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Experimental performance of Thermo – Electric Generator integrated with heat pipe

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Abstract - The present study experimentally investigates the performance of Thermo-Electric Generator (TEG) integrated with heat pipes. The heat pipe assembly has distilled water as the working fluid with 4 number of C-shaped heat pipes. The thermal energy of high pressurized steam is used to increase the temperature of the hot side of TEG. The readings of voltage and power output for closed circuit were taken experimentally for a pressure range of 1-10 bar (gauge) for natural as well as forced convection. Further, the results of this configuration were compared with the earlier arrangement of heat sink (without heat pipe configuration). It is found that the performance of TEG integrated with heat pipe shows a significant increase in voltage and power output in comparison with TEG without heat pipe. The outcomes of this study will be useful for utilizing waste thermal energy for generating power that can be utilized for operating auxiliary thermal equipments.

Keywords: Thermo – electric generator, heat pipe, thermal energy

I. INTRODUCTION

Growing demand for energy consumption has become a major problem in today's scenario. A substantial part of global energy usage is consumed in the form of thermal energy. The thermal energy in industrial applications which is being dissipated as waste heat to the environment can be utilized further for power generation. Two promising technologies that are found to be useful for this purpose are Thermo – Electric Generator (TEG) and heat pipe. A heat pipe as seen in figure 1 utilizes the latent heat of the vaporization and effectively transports thermal energy from one end to the other [1]. When heat is applied at the evaporator section of heat pipe, the liquid in the heat pipe evaporates. Condensation of the vapor occurs at condenser section of heat pipe. As it condenses, the vapor gives up the heat it absorbed at the evaporation section. The condensate then returns back to the evaporator section, through the wick structure due to capillary action.

TEG works on the principle of Seebeck effect which states that the temperature difference between junctions of two dissimilar conductors or semiconductors produces a voltage difference between the two junctions. As thickness of TEG is very small, most of the heat is transferred to cold side from hot side by heat conduction thus reducing the efficiency of TEG. So, to maintain the temperature of cold side as minimum as possible, heat pipe is used at cold side of TEG. Heat pipe transfers the heat from cold side of TEG to the surrounding environment, thus maintaining better temperature difference across TEG. The present study deals with the experimental performance of TEG integrated with heat pipe.

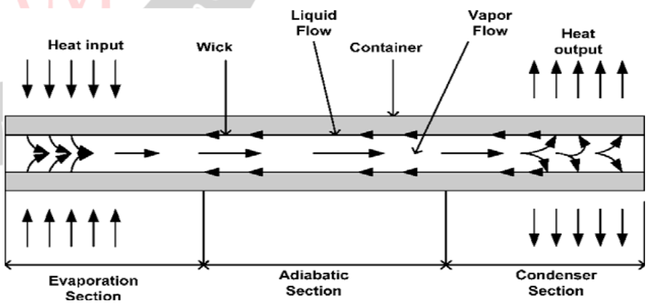

Fig. 1 Schematic of heat pipe operation [2]

II. LITERATURE REVIEW

M. F. Remeli et al. [3] performed experimental investigation for power generation by using the combination of heat pipes and thermo-electric generators. The experimental investigation was done on the model of power production by TEGs using heat pipes and simulated hot air. The results obtained showed that as the ratio of mass flow rate in upper duct to the lower duct increased, the overall system performance went on increasing. A higher mass flow rate ratio resulted in a higher amount of heat transfer and higher power output. A new method of

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recovering waste heat and electricity using a combination of heat pipes and TEGs was explored by Muhammad Fairuz Remeli et al. [4]. In this study, Bismuth-Telluride (Bi_2Te_3) based TEGs were sandwiched between two finned heat pipes to achieve a temperature difference across the TEG for thermoelectricity generation. The modeling results showed that the system had the capability of recovering 1.345 kW of waste heat and generating 10.39 W of electrical power using 8 installed TEGs. Ju-Chan Jang et al. [5] investigated the method of improving the power generation of a TEG system. In this study, for hot gas exhaust temperature of 170 ^{o}C, the TEG system with a wickless loop heat pipe was able to generate a voltage output of around 1.3 V. Two TEGs for a conductive block model and four Bi_2Te_3 TEGs with a heat pipe-assisted model were installed in the condenser section. F. P. Brito et al. [6] explored the potential of TEG in combination with variable conductance heat pipes. Bin-Juine Huang et al. [7] investigated the performance of TEG with loop heat pipe. This study proposed a TEG design using loop heat pipe to dissipate the heat to the environment by natural convection.

