Thermoelectrical Generator for Waste heat Recovery- Review

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Abstract – *Nowadays, an increasing environmental issues of emission due to discharge of engine exhaust and industrial waste heat. The Thermo electrical Generator can produce clean energy conversion and are environmental friendly. Thermo electrical power generators have emerged as a promising alternative green technology. Thermo electrical power generators provide a potential application in the direct conversion of waste heat energy in to electrical energy. The purpose of this paper is to review on different cooling systems, thermal uniformity of exhaust heat exchanger, and various operating conditions.*

Key Words: Heat Exchanger, thermo electrical generator, Thermal uniformity, Waste Heat.

1. INTRODUCTION

Approximately 30% of the energy generated by the combustion of fuel in the engine cylinder will be converted by the cylinder piston motion into the brake force of vehicles (5% of it will be neutralized by friction loss of machine members). In addition, about 70% of it cannot be converted into mechanical energy, but disperses to the environment as waste heat [1].There are large potentials of energy savings through the use of waste heat recovery technologies. Waste heat recovery entails capturing and reusing the waste heat from internal combustion engine and using it for heating or generating mechanical or electrical work. It would also help to recognize the improvement in performance and emissions of the engine if these technologies were adopted by the automotive manufacturers [2].

Over the last 30 years, there has been growing interest in applying this thermoelectric technology to improve the efficiency of waste heat recovery, using the various heat sources such as geothermal energy, power plants, automobiles and other industrial heat-generating process [3].The power generation of exhaust TEG (thermoelectric generator) depends on heat energy and thermoelectric conversion efficiency. High efficiency heat exchanger is necessary to increase the amount of heat energy extracted from exhaust gas[4].

Thermoelectric Module (TEM) offers thermoelectric energy conversion in a simple and reliable way along with advantages of not involving moving or complex parts, silent in operation, maintenance free and environmental friendly [5]. Owing to these advantages, there have been considerable emphases on the development of the small TEGs for a variety of aerospace and military applications over the past years. More recently, there is a growing interest for waste heat recovery TEG, using various heat sources such as combustion of solid waste, geothermal energy, power plants, and other industrial heat-generating processes. In the case of TEG for waste heat recovery power generation, there have been many conceptual designs of a power conversion system which are potentially capable of obtaining application in this area [6].In general, the cost of a thermoelectric power generator essentially consists of the device cost and operating cost. The operating cost is governed d by the generator's conversion efficiency, while the device cost is determined by the cost of its construction to produce the desired electrical power output [7].

2. THERMOELECTRIC THEORY

Thermoelectric modules are devices which can convert heat or temperature different directly into electrical energy. A two element of semiconductor bismuth telluride (Bi_2Te_3) is a common material used in thermoelectric modules. Bismuth telluride has high See beck coefficient such as the efficiency of generated voltage per unit temperature different is high thermoelectric elements are made from P-type and N-type semiconductors that are connected by metallic interconnect. When there is temperature gradient on the two sides of the semiconductors, a voltage is created. Current will flow through the N-type element, cross a metallic interconnect and passes into P-type element as shown in Fig.1. The current can then be used to power a load. The thermoelectric module converted the thermal energy into electrical energy. Every P-type or N-type of thermoelectric element is a single power generation unit. As shown in Fig.1, the P-type and N-type semiconductor elements are configured thermally in parallel, but electrically in a series circuit.

The total output electrical voltage from the thermoelectric module is series-adding of the voltage of each semiconductor. In a truly thermoelectric element, many such P-type and N-type semiconductors are employed to bring the See beck voltage up to useful levels. Fig.2. shows a two coupled thermoelectric element [5].

