_{0.} V_T = \int_D Q V_T \quad (7)$$

$$\int_D J.\nabla v_V + \int_B J_0 \ v_V = 0 \quad (8)$$

Solving the equation the first condition set as T=T_0 on a boundary condition as 300k (user defined) and v=V_0 on a boundary condition which is taking from the material properties. In the 2nd condition the heat flux (q_0)=0 and the current density(J_0)=0on the boundary condition. As because these values are naturally weak form of the partial integration and this condition represents the thermal and electrical insulation.

3. SIMULATION OF µTEG WITH MICROFLUIDIC PROPERTY

Using comsol multiphysics version 4.4 version the basic structure of micro thermoelectric generator has simulated. The micro thermoelectric generator made by the material bismuth-telluride which has highest figure of merit at room temperature [1]. In the proposed system cross sectional area is 50µm×50µm. In the thermoelectric material properties in the p type bismuth–telluride leg seebeck coefficient is 260.4×10^{-6}. where as for the n type bismuth-telluride leg the seebeck coefficient is -262.26×10^{-6}. The electrical conductivity of the bismth-telluride is 2.3×10^{3}s/m. In the above of the micro thermoelectric generator the contact layer made by copper as because copper is a good conductive material. After chosing heat transfer in solid physics,the hot side temperature is applied as 1000k and the cold side temp is applied as 300k. In the thermoelectric effect,at the end of the thermoelectric leg make the electric potential(v) as 0. Then study the electric potential distribution of the micro thermoelectric generator. But applying microfluidic heat transfer system which will reduce the thermal contact resistance and make the temperature gradient more than the previous, therefore the more output power is achieved. In this proposed structure to get more output power ,laminar flow is interfaced with heat transfer module module. To implement laminar flow properties in this structure above the micro thermoelectric generator a square shaped channel is formed which is made by silicon. In the intermediate part of the channel, water as a microfluidics material is applied. The thermal conductivity of the silicon is 149w/9(m-k) and the electrical conductivity of the material is 1.56×10^{-3} s/m. The laminar flow property is used here to compute the velocity and the pressure fields for the flow of a single phase fluid. In that laminar flow properties for inlet velocity 0.01m/s is selected initially, later this flow rate has varied for getting more output power. During inerfacing the microfluidics property in the solid,fluid structure interaction helps how the fluid flow can deform structures.

Here in the following figure the boundary is selected with a boundary condition where the solid and fluid has an interaction.In that fluid structure interaction, a linear elastic material has chosen.where the young's modulus of the material (silicon) is 179×10^{10}pa and the poisson's ratio is 0.27. The square shaped channel through where the fluid will flow is fixed. Under the simulation procedure the Figure-1 shows the design and the temperature distribution of the micro thermoelectric generator. Figure-2 shows the design and voltage distribution of the same micro thermoelectric generator. Figure-3 shows the temperaure distribution of the modified Figure µTEG. Figure-4 shows the design and flow and stress distribution on the micro thermoelectric generator. Figure-5 shows the modified design and the voltage distribution of the micro thermoelectric generator. Figure-6 shows the velocity distribution of the micro thermoelectric generator where the Figure-7 shows the voltage distribution of the µTEG for the flow rate is 0.15m/s. Figure-8 shows the voltage distribution of µTEG for the fow rate 0.3m/s.

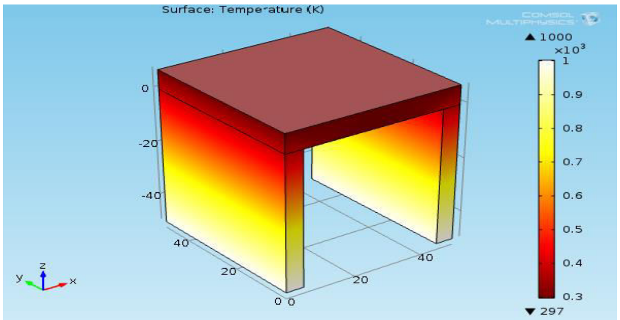

Figure-1. Temperature distribution of µTEG.

