Design, Development and Testing of Thermoelectric Refrigerator and Power Generator

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Abstract—**Thermoelectricity is the conversion of heat energy into electrical energy and vice versa. This can be achieved with the help of thermoelectric modules. The underlying principles viz. Seebeck effect and Peltier effect are discussed in the article. In this work experimental studies were performed in order to analyse the aforementioned phenomena. Results were obtained for power generation and refrigeration effect and innovative applications for day to day life are suggested.**

***Keywords*— Thermocouple, Thermoelectricity, Seebeck effect, Peltier effect, Thermoelectric module, Thermoelectric refrigeration, Thermoelectric power generator.**

I. INTRODUCTION

The vast majority (~90%) of the world's power is generated by heat energy, typically operating at 30-40% efficiency. Thus, roughly 15 terawatts of power in the form of heat is lost to the environment. Devices based on the thermoelectric effect could be used to convert this waste heat into useful electricity [1].

Thermoelectric effect is the direct conversion of temperature difference into electric voltage and vice versa, the basic application of which is the thermocouple. Thermocouple is a junction between two different metals that produces a voltage related to a temperature difference. Any junction of such type will produce an electric potential related to temperature.

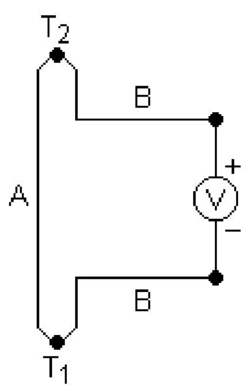


Fig. 1 Schematic representation of a thermocouple [2]

The Peltier effect bears the name of Jean-Charles Peltier, a French physicist who in 1834 discovered the calorific effect of an electrical current at the junction of two different metals. When a current is made to flow through a circuit, heat is absorbed at one junction and evolved at the other junction. The Peltier heat absorbed per unit time [4], $\dot{Q}$ is equal to

$$\dot{Q} = \pi_{AB} I = (\pi_B - \pi_A) I$$

Where π_{AB} is the Peltier coefficient of the entire thermocouple and π_A and π_B are the coefficients of each material.

The Seebeck effect is the direct conversion of temperature differences into electricity. The effect is that a voltage is created due to the temperature difference between two different metals or semiconductors. This causes a continuous current in the conductors if they form a complete loop. The voltage created is of the order of several microvolts per Kelvin difference. In the circuit the voltage developed can be derived from:

$$V = \int_{T1}^{T2} (S_{B_T} - S_{A_T}) dT$$

S_A and S_B are the Seebeck coefficients of the metals A and B as a function of temperature, and T_1 and T_2 are the temperatures of the two junctions.

II. PHYSICAL ORIENTATION OF THERMOELECTRIC MODULE

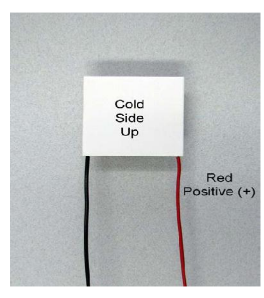


Fig. 2 A typical thermoelectric module [3]

A typical thermoelectric module used in our experiments consists of an array of Bismuth Telluride semiconductor pellets that have been ‘doped’ so that one type of charge carrier– either positive or negative– carries the majority of current.

The pairs of P/N pellets are configured so that they are connected electrically in series, but thermally in parallel. Metalized ceramic substrates provide the platform for the pellets and the small conductive tabs that connect them. The pellets, tabs and substrates thus form a layered configuration. Module size varies from approximately 0.25” by 0.25” to 2.0” by 2.0”.