III. OBJECTIVE

The main objective of the present study is experimental analysis of TEG integrated with heat pipe, for exhaust steam application. Table 1 summarizes the specifications for the experimental investigations.

Table 1 Specifications of experimental investigations

Specifications	
Exhaust steam	Steam quality: Saturated steam Pressure range of steam: 1-10 bar (gauge)
TEG module	Module: TEG127-1.4-1.0 Dimensions: 40×40 mm Seebeck coefficient: 0.05818 V/K
Heat pipe	Capacity: 200 Watts

IV. METHODOLOGY

Figure 2 shows the earlier arrangement of heat sink (without heat pipe configuration).

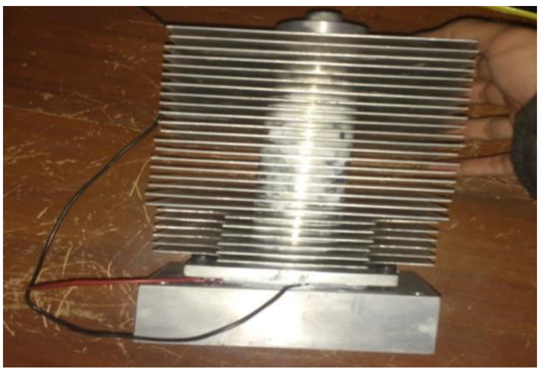

Fig. 2 Earlier arrangement of TEG with heat sink (without heat pipe configuration)

Figure 3 shows the new arrangement of TEG integrated with heat pipe. TEG is made up of n-type and p-type semiconductors which are sandwiched between two ceramic plates. Bismuth-Telluride (Bi_2Te_3) is used as a semiconductor for TEG in the present study. The heat pipe assembly has distilled water as the working fluid with 4 number of C-shaped heat pipes. Each heat pipe is of 9.5 mm outside diameter with 0.07 m evaporator length, 0.1 m condenser length and 0.08 m adiabatic length. The heat pipe is made up of copper whereas fins and block are made up of aluminum. The dimension of block is 0.09m × 0.04m × 0.012m.

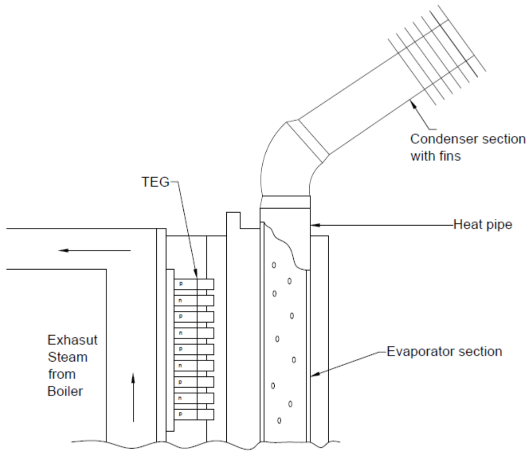

Fig. 3 Schematic of TEG integrated with heat pipe (New arrangement)

The TEG is mounted on the exhaust steam pipe of the boiler as shown in the figure 4. The heat energy of high pressurized steam is used to increase the temperature of the hot side of TEG. Metal block is attached on steam pipe as shown in figure 4. The heat pipe is used on cold side of the TEG to decrease the temperature of cold side by improving the heat dissipation rate. The output from the TEG can be used for operating auxiliary devices such as flow meter.

