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Electricity generation using Thermopile system from the flue gases

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ABSTRACT

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction.
This contribution analyzes approaches that led to discovery of thermoelectricity. Thermoelectric restrictions imposed on the application areas of thermoelectric generators and, accordingly, the ensuing rational lines of their practical applications are considered. The possibilities of thermoelectric systems' contribution to "green" technologies, in particular, to waste heat recovery from industry exhausting flue gases.
Attention is focused on the selection of the thermoelectric system and the experimental model representing the system. Finally there is theoretical model calculation for generation of emfs(voltage) and validation comparing the experimental results of the emfs(voltage).

KEYWORDS: thermoelectricity and its effects, thermocouples, flue gases, analytical model

INTRODUCTION:

The phenomenon involving an interconversion of heat and electrical energy may be termed as thermoelectric effect. This is the direct conversion of temperature differences to electric voltage and vice-versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charged carriers in the material to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence inducing a thermal current. This effect can be used to generate electricity, measure temperature or change the temperature of objects. The Seebeck, Peltier and Thomson effects are three related reversible thermoelectric effects. The thermocouple is well known and has been used extensively over the last 100 years for measurement of temperature and process control. The principle governing the operation of thermocouple devices is the Seebeck effect.

In 1821, Thomas Johann Seebeck, a German scientist, discovered that a small electric current will flow in a closed circuit composed of two dissimilar metallic conductors when their junctions are kept at different temperatures.

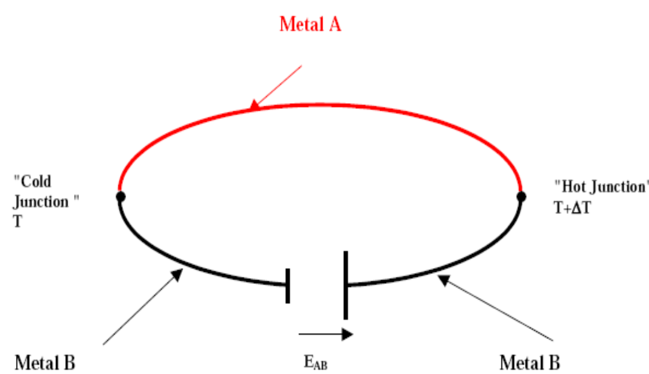

Fig 1 illustration of Seebeck effect

The electromotive force, or emf (V), that appears in an open circuit is the emf developed by the thermocouple to block the flow of electric current. If the circuit is opened the emf created, E_{AB}, is called the Seebeck voltage.

The emf E_{AB} (V) created is directly proportional to the differential temperature ΔT (K) between the two junctions (S_{AB} is seebeck coefficient)

$$E_{AB} = S_{AB} \times \Delta T$$

In 1834, Jean Charles Athanase Peltier, a French physicist, discovered that when an electric current flows across a junction of two dissimilar metals, heat is liberated or absorbed depending on the direction of this electric current compared to the Seebeck current. The rate of heat liberated or absorbed P is proportional to the electric current flowing in the conductor, that is

$$P = P_{AB} \times I$$

where P_{AB} (V) is called the relative Peltier coefficient. This effect is the basis of thermoelectric refrigeration or heating. The Peltier effect is illustrated in Figure

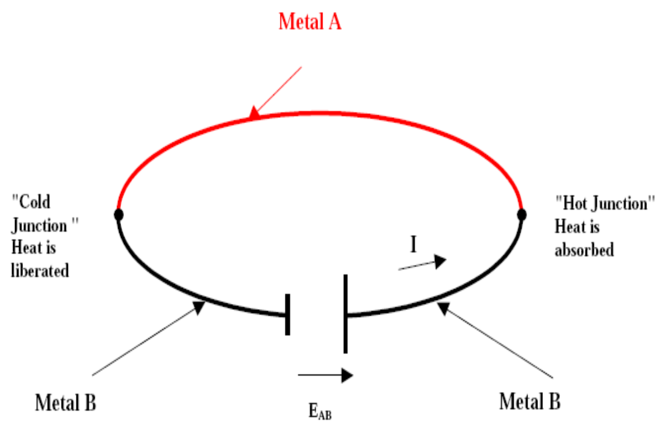

Fig 2 illustration of Peltier effect

In 1852, Thomson discovered that if an electric current flows along a single conductor while a temperature gradient exists in the conductor, an energy interaction takes place in which power is either absorbed or rejected, depending on the relative direction of the current and gradient. More specifically heat is liberated if an electric current flows in the same direction as the heat flows; otherwise it is absorbed. Figure below illustrates the Thomson effect.