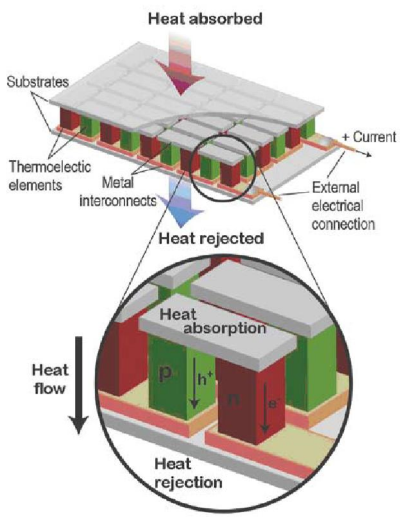


Fig. 3 Magnified view of the thermoelectric module [4]

The cooling performance of a thermelectric module is expressed by the term ‘figure or merit’ (Z) [5]. This is more commonly expressed as the dimensionless figure of merit ZT by multiplying it with the average temperature of hot and cold side of the module. To date, the best reported *ZT* values have been in the 2–3 range [6].

The specifications of the module used in the experiment are listed below.

TABLE I
SPECIFICATIONS OF MODULE

Sr. No.	Parameter	Specs.
1	Dimension	(40x40x40)mm^3
2	V_{max}	15.4 V
3	I_{max}	10.5A
4	ΔT_{max}	66°C
5	Q_{max}	100W

*The above module was imported from Heibei (HB) Company Ltd., China.

Where, V_{max} : Voltage at which the heat removed (Q) is maximum.
I_{max} : Current at maximum voltage (V_{max}).
ΔT_{max} : Maximum temperature difference that can be obtained.
Q_{max} : Maximum heat absorbed.

III. WORKING

A. *Thermoelectric Refrigerator*

Thermoelectric Refrigerator uses the principle of heat pumping. When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. The surface where heat energy is absorbed becomes cold; the opposite surface where heat energy is released becomes hot. The detailed working is as follows.

When the supply is given to the module, current will flow through the assembly; the direction of electron flow will be opposite to that of current flow. The electron will flow from negative terminal to the hot plate where it will release its energy in the form of heat thus making it hotter. Since the p-type material has a scarcity of electrons thus the electron travels through p-type material according to the law of diffusion [7], thereby reaching the other plate.

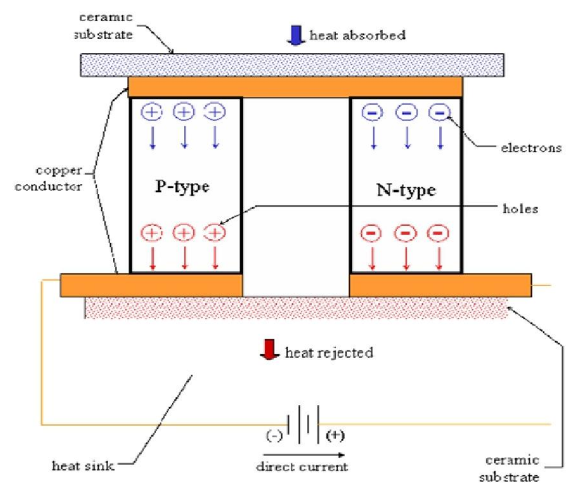


Fig. 4 Working of Thermoelectric Refrigerator [8]

Here, it will absorb the energy from that plate thus getting self excited and in turn making the plate cooler. This excited electron passes through n-type semiconductor reaching hot plate. Here it again releases its energy making the plate hotter. Further the electron completes the circuit and the cycle repeats.

B. *Thermoelectric Power Generator*

Thermoelectric Power Generator, a direct application of Seebeck effect converts heat energy into electrical energy. When a temperature gradient is created across the thermoelectric device a DC voltage develops across the terminals. When a load is properly connected the electric current flows in the circuit. The detailed working is as follows.

Heat is absorbed by the free electron (n-type semiconductor) from the hot side and it gets excited. It gains the kinetic energy and on account of it moves from hot plate to cold plate through n-type semi conductor.