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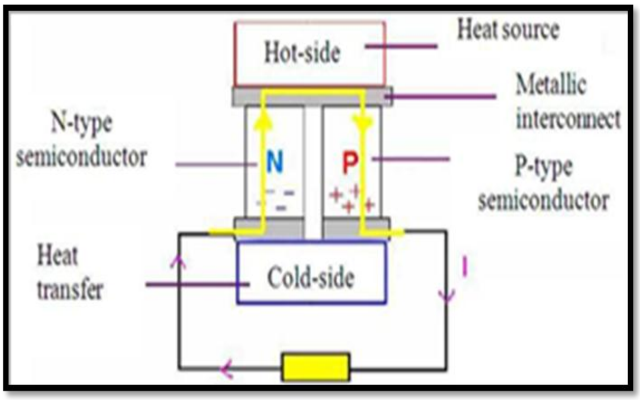


Fig- 1 :Operating principle of thermoelectric material [5]

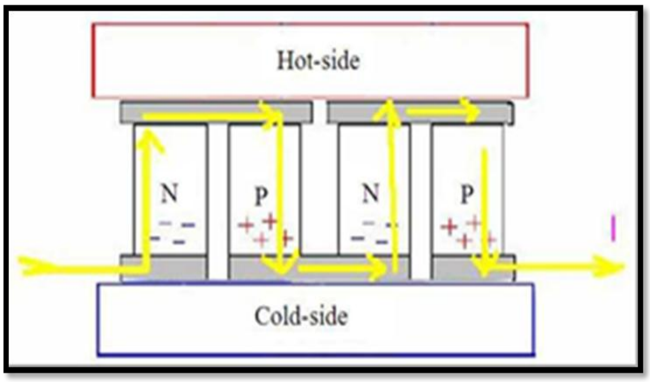
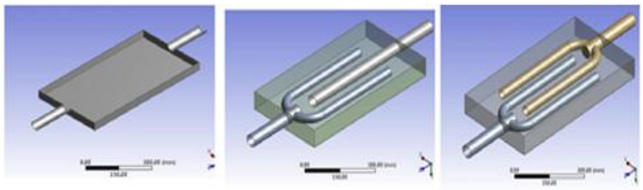


Fig- 2: A two coupled thermoelectric elements [5]

3. THERMAL UNIFORMITY OF EXHAUST HEAT EXCHANGER

The prototype exhaust heat ex-changers were designed and fabricated by Hongliang et al. The test bench was built to evaluate thermal uniformity and pressure drop characteristics over a wide range of operating conditions. Two exhaust heat exchangers with muffler-like Internal structure were proposed as 1-inlet 2-outlet and 2-inlet 2-outlet based on the referenced structure: empty cavity. There was nothing in the empty cavity shown in Fig.3a, but for 1-inlet 2-outlet the inlet pipe was inserted deeply into the cavity and the main outlet pipe was divided into 2 branch outlets shown in Fig.3b, 2-inlet 2-outlet included two same pipes in the outlet and inlet shown in Fig.3c. For the consistence of comparison,3 structures were in the same shell with 670 mm 360 mm 81 mm, all the inlet and outlet of the structures were 51 mm in diameter[4]. To verify the effect of internal structures, a test system was developed given in Fig.4. It had three parts: heat source as automobile exhaust, transducers and data acquisition system. Several transducers were used: pressure transmitters, differential pressure transmitters, K-type thermocouples and infrared camera to record the temperature distribution of exhaust heat exchanger. Keithley 2701 with 20-channel 7701 module was used to scan and save test real-time data.



(a) Empty cavity (b) 1-inlet 2-outlet (c) 2-inlet 2-outlet.

Fig- 3: Three internal structures [4]

Fig- 4: Test bench [4]

The different thermal performance and pressure drop stemmed from temperature field and velocity field of heat exchanger. In this section, the exhaust heat exchangers with three different internal structures were compared on the test bench in thermal uniformity and pressure drop [4].For empty cavity structure, the hot air flowed out of the inlet and expands freely in the cavity shown in Fig.5, the impact area of external surface was in the downstream area of inlet and hotter than the rest, but it was relatively small, the minimum and maximum face temperature were 750C in the corners near the inlet, 910C in the central zone, respectively, and the temperature distribution was non uniform as a whole.

