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Electricity Generation Using Seebeck Effect from Waste Heat

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Abstract

The application of the alternative green technology in converting waste-heat energy directly into electrical power improves the overall efficiency. Thermoelectric generators (TEG) have emerged as a promising alternative green technology due to their distinct advantages. TEG works on the principle of Seebeck effect. This review includes experimental analysis on a T-type thermocouple subjected to a temperature gradient. The voltage obtained is a function of temperature gradient. Thermoelectric power generation offer a potential application in the direct conversion of waste-heat energy into electrical power where it is unnecessary to consider the cost of the thermal energy input.

1. Introduction

In today's world, where the population is continuously rising and the demand for energy resources is going up. About 66% of the energy in any process is dissipated as heat into the surroundings. This waste energy can be converted into electrical energy (useful energy) and can be utilised elsewhere. Thermoelectric power generation provides a method of increasing the production of energy without environmental degradation. Thermoelectric generators (TEGs), or Seebeck elements, enable conversion of thermal energy into electricity without any moving parts. The Seebeck elements can be used for temperature sensing and power generation applications. TEGs generate electric current in a closed-circuit across a load when a temperature gradient develops between the two ends of the device.

2. Literature Review

Many research conducted recently have shown the importance of Thermoelectricity generation from waste heat and studied how this can be optimized. Auparay devised a system to know the seebeck coefficients of metals and semiconductors which consist of voltage measurement by Textronix DM 5120 (the Seebeck voltage) is the potential difference measured by the sample-copper differential thermocouple (DTC). The voltage measured by Keithley 195A DMM (the temperature voltage) is the potential difference across the chromel-alumel DTC. These measurements are gathered by computer using Seebeck 9.1 software. Mathematica is used to get the sample's Seebeck coefficient [1].

Taguchi [2] had designed a model and patented it for thermoelectric generation in Automobile. The cooling water pipe was in the direction from the upstream toward downstream of the exhaust gas. The stacks of thermoelectric power generation elements were attached to the exhaust pipe. The cooling water pipe and the exhaust pipe pass the cooling water and the exhaust gas, respectively, in opposite directions so that the downstream stack had an increased difference in temperature between the exhaust pipe and the cooling water pipe, and the stacks provide power outputs having a reduced difference, and hence an increased total power output. Thus an exhaust heat recovery power generation device can provide increased thermoelectric conversion efficiency without complicated piping.

Later, Reddy, et al. [3] modeled a Automotive ThermoElectric Generator (ATEG) based on the platform of Taguchi model. The approach taken by them is theoretical analysis by understanding the basic physics (mathematical equations) of the ATEG system. These mathematical equations are modeled in MATLAB/Simulink environment for computer simulation. The inputs to this model, for simulation, are given from the IC engine test bench data. The results indicate that the ATEG system is suitable to drive all the electrical loads in a small (< 1.4 liter engine) and mid-sized (between 1.4 liter and 2 liter engine) IC engine driven Automobiles. Therefore,

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ATEG system forms a great candidate to replace the alternator for small and midsized Automobiles. Replacing the alternator by the ATEG eliminates the load of the alternator on the IC engine and increases the overall fuel efficiency of the automobile greatly (about 4-7% depending on the IC engine and electrical demand of the car). In their model, the engine coolant temperature and mass flow rates are fixed to the value at which the thermostat at the coolant path opens. Its values are 363 K & 0.315 Kg/s respectively. The voltage from the ATEG is kept constant at a value of 14.4V. This is done by the DC converter model and a constant voltage is required to charge the battery. The drive cycle of their test is 3600 seconds. The average electrical power obtained over a drive cycle is about 600 W.

Researchers at BMW obtained 200 W of electrical power from a TEG comprising 24 Bi_2Te_3 modules in a 3-L-engine BMW 535i vehicle driven at 130 km/h The bench test of BSST's cylindrical TEG, designed for the Ford Lincoln MKT and the BMW 96, reported electrical power generation exceeding 700 W General Motors noted that achieving 350 W and 600 W is possible in a Chevrolet Suburban under city and highway driving conditions, respectively, with an average of 15 kW of heat energy available over the drive cycle[5] .

While current projected TEG efficiencies are low (typically less than 5%), the fact that the energy available is essentially free and that the units are mechanically simple has fostered renewed interest

3. Experimental Equation

To generate the voltage, either the conductor or semiconductor should be of different materials under the same temperature gradient. The voltage generated by the measuring conductor would simply:

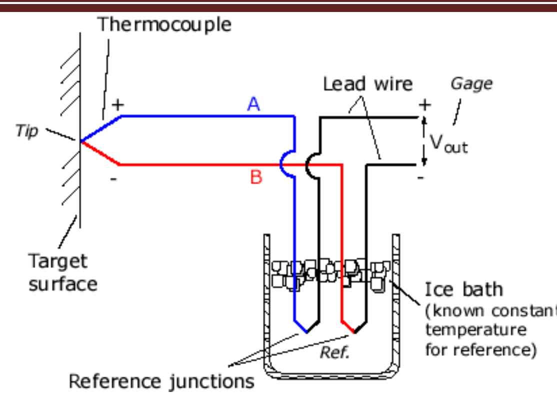

Fig: 1. Schematic Diagram for Calculation of Voltage Generated

The voltage output Vout measured as:-

$$V_{out} = \int_{Gage}^{Ref} S_{Lead}(T)\frac{dT}{dx}dx + \int_{Ref}^{Tip} S_A(T)\frac{dT}{dx}dx \quad (1)$$

$$+\int_{Tip}^{Ref} S_B(T)\frac{dT}{dx}dx + \int_{Ref}^{Gage} S_{Lead}(T)\frac{dT}{dx}dx \quad (2)$$

$$= \int_{T_{Ref}}^{T_{Tip}} S_A(T)dT + \int_{T_{Tip}}^{T_{Ref}} S_B(T)dT \quad (3)$$

$$= \int_{T_{Ref}}^{T_{Tip}} [S_A(T) - S_B(T)]\,dT \quad (4)$$

If the seebeck coefficients are nearly constant across the targeted temperature range, the integral in the above equation can be simplified as

$V_{out} = (S_A - S_B)*(T_{Tip} - T_{Ref})$ (5)

Where,

T_{Tip} = Temperature of Tip

T_{Ref} = Temperature of Reference

S_A = Seebeck Coefficient of metal A

S_B = Seebeck Coefficient of metal B

S_{lead} = Seebeck Coefficient of Lead Wire

From above equation, Seebeck Coefficient of different material can be obtained which is demonstrated in Table 1.

Table: 1. The Seebeck coefficients of some common metals and semiconductors at 0^o C (32^o F)

Material	Seebeck Coefficients*	Material	Seebeck Coefficients*
Aluminum	3.5	Gold	6.5
Rhodium	6.0	Antimony	47
Iron	19	Selenium	900
n-type Bi_2Te_3	-230	Lead	4.0
Silicon	440	$SnSb_4Te_7$	25
$SnBi_4Te_7$	120	PbTe	-180
Carbon	3.0	Nichrome	25
Sodium	-2.0	Constantan	-35
Nickel	-15	Tantalum	4.5
Copper	6.5	Platinum	0
Tellurium	500	Germanium	300

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The main factor responsible for the efficiency of thermoelectric generator model is to select Ideal thermoelectric material and it should have to be higher Figure of Merit (Z) as Z is a measure of its efficiency as an energy conversion component :-

$$Z = \frac{\sigma S^2}{\lambda}$$

Where,
σ = electrical conductivity
S = Seebeck Coefficient
λ = thermal conductivity

4. Experimental Analysis

In our Experiment, we emphasized on the importance of junction temperature and reference temperature. Thus, we used a T-Type thermocouple which is a combination of Copper wire (at +ve) and Constantan wire (at –ve).
We preceded this in two cases.
Case 1:
Junction Temperature – Temperature of boiling water,
Reference Temperature – Room Temperature

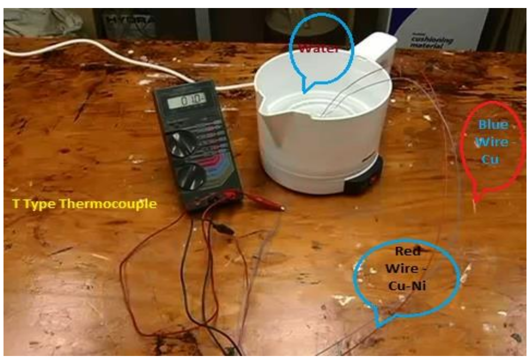

Fig: 2. Experimental Analysis – Case 1

The voltage obtained is 1.0 mV
Case 2:
Junction Temperature – Temperature of boiling waste
Reference Temperature – Temperature of Ice

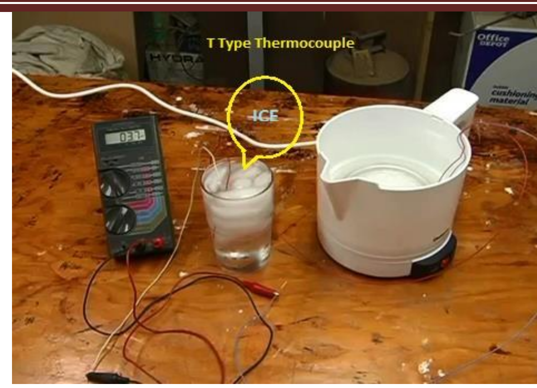

Fig: 3. Experimental Analysis – Case 2

The Voltage obtained is 3.7 mV
Thus by changing the reference temperature, we increased our output voltage by 3.7 times. But still it is not efficient, as the temperature of ice just start to increase and temperature of water just start to decrease, the output voltage decrease from its maximum value.

5. Conclusion

Thermoelectric power generation offers a promising technology in the direct conversion of waste-heat energy, into electrical power. Currently, waste heat powered thermoelectric generators are utilized in a number of useful applications due to their distinct advantages.

Thus we aim to develop a cheap and more efficient thermoelectric generator module to harvest energy from automobiles and to provide a cheap tool to the rural area to light their homes by the use of model like BioLite stove [5]in India.

Future developments in this area might focus onto finding more suitable thermoelectric materials that could handle higher temperatures from various heat sources at a feasible cost with acceptable performance.

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