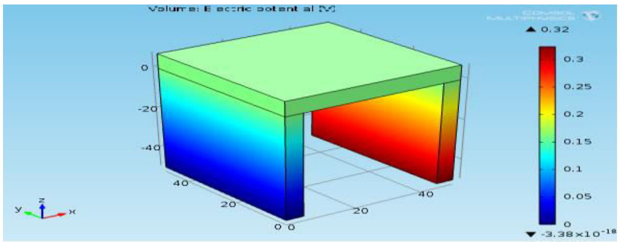

Figure-2. Voltage distribution of µTEG.

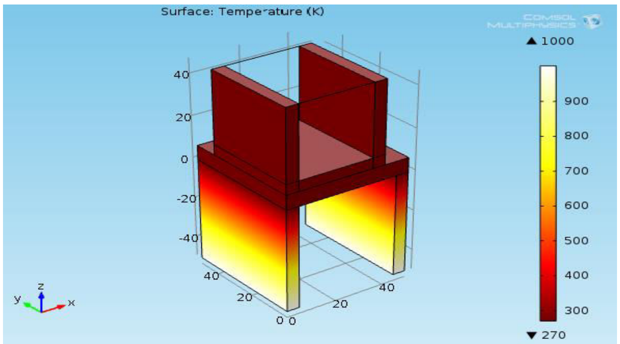

Figure-3. Temperature distribution in modified design in µTEG.

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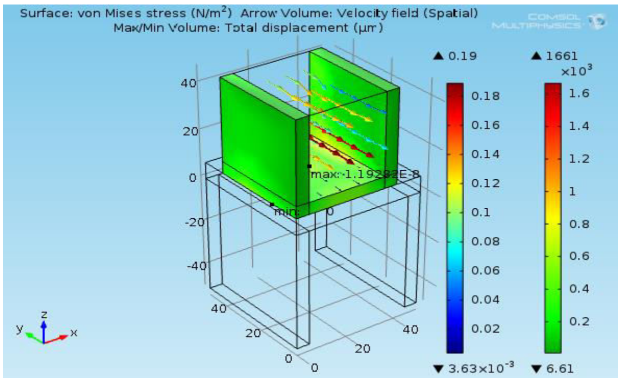

Figure-4. Flow and stress distribution of μTEG.

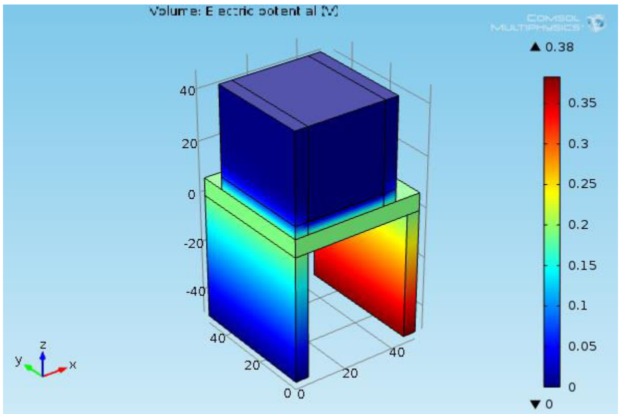

Figure-5. Voltage distribution in modified design of μTEG.

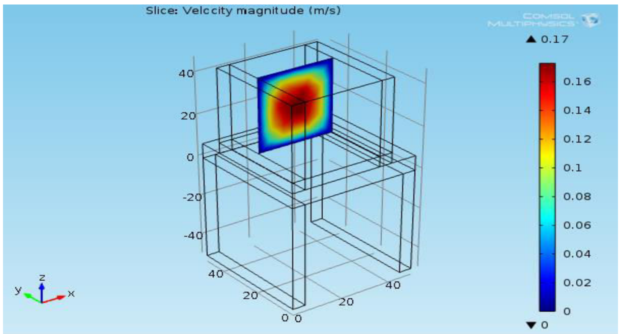

Figure-6. Velocity distribution in modified design of μTEG.