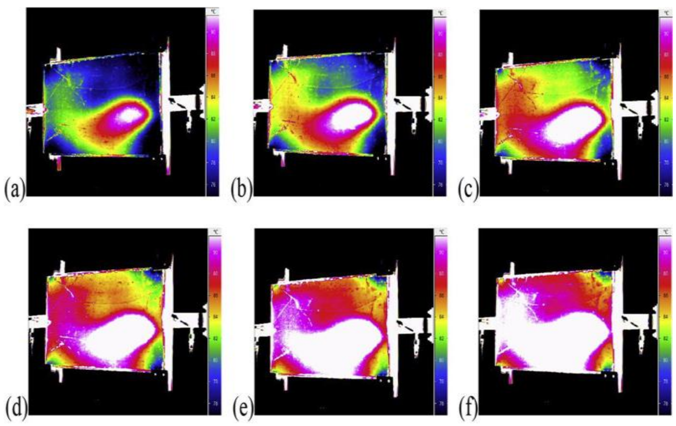


Fig- 5: Infrared thermal images of the empty cavity at 400^0C inlet temperature and mass flow: (a) 117 kg/h, (b) 138 kg/h, (c) 160 kg/h, (d) 180 kg/h, (e) 198 kg/h, (f) 216 kg/h [4]

It was the hot deformation and low machining accuracy that resulted in the inclined outlet and the inclined flow. The temperature rose and kept a similar but hotter distribution when the inlet temperature was 4000 C and inlet mass flow increases from 117 kg/h to 216 kg/h gradually [4].In regard of 1-inlet 2-outlet structure, the hot air flowed out of the long inlet in the cavity body, expanded and reflected by the opposite wall, and then moved relatively uniform to the two branch outlets shown in Fig.6. The impact area of high temperature was around the wall against the internal inlet, the minimum and maximum face temperature were 70^{0}C in the corners near the outlets, 110^{0}C near the inlet, respectively, and its temperature distribution was more uniform than the empty cavity and 2-inlet 2-outlet. In the higher frequency fan rotated, the more air mass flowed, and the higher face temperature was. The temperature kept a similar but hotter distribution as the mass flow increased [4].

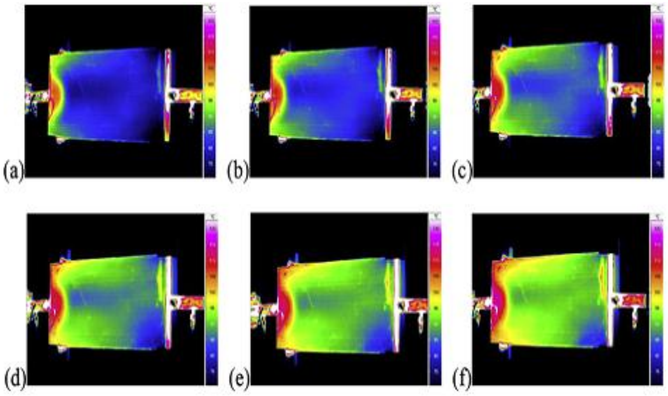


Fig- 6: Infrared thermal images of 1-inlet 2-outlet at 400^{0}C inlet temperature and mass flow: (a) 112 kg/h, (b) 135 kg/h, (c) 155 kg/h, (d) 174 kg/h, (e) 191 kg/h, (f) 202 kg/h [4]

The 2-inlet 2-outlet structure was configured with two branch inlets and two branch outlets, this geometrical complexity increased hydraulic disturbance, resulting in the more pressure drop and lower face temperature given in Fig.7 than the 1-inlet 2-outlet. The impact area near the wall facing the branch inlets was hotter than the rest, the minimum and maximum face temperature were 65^0 C in the corners near the outlets, 97^0 C near the outlets, respectively, and the temperature decreased gradually along the flow direction.

The whole temperature field was also less uniform than 1-inlet 2-outlet because the lower right corner with low temperature was caused by a symmetrical branch outlets in 2-inlet 2-outlet.Also shown in Fig 8 the performance of exhaust heat exchanger such as the surface temperature and pressure drop was dependent on exchanger's type and geometry, operating condition, and the temperature field was coupled with flow field.

According to this theory, segmental baffles increased the field synergy number and brought performance improvement on the shell-and-tube heat exchanger2-Inlet 2-outlet was more than the other in the field synergy number, but the cost was its pressure drop as large as 4 to 6 times of the empty cavity. The main content of the structure geometry modification of exhaust heat exchanger was enhanced heat transfer structures: to promote the variation of the velocity field and the uniformity of the temperature profile in the next stage.