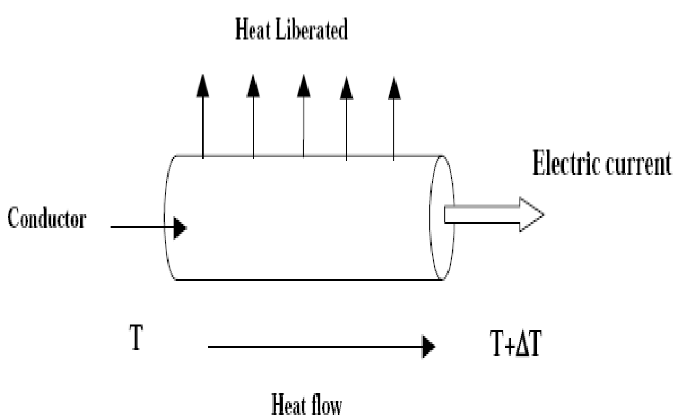

Fig 3 illustration of the Thomson effect

The power P absorbed or rejected per unit length is proportional to the product of the electric current I and the temperature gradient that is

$$P = \sigma \frac{dx}{dt} I$$

While practical applications of the Thomson effect are few, the Seebeck effect is widely used in thermocouples to measure temperature and the Peltier effect is occasionally used for air conditioning and refrigeration units. Seebeck effect is the result of both the Peltier and Thomson effects.

Types of thermocouples

There are several different recognized thermocouple types available. but the basic 3 types are
Base metal thermocouples
Noble metal thermocouples
Refractory metal thermocouples

The noble metal and the refractory metal thermocouples are cost expensive so base metal thermocouples are better for the experimental work and comparison.

Base metal thermocouples

Base metal thermocouple types are composed of common, inexpensive metals such as nickel, iron and copper. The thermocouple types E, J, K, N and T are among this group and are the most commonly used type of thermocouple. Each leg of these different thermocouples is composed of a special alloy, which is usually referred to by their common names.

For the evaluation of different type of thermocouples, from the literature available the graphs are studied of the temperature ranges versus the thermocouple voltage.

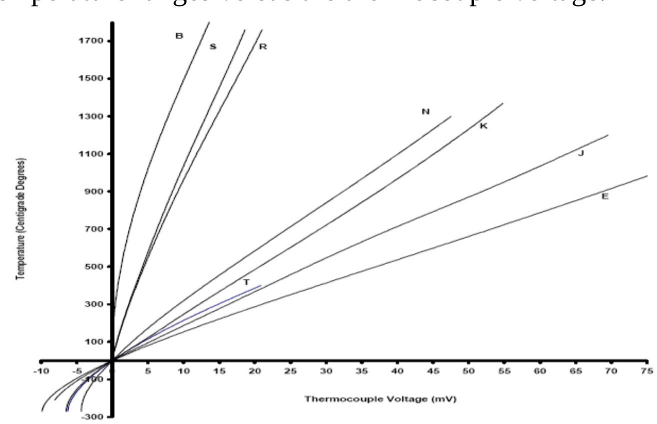

Fig 4 Voltage-Temperature Characteristics of B, E, J, K, N, R, S, and T Type Thermocouples

From the figure above we can find that the type E thermocouple gives the maximum thermocouple voltage for given temperature difference and that is 68$\mu V/°C$ so we will work with type E thermocouple. The type E thermocouple is composed of a positive leg of chromel (nickel/10% chromium) and a negative leg of constantan (nickel/45% copper).The temperature range for this thermocouple is –330 to 1600°F (-200 to 900°C). Our main objective is to get maximum voltage so we are opting for series thermoelectric circuits which is famously called thermopiles.

Experimental section(Design and fabrication of the thermopiles and voltage generation)

In the fabrication there are basically 3 steps:

Gather required stuffs

Making thermocouple

Build a Thermopile

Step 1 Gather required stuffs

The needs are chromel and constantan wires, soldering irons, wire cutters, general purpose board (insulating plate), thermometer, multimeter and gas stove.

Step 2 Making thermocouple

A thermocouple is made by connecting two different metals, with one metal between two samples of the second metal. If one of the two conjunctions is warmer than it's opposite side, small voltage is generated.