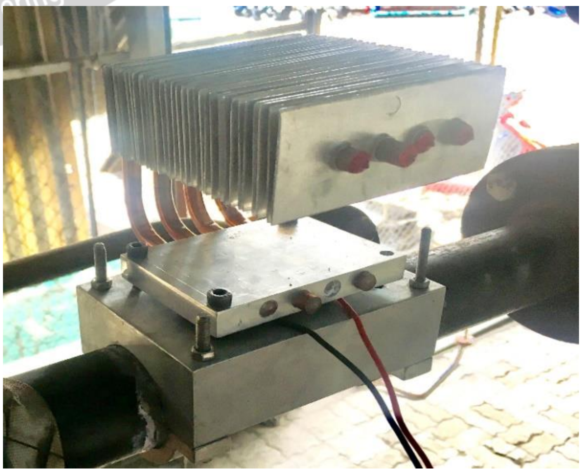

Fig. 4 Test rig with experimental setup

The system integration for the present experimental study is shown in figure 5. The pressure of exhaust steam is controlled by using pressure relief valve (PRV). As the

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pressure is increased the temperature difference across TEG increases thereby increasing the voltage output. The readings are taken at a pressure interval of 1 bar in the range of 1-10 bar (gauge).

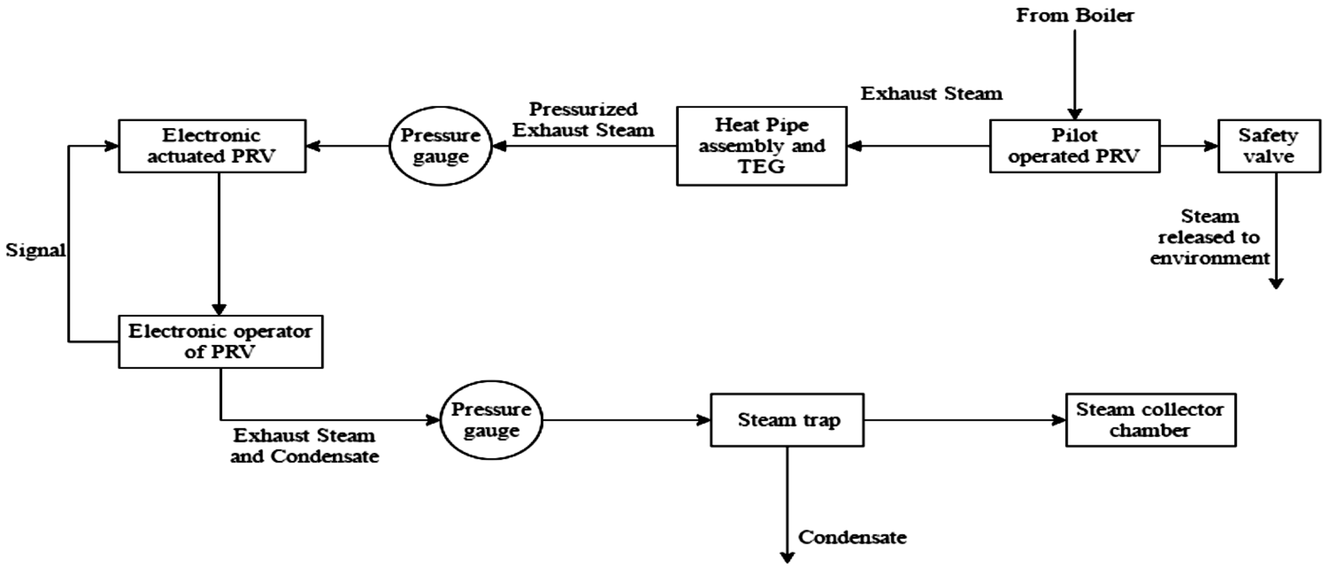

Fig. 5 System Integration

V. RESULTS AND DISCUSSIONS

Table 2 and 3 shows the performance of TEG integrated with heat pipe with forced convection and natural convection.