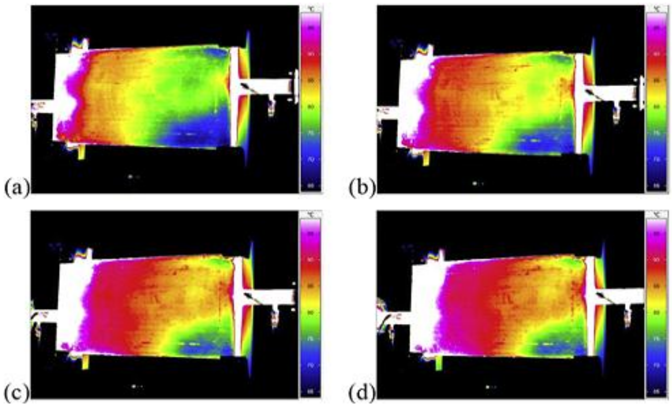


Fig- 7: Infrared thermal images of 2-inlet 2-outlet at 400 ^{0} C inlet temperature and mass flow: (a) 108 kg/h, (b) 129kg/h,(c)149kg/h,(d)156kg/h [4].

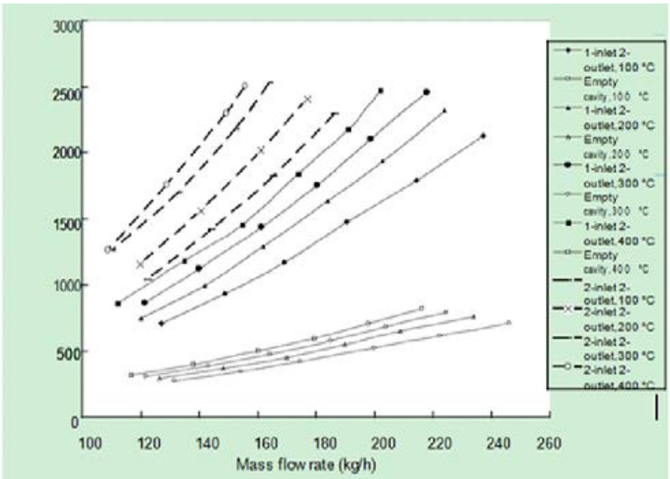


Fig- 8: Pressure drop of three structures under different conditions [4]

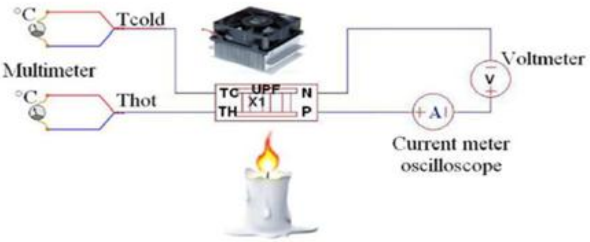
A test bench was developed by Hongliang Lu et al. to test muffler-like exhaust heat exchangers with different structures. The symmetrical 1-inlet 2-outlet increased hydraulic disturbance and enhances heat transfer, resulting in the more uniform flow distribution and higher face temperature than the 2-inlet 2-outlet and empty cavity [4].

4. DIFFERENT COOLING SYSTEM

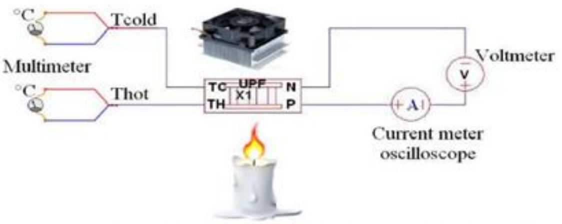
An experimental investigation has been carried out by Mohd et al. to identify the most suitable cooling system techniques to achieve a stable and sustainable power output. Four types of Thermoelectric Module (TEM) was fitted and tested on different cooling system techniques. Testing was conducted using a candle flame as a heat source to produce a suitable temperature with the maximum temperature of 200°C. An electronic circuit is used to provide a constant and sufficient power. Table1.shows the four types of TE modules used in the experiment. A sandwiched structure of heater (candle)/alloy plate/TE module/alloy plate/ cooling system was introduced to measure a every single TE module. Thus, the TE module was clamped between two alloy plates. Each TE module were inserted into these two alloy plates respectively to measure the temperature difference between the hot and cold sides of a TE module [5].