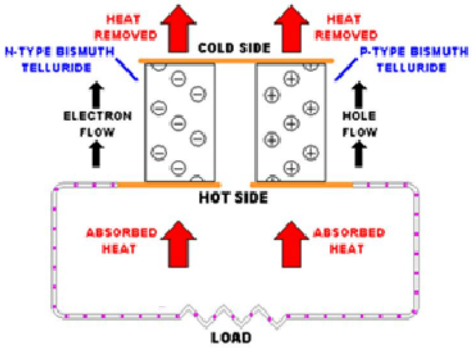


Fig. 5 Working of Thermoelectric Power Generator [9]

The excited electron then passes through the cold plate which is generally made up of material having low thermal conductivity to ensure constant temperature gradient across p-n couple. Since the p-type material has a scarcity of electrons thus the electron travels through p-type material according to the law of diffusion. The excited electrons then passes through the conductive wire through load thus producing electricity.

IV. Experimental Setup

A. *Thermoelectric Refrigerator*

The Thermoelectric refrigerator assembly consists of a wooden box (6"x 6" x 4.8") enclosing an aluminium chamber (4.3"x 4" x 4") which acts as cooling chamber. The space between the two is filled with glass wool serving the purpose of a heat insulator. The modules used in the experiment (4 in nos.) are sandwiched between the lower surface of the cooling chamber and water cooled heat exchanger. The modules are connected in series and a supplied with a voltage of 35V and a current of 4 Amp.

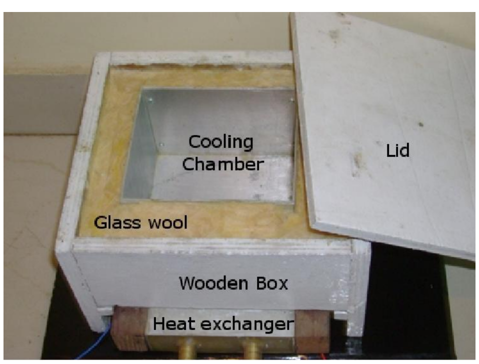


Fig. 5 Illustration showing assembly of thermoelectric refrigerator

The electric current actuates the modules to absorb the heat from the cooling chamber thereby producing a refrigeration effect. This absorbed heat is then dissipated into the surroundings with the help of water cooled heat exchanger. The parameters considered for experimental analysis are minimum temperature inside the refrigerator and time required to achieve this temperature.

B. *Thermoelectric Power Generator*

The Thermoelectric Power Generator assembly consists of modules (4 in nos.) sandwiched between a water cooled heat exchanger and an aluminium plate. Modules are connected in series and a resistive load is connected across two extreme terminals forming a closed circuit. In order to generate a temperature gradient a heat source (electric heater) is fixed above the aluminium plate for experimental purpose.

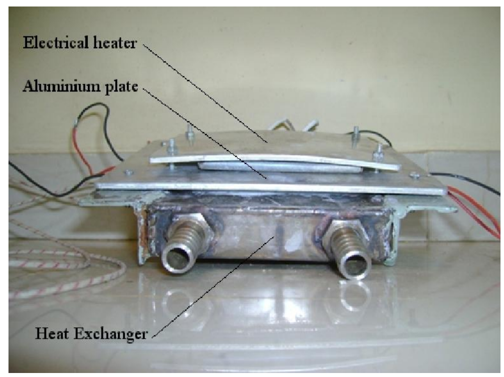


Fig. 6 Illustration showing assembly of Thermoelectric Power Generator

A constant temperature difference is maintained across the two faces of the modules. This temperature difference causes an electric current to flow through the circuit. The parameters considered for experimental analysis are voltage induced and power generated.

C. *Module Connections and Power Supply*

The modules are arranged in such a manner that the positive terminal of one module is connected to the negative terminal of the other module thus forming a series connection.

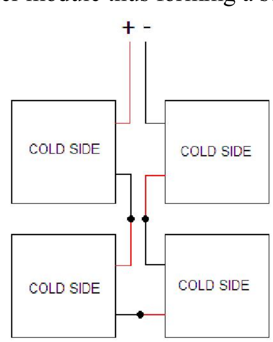


Fig. 7 Schematic diagram showing series connection of Thermoelectric modules.