Table 2 Performance of TEG integrated with heat pipe with forced convection

Pressure (bar)	Closed circuit voltage (Volts)	Power output in Watts for R = 24 Ω
1	1.861	0.144305
2	2.075	0.179401
3	2.263	0.213382
4	2.59	0.279504
5	2.638	0.28996
6	2.687	0.300832
7	2.93	0.357704
8	2.998	0.3745
9	3.101	0.400675
10	3.13	0.408204

Table 3 Performance of TEG integrated with heat pipe with natural convection

Pressure (bar)	Closed circuit voltage (Volts)	Power output in Watts for R = 24 Ω
1	1.413	0.08319
2	1.678	0.11732
3	1.702	0.120700
4	1.925	0.154401
5	2.016	0.169344
6	2.108	0.185152
7	2.193	0.200385
8	2.23	0.207204
9	2.298	0.220033
10	2.417	0.243412

Figures 6 and 7 shows the comparison of TEG integrated with and without heat pipe.

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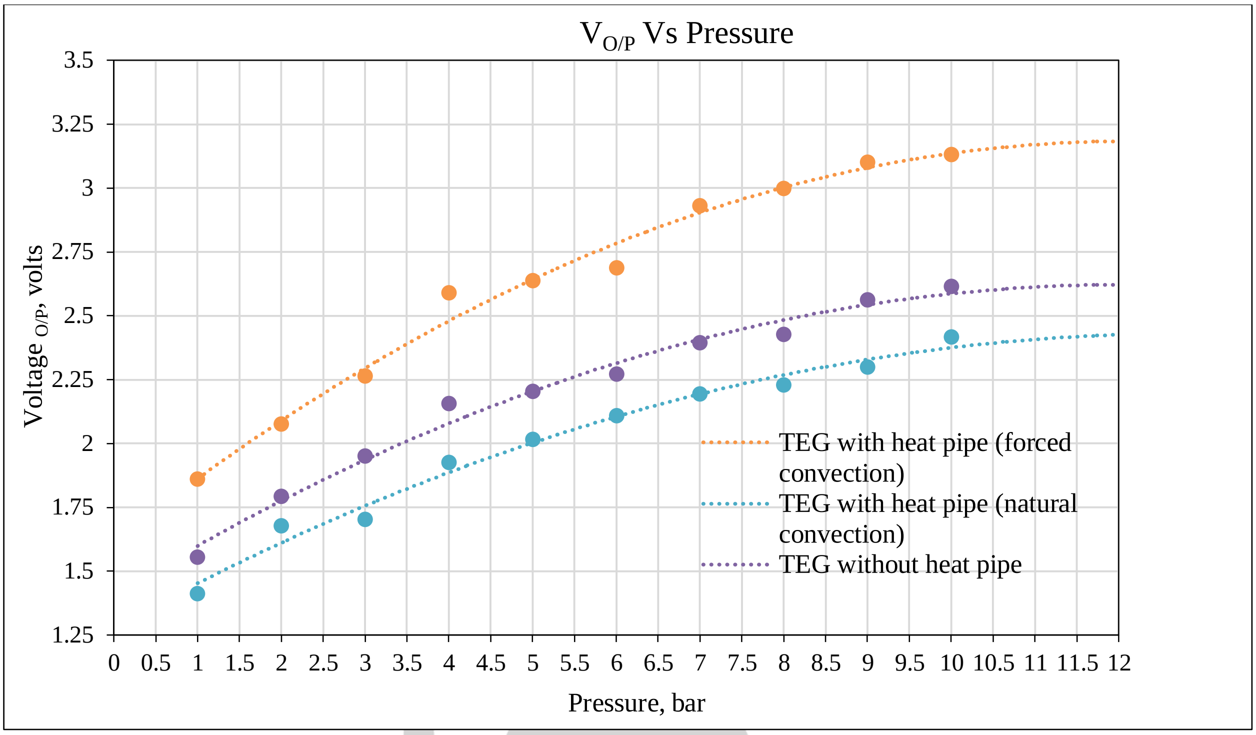