Cut and solder a length of 3.5 cm of chromel wire between two similar lengths of constantan wire as shown in figure above. If you connect the two ends of this to a digital multi-meter, and warm one of the two connections with a lighter, you will be able to detect a tiny voltage. Now let's make bunch in series of the thermocouple to get more voltage which is famously known as thermopile.

Step 3 Build a Thermopile : We have to make our thermopile as shown in the fig below.

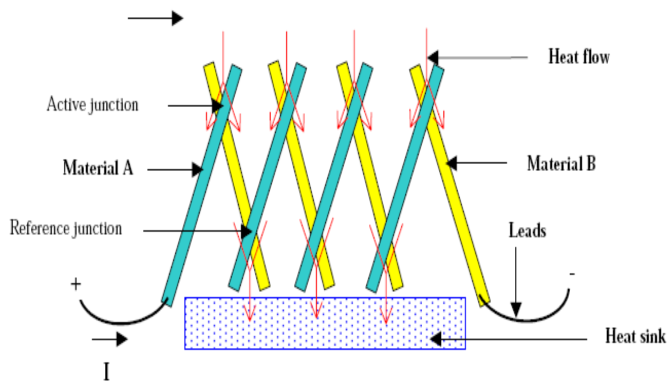

Fig 5 schematic of thermopile

So keep on soldering the different alloy wires and put it of the hollow ring of the general purpose board(GPB)as shown in the fig below.

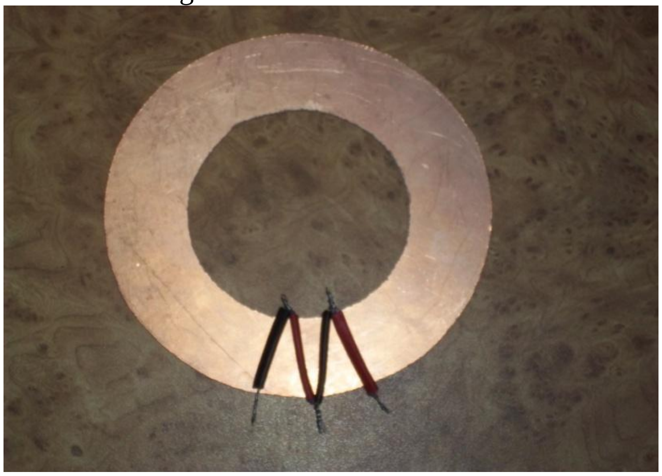

Fig 6 Thermocouples mounted on the GPB

When fabrication is all finished, you should have something that looks roughly like the the one in the picture.

Fig 7 Completely fabricated thermopile mounted on the hollow GPB

Now you can go and get to the stove in the kitchen. Light the stove with the lighter and place it so that center will be the stove flame.

Secure your thermopile in place on top of the stove with a little bit of cooling at each cold junction. Take the readings of the voltage and note it down along with hot junction temperature.

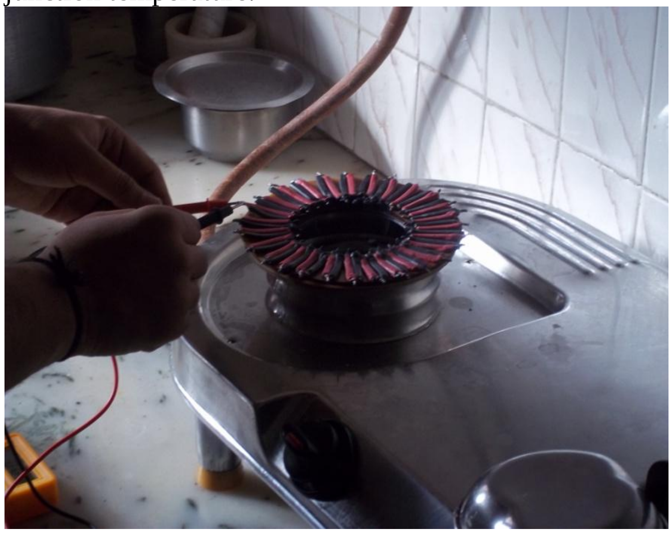

Fig 8 note down the voltage

Here with the experimental setup the generated voltage was 26 mV as shown by the multimeter, having 26 loops in it.

Thermocouple analytical model (theoretical calculation)

The principle of cold junction compensation is considered for the evaluation of the voltage generated for calculation.

It is also called reference junction compensation. When measuring temperature using thermocouples, the reference terminal may not be held at 0°C, but at the surrounding temperature of T_1°C instead. Without any compensation, the thermocouple output will be reduced by T_1°C. This is compensated by adding potential difference to the internal amplifier corresponding to T_1°C.

So now if the hot junction temperature is T_2°C and cold junction temperature T_1°C then by cold junction compensation principle

$$VTC_{T2-T1} = VTC_{T2} - VTC_{T1}$$

(A)

The temp of the hot junction by thermometer id 60°C and ambient is 34°C.so applying above equation theoretical voltage generated (VTC) will be

$$VTC_{60-34} = VTC_{60-0} - VTC_{34-0}$$

Reference for the following examples and associated data is the NIST, National Institute of Standards and Testing, equation below illustrates the power series model used for all thermocouples

$$VTC = \sum_{i=0}^{n} C_i \times (T)^i$$

(B)

Here VTC in mV and temperature in °C and C_i is the co efficient for the thermocouple type E.

The set of coefficients used in Eqn. to model E Type thermocouple is shown for 3 significant digits in the Table below.

Table 1: Coefficients C_i for the Type E Thermocouple

C_i Coefficients	**Value -270 to 0°C (mV/°C)**	**Value 0 to1000°C (mV/°C)**
C0	**0.00E+00**	**0.00E+00**
C1	**5.87E-02**	**5.87E-02**
C2	**4.54E-05**	**4.54E-05**
C3	**-7.80E-07**	**2.89E-08**
C4	**-2.58E-08**	**-3.31E-10**
C5	**-5.95E-10**	**6.50E-13**
C6	**-9.32E-12**	**-1.92E-16**
C7	**-1.03E-13**	**-1.25E-18**
C8	**-8.04E-16**	**2.15E-21**
C9	**-4.40E-18**	**-1.44E-24**
C10	**-1.64E-20**	**3.60E-28**
C11	**-3.97E-23**	
C12	**-5.58E-26**	
C13	**-3.47E-29**	

Using equations A and B find out the VTC at the hot and cold junction. The VTCs are

$\boldsymbol{VTC_{60-0} = 3.69\ mV}$ **(hot)** &

$\boldsymbol{VTC_{34-0} = 2.05\ mV\ (cold)}$

So the resulting voltage here will be **1.64 mV** per single thermocouple loop

There are 26 loops so the final VTC=no. of loops*VTC_{single} **=42.64 mV**

In the power plants and other industries there are lots of flue gases produced, having significant amount of thermal energy in the form of heat. The heat is not even considered for recovery for the thermal energy wasted.To utilize this wasted heat of flue gases we can use the principle of thermoelectricity. The model proposed above can recover the wasted heat and we can utilize then


Fig 9 flue gases

heat in the form of the voltage. In the chimneys the temperature of flue gases would be around 110°C which can be our hot junction in the proposed model & the ambient air can be our cold junction having temperature 35°C.so there is clearly 80°C temperature difference.

Applying the same theoretical model with equations to the flue gas case then by doing the calculations same as above will give us $4.583\ mV$ for one thermocouple loop. so by adding these in series in large no we can generate applicable amount of electricity.

RESULTS AND DISCUSSION

The difference in the practical and theoretical results vary because the gap between hot junction and the reference junction is less. Because of that some of the heat of the hot junction can effect the heat at the cold junction resulting in increase in the cold junction temperature. This heat effect can be reduced by maintaining certain gap between both junctions. By using this thermoelectric system one can generate applicable amount of electricity from the high temperature difference and it is available at low cost. Thus by this one can save energy which is wasted in the industries. By doing this one can make energy integrated industry and energy efficient system.

Even this system can be directly introduced to the vehicles exhaustion system where also there will be ample amount of heat is just wasted which can be integrated upto certain limit. In heavy duty vehicles the smoke coming out of the exhaustion system will form the NO_x gases which are major concern for the green house gases. But by just having this system installed the temperature will come down of exhaust gases so, the formation of the NO_x gases will be minimal. The mV generated by the flue gases now can be increased by just applying many more no of loops around them. And if this concept of thermoelectric system is taken to the nano level or micro level then there will be ample amount of electricity can be generated which are just wasted into the atmosphere.

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