Power supply of following specifications was used for the experiments.

TABLE II
SPECIFICATIONS OF POWER SUPPLY

Sr. No.	Parameter	Specs.
1	VA Rating	500 W
2	Max. Voltage	50 V
3	Max. Current	10 A

Fig. 6 Illustration of power supply used in experiments

V. EXPERIMENTAL RESULTS

A. *Thermoelectric Refrigerator*

The experiment was performed with the following initial conditions.

TABLE III
INITIAL CONDITIONS

Sr. No	Parameter	Specs.
1	No of modules used	4
2	Ambient temperature	33°C
3	Maximum voltage supplied	35V
4	Maximum current supplied	4A
5	Inlet water temperature	33°C
6	Outlet water temperature	34°C

The Results obtained are tabulated below.

TABLE IV
RESULTS

Sr. No.	Parameter	Specs.
1	Refrigerator temperature (T_{min})	5°C
2	Time required for T_{min}	8 min

B. *Thermoelectric Power Generator*

The experiment was performed under following conditions.

TABLE V
INITIAL CONDITIONS

Sr. No	Parameter	Specs.
1	No of modules used	4
2	Hot side temperature	133°C
3	Cold side temperature	33°C
4	Supplied voltage (A/C)	183V
5	Supplied current	1.45A
6	Inlet water temperature	33°C
7	Outlet water temperature	34°C

The following results were obtained for a constant temperature difference of 100°C.

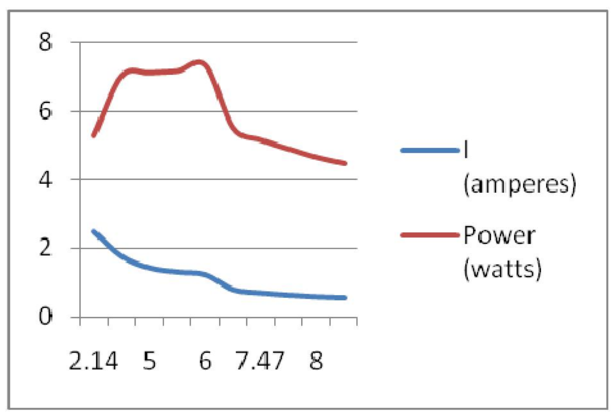
TABLE VI
RESULTS

Volt (V)	Current (I)	Power (W)
2.14	2.47	5.28
4.08	1.75	7.01
5.0	1.42	7.1
5.5	1.3	7.15
6.0	1.22	7.32
6.96	0.79	5.5
7.47	0.69	5.15

The graph was plotted for the above observation.

Abscissa
(X): Output voltage (V)

Ordinate
(Y_1): Output Current (A)
(Y_2): Output Power (W)



VI. CONCLUSION

In laboratory we successfully achieved a temperature of 5°C by using four Thermoelectric cooling modules at low load condition. The efficiency may be further increased by using modules of higher Figure of Merit $(ZT)_{max}$, increasing the number of modules and providing a more efficient heat dissipation system. The system requires very less maintenance on account of the absence of moving parts like a compressor. Moreover it is portable. At present, though the cost of the Thermoelectric refrigerator is a slightly on the higher side, mass production and research on more efficient modules would make it an economical substitute for the existing household refrigerators.

In the laboratory using four cooling modules we generated a power of about 7 watt for the temperature difference of 100°C (operating range T_{min} = 33°C, T_{max} = 133°C) . In practical applications solar energy or exhaust heat can prove to be an efficacious source of heat energy which would help to generate the necessary temperature difference. Solar thermal energy can be stored in heat storage systems like phase change materials viz. potassium nitrate, sodium nitrite [10] for its use during night time and in durations of poor sunlight. Experimental thermal to electrical efficiency values of 10% have been achieved till date [11]. Thermoelectric Power Generators under construction will have an efficiency of about 17%. It is predicted that in the future Thermoelectric modules may have an efficiency of about 25% but it is expected to reach 35-40%.

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