Fig. 6 Voltage output Vs Pressure

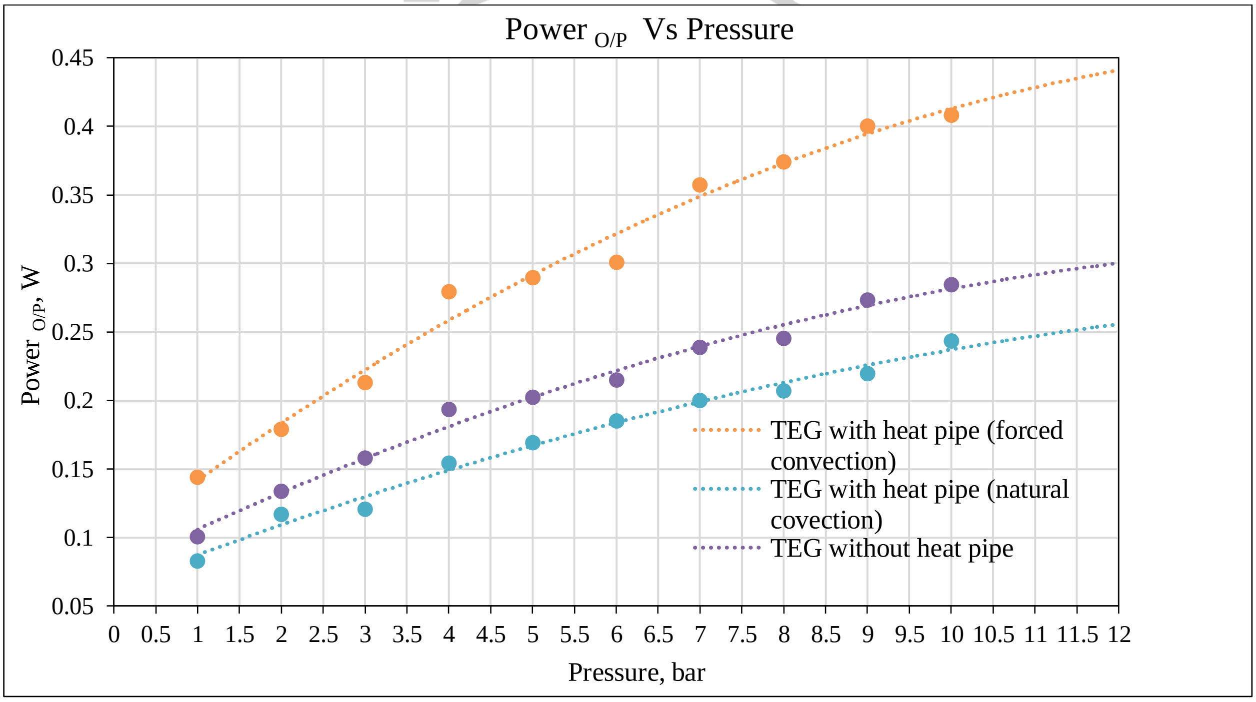

Fig. 7 Power output Vs Pressure

The performance of TEG integrated with heat pipe shows promising results with forced convection. The velocity of air was kept at 1 m/s for forced convection. The performance of TEG with heat pipe can be further investigated at varying velocities. It is also implicit that the voltage output and power output of TEG increases with increase in the pressure of exhaust gas. As the pressure of exhaust gas increases, the heat input to the hot side of the TEG increases. Since the heat input increases, the heat pipe assembly transfers more heat from the cold side of the TEG to the environment. The increase in voltage and power output is observed when the temperature difference across the TEG is increased. In a temperature gradient, electrons and holes tend to accumulate on the cold side. As the temperature gradient is increased the more and more electrons and holes with high velocity try to accumulate on the cold side of the TEG. This gives the increment in

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electric field between the cold side and hot side of the TEG resulting in the increase of voltage and power output.

VI. CONCLUSIONS

The present study investigates the performance of TEG integrated with heat pipe for utilizing the waste heat from the exhaust steam. The power output obtained from this configuration can be used for operating auxiliary devices such as flow meter. The experimental investigations shows promising results for TEG integrated with heat pipe with forced convection. At an exhaust steam pressure of 10 bar and at a velocity of 1 m/s, the TEG integrated with heat pipe had a significant increase of 20 % in voltage output and 43 % in power output, in comparison with TEG without heat pipe. The outcomes of this study will help in utilizing waste thermal energy for generating power that can be utilized for operating auxiliary thermal equipments. The further investigations on various operating conditions as well various combination of TEG materials and heat pipe configurations, will provide a comprehensive understanding of this technology for energy recovery applications.

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