Table 1 TE Modules and parameters [5]

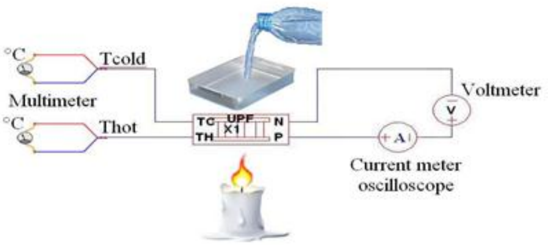
TE Module	N	Imax (A)	Qmax (W)	Vmax (V)	DT max (⁰c)	Tmax (⁰c)
TEG199-150-2	199	4.462	11.745	10.529	100	150
TEG07111-5M31-34CP	71	24.00	126.400	8.500	60	125
RC12-8	127	7.40	78.000	16.400	74	50
TEG19811-9L31-02CN1	198	2.00	28.000	23.700	65	200



(a) Method 1 (heat sink as a cooling system)



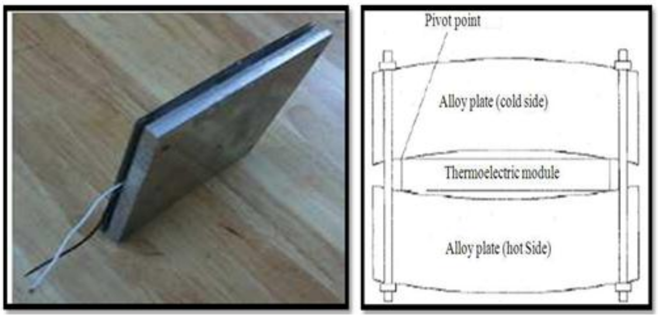
(b) Method 2 (fan as a cooling system)



(c) Method 3 (water as a cooling system)

Fig- 9: Different types of Cooling Methods [5]

The current, voltage and temperature different of the TE module have been recorded for every changing methods of cooling system within 2 hours as shown in Fig. 9 a-c. The cooling system is used to release heat and maintain cold-side Temperature (Tc) of the TE module. This technique used to hold alloy plate at the hot side and cold side of the module, the TE module acts as a pivot point shows in Fig.10.(a and b) bowing of the alloy plates will cause excessive forces on the module around and a gap in the centre of the TE module[5].



(a) (b)

Fig- 10: (a) Photograph of two alloy plate after clamping process (b) Bowing of source [5]

Table 2 (a) Average data of TEM type 07111-5M31-34CP [5]

Method	I(Amp)	V(Volt)	ΔT (°C)	P(Watt)
1	0.068	0.39	40.8	0.030
2	0.084	0.44	81.3	0.037
3	0.110	0.35	73.5	0.038

Table2 (b) Average data of TEM type RC12-8 [5]

Method	I(Amp)	V(Volt)	ΔT (°C)	P(Watt)
1	0.115	1.267	72.7	0.134
2	0.121	1.431	92.6	0.166
3	0.072	1.405	48.0	0.101

Table2 (c) Average data of TEM type 198-9L31-02CN1 [5]

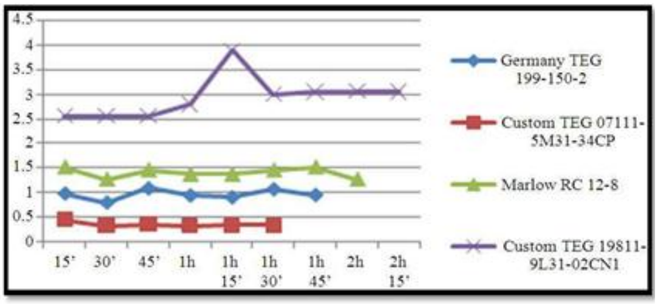
Method	I(Amp)	V(Volt)	ΔT (°C)	P(Watt)
1	0.081	2.769	50.40	0.229
2	0.086	2.326	95.50	0.198
3	0.055	2.952	105.80	0.232

Table 2(d) Average data of TEM type 199-150-2 [5]

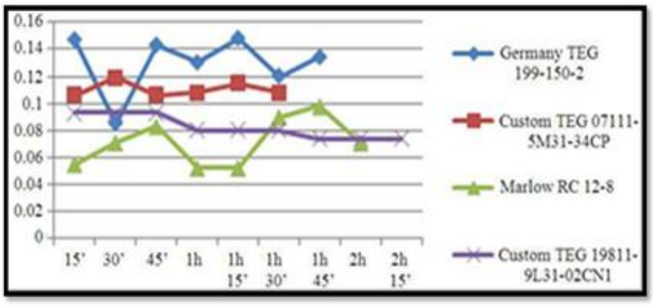
Method	I(Amp)	V(Volt)	ΔT (°C)	P(Watt)
1	0.062	1.119	40.0	0.0700
2	0.294	0.719	70.6	0.0902
3	0.129	0.953	96.7	0.1260

All TE modules have been successfully tested for every suggested technique individually. The data measurements have been collected every 15 min using electronic instruments and workbench. The following will discuss the performance and efficiencies of all TE modules.

Fig. 9(a-c) shows the four TEMs performance in terms of voltage, current and power. From the results as shown in Table 2 a-d, heat was The heat sink cannot release heat rapidly and getting hot. As the result, the TEMs do not achieve the high performance specifications accordingly. The technique was the lowest performance compared to the other technique. After that they can taking all reading then he decide that Water Based cooling system is best. They show following Graphs [5].



(a)



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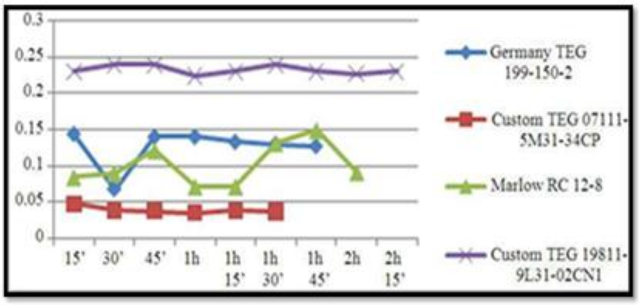

Fig-10: (a) Voltage Vs time (b) Current Vs time (c) Power Vs time [5]

The water can released the heat rapidly and maintain the temperature different DT. The output voltage is also high due to temperature different relatively.

TEM 19811-9L31-02CN1 is the most efficient TE modules during the all experiments. TEM 19811-9L31-02CN1 shows the highest performance and efficient followed by TEM RC12-8, TEM 199-150-2 and TEM 07 111-5M31-34CP.

5. LOW TEMP. WASTE HEAT TEG

An experimental Thermoelectric generator unit incorporating the commercially available thermoelectric modules with the parallel-plate heat exchanger has been constructed by Xing Niu et al. has experiments are carried out to examine the influences of the main operating conditions, the hot and cold fluid inlet temperatures, flow rates and the load resistance, on the power output and conversion efficiency. The schematic diagram of an experiment setup of TEG for low-temperature waste heat recovery is shown in fig.11.The system consists of the heat exchanger/thermoelectric converter, the cold fluid loop, the hot fluid loop and a data acquisition system. The cold and hot fluid loops include fluid baths with temperature controlled electrical heaters, pumps and air cooler.

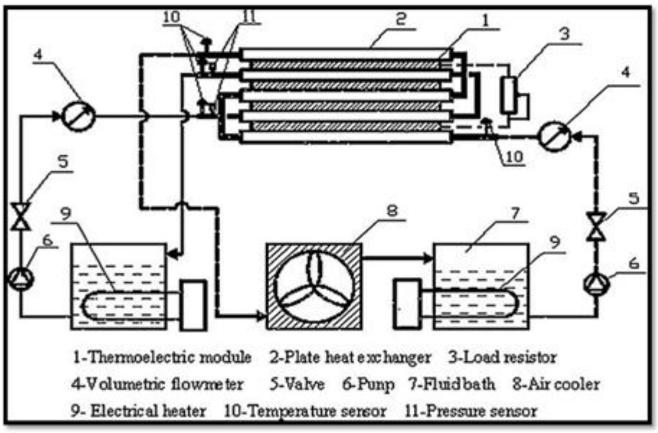

Fig- 11: The schematic diagram of an experimental setup of TEG [6]

The TEG unit with two-fluid, counter/parallel flow type, multi-layer plate heat exchangers/thermoelectric modules is shown schematically in Fig.12.Three cold fluid passages and two hot fluid passages are Isolated by these thermoelectric panels, in which the cold and hot fluids flow in the opposite or same direction as a counter/parallel flow type for the whole system.

This configuration makes the system more compact and suitable for the large-scale power generation, and the thermal energy can be efficiently recovered. In addition, thermal grease is placed between all of the thermoelectric modules/fluid passages interfaces in order to minimize the thermal contact resistance. In order to reduce side heat losses from the heat exchanger/thermoelectric converter, the fully assembled unit is surrounded on the outside by insulation board with the thickness of 10 mm. For a given TEG construction design, the power output W˙ and conversion efficiency are related to the cold and hot fluid conditions as well as the external load resistance [6].

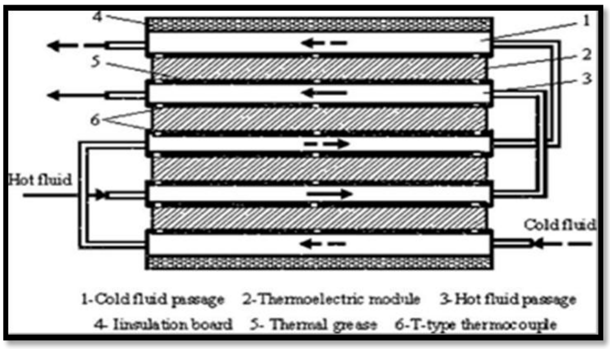

Fig- 12: The schematic diagram of TEG [6]

Fig.13 shows typical measured power output curves with varying the external load resistance at a range of hot fluid inlet temperature and the fixed cold fluid inlet temperature as well as fluid flow rates.

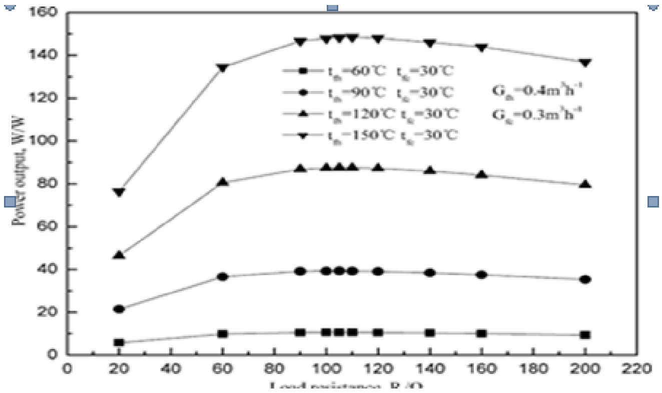

Fig- 13: The variation of power output with the load resistance [6]

It can be seen that the power output increases with increasing the inlet temperature of hot fluid at different load resistance. Furthermore, the peak of the measured power curves occurs where the load resistance is in the range of about 100–120. Actually, previous studies have reported that the maximum power of a thermoelectric module is achieved when load resistance equals the effective internal resistance of the module. Therefore, the output power of TEG can be optimized by balancing the internal and external resistance in practice [6].

6. CONCLUSIONS

In this review paper work, cooling system, Thermal Uniformity, Pressure drop, and operating condition of Thermo electrical Generator have been studied. Water based cooling system has high stability and capability to maintain temperature different between hot and cold side of Thermoelectric module.

1-Inlet 2-Outlet heat exchanger shows more Thermal temperature distribution and higher face Temperature. The pressure drop structures of Increased in different growth with the mass flow rate.2-Inlet and 2 Outlet among three structures shows high pressure drop. The Power output of Thermo electrical Generator Increases with increasing the inlet Temperature. of hot fluid at different load resistance. The peak of the measured power curves occurs where the load resistance is in the range of about 100-120Ω. The maximum power of Thermo electrical module is achieved when load resistance equal to internal resistance of the Thermo electrical Module.

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