THERMOELECTRICITY FROM WASTE HEAT OF FLUE GASES

[1] *MR. H. G. SUTHAR*

[1]M.E. [Energy Engineering] Student, Department Of Mechanical Engineering, Government Engineering College Valsad, Gujarat

hitu1118@gmail.com

ABSTRACT**:** *The three top operating expenses are often to be found in any industry like energy (both electrical and thermal), labour and materials. If we were found the manageability of the above equipments the energy emerges a top ranker. So energy is best field in any industry for the reduction of cost and increasing the saving opportunity. Thermoelectric methods imposed on the application of the thermoelectric generators and the possibility application of Thermoelectrity can contribute as a "Green Technology" in particular in the industry for the recovery of waste heat. Finally the main attention is too focused on selecting the thermoelectric system and representing the analytical and theoretical calculation to represent the Thermoelectric System.*

Keywords— Thermoelectricity and its effect, thermocouples types, analytical model.

I: INTRODUCTION

The thermoelectric effect 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. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices are efficient temperature controllers [2][4].

II: HISTORY

Thermo-electric generators convert heat directly into electricity, using the voