Design and Simulation of Thermoelectric Generator to Enhance the Cooling Rate and Power Generation from Waste Heat of Chimney by Employing Different Angles of Flaps †

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Abstract: This study consists of a modern and economic way to recover the heat wasted from the industrial chimneys which are cooled down by natural sources by using thermal electric generator heat sinks. A flap with altered heat sink (which is attached at the top of thermo-electric generator) is used in place of convectional heat sink base. A 3D model is proposed by using AUTODESK Fusion 360 and is solved by using Workbench 2021 R1 ANSYS. The presented setup fully describes the transfer of heat along the one vertical bar inside the TEGs module which is mounted along the vertical wall of the Chimney. The impact of Flap dimensions (Height, Depth, and Angle) and conductive material performance is studied. The flap angles are 45°, 50° and 60° and depths of the flap are 28 mm, 30 mm and 33 mm. This altered heat sink accomplishes about 28% enhance in the rate of cooling of TEGs module. The maximum output power, i.e., 105 mV of the TEGs module is at 60° and at 33 mm depth. The results show that remodified heat sink maintains the system simple and requires less maintenance and also improves the cooling rate of the thermoelectric generator, which as a result improves its performance and make it reliable.

Keywords: thermoelectric generator; cooling rate; power generation; waste heat; modified

1. Introduction

The operation of the TEG is dependent upon Seebeck effect, which is used to generate electrical power generation by applying significant temperature difference over the minimal thickness. Lv et al. [1] suggested different techniques for the finer cooling of the TEGs. Demir and Dincer proposed shell and tube type heat exchanger for the removal of exhaust fumes from the exhaust, while fresh air is used to cool the TEGs module. Maximum production of power from this system is 158 W correlate with the density of power 108.8 W/m² [2]. Figure 1 shows (a) TEG module domain and its (b) Geometry.

Figure 1. (a) TEG Module Domain (b) Geometry of TEG.

Only limited research has been carried out on the TEG for recovery of dissipated heat from a smokestack when it subjected to passive cooling. Ansys fluent module is used to...
solve a 3D CFD model described in this paper. The heat is deviated away from the chimney by employing flaps on the upper side of the heat sink. Flaps are angled at various angles and have varying depths. The 3D model represents all the features of the temperature distribution, directional electric field strength, potential difference, and total heat flow rate. The goal of the study is to recuperate the heat dissipated from the funnel and transfer this wasted heat into electrical power.

2. Methodology

2.1. Physical Domain

Flap used has a specific inclination angles ‘α’ and specific length ‘Lf’ in respect of the upright surface of the chimney. Flap contiguity with heat abstraction thickness of base is 0.5 mm and fins of the heat sink is 2 mm. Number of fins mounted on heat sink is 13, with a height of 30 mm and its thickness is 2 mm, its height from the base of the heat sink is 30.5 mm. The purpose of these modifications in the heat sink is used to increase the heat transfer and cool the TEG’s module mounted on chimney’s vertical surface [3]. A heat spreader has a thickness of 75 × 90 × 0.5 mm is mounted between heat sink vertical surface and wall of chimney. TEG module structure consists of 36 Thermocouples whose positive leg is made up of Bismuth Telluride (BiTe+) and negative leg is (BiTe−) having leg length ‘Lg’ 1.4 mm. Figure 2 shows the TEG schematic diagram.

![Figure 2. Schematic diagram of TEG.](image)

2.2. Governing Equations

For solid domain, heat scattering equation is used to govern the rate of heat transfer across (TEG, spreader, and heat sink) [4]. Following equations help to govern flow of fluid and heat transfer which surround the heat absorber [5]. Equations (4)–(6), respectively, represent them [6,7].

\[
\nabla \cdot \left( \frac{\nabla T + \| \mathbf{J} \|^2}{\sigma} - \frac{T}{\alpha} \frac{\partial \mathbf{J}}{\partial T} \cdot \nabla T \right) = 0
\]

(1)

\[
\nabla \cdot \mathbf{J} = 0
\]

(2)

\[
\varphi = \frac{\mathbf{J}}{\sigma} + \alpha \nabla T
\]

(3)

\[
\nabla \left( \rho \nabla \varphi \right) = 0
\]

(4)

\[
\nabla \left( \rho \nabla \varphi \right) = -\nabla P + \rho g
\]

(5)

\[
\nabla \left( \nabla (\rho E + P) \right) = \nabla (k \nabla T)
\]

(6)

2.3. Material Properties

Figure 3 shows Material behavior of positive and negative leg. Material used is Bismuth-Telluride alloy.
3.2. By Using Conductive Flap

These governing equations are valid for TEG modules as long material and formation do not change [11]. There are considerations of the buoyancy effect in which ambient pressure varies linearly with the change of height Equation (14).

\[
P_{amb} = 101325|P_a| - \rho g H
\]  

(14)

3. Results and Discussion

3.1. Impact of Flap Depth

Figure 4 displays effect of temperature and voltage on depth of flap. The result shows that by using conventional heat sink with TEG module has the lowest output power and has minimum efficiency.

\[
q_{TEG} = |W| = -2.648 \times 10^{-4} \Delta T^2
\]  

(10)

\[
|W| = -4.81 \times 10^{-13} \Delta T^5 + 2.16 \times 10^{-10} \Delta T^4 + 3.06 \times 10^{-8} \Delta T^3 + 1.92 \times 10^{-5} \Delta T^2
\]  

(11)

\[
V_{TEG} = 7.43 \times 10^{-6} \Delta T^2 + 5.29 \times 10^{-13} \Delta T
\]  

(12)

\[
\eta_{TEG} = 1.79 \times 10^{-7} \Delta T^2 + 3.46 \times 10^{-5} \Delta T
\]  

(13)

3.2. By Using Conductive Flap

It is clearly shown from the Figure 5 that as we use flap to enhance the cooling rate of TEG the output voltage also increases.
4. Conclusions

This study presents numerical investigation to effectively recover waste heat from the industrial sources and produce electricity using thermoelectric generator. The flap angle and the depth of the flap are varied to find the best configuration. Flap of 45°, 50° having depth of 30 mm, 30 mm, respectively, and 60° having depth of 26 mm, 30 mm and 33 mm are used. Flap with angle 60° having depth 33 mm provides maximum cooling rate 28% and produce voltage 105 mV.

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