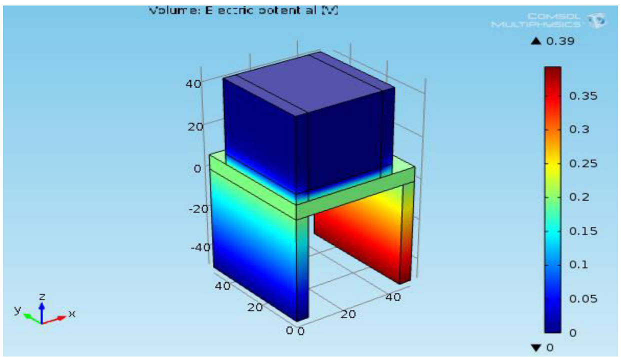

Figure-7. Voltage distribution of μTEG for flow rate 0.15m/s.

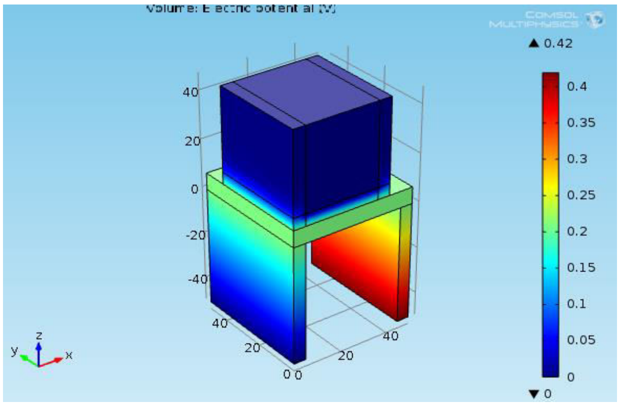

Figure-8. Voltage distribution of μTEG for flow rate 0.3m/s.

4. RESULT AND DISCUSSIONS

In the Figure-9 the measured output voltage is plotted in respect to the flow rate. In the plotted graph the flow rate is varied in between 0.01m/s to 0.300m/s. From the several experimental studies on micro thermoelectric generator using microfluidics property, it has shown that due to increase the flow rate, the heat transfer resistance (R_{HTS}) decreases and causes the rise in heat capacity rate of the fluid. Due to the less temperature in fluid, emitted heat from the solid surface and makes the temperature gradient more than the previous. For creating the more temperature gradient between the heat source and the heat sink the output power of the micro thermoelectric generator is more than the previous. Increasing the flow rate from 0.01m/s to 0.300 m/s, the electric potential of the micro thermoelectric generator has increased to 16% more than the previous.

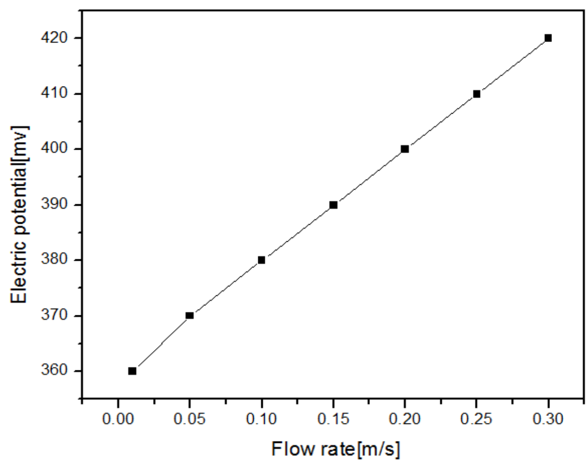

Figure-9. Electric potential (mv) vs flow rate (m/s).

CONCLUSIONS

From the result of the proposed micro thermoelectric generator we can conclude that the effect of the microfluidics property enhances the temperature gradient between the heat source and heat sink. This makes an optimized micro thermoelectric generator which is more powerful than the micro thermoelectric generator where the microfluidics property is not used. The coupling of the heat transfer system with micro thermoelectric generator reduce the heat transfer resistance which again improved the temperature gradient across the heat source and the heat sink of the micro thermoelectric generator to produce more output power. More improved design like instead of taking only one square type channel choose a manifold structure with a stacked of micro thermoelectric generator and through the manifold structure the fluid will flow, will be the future work. For this case we have to minimize the pumping power to get more output power from the micro thermoelectric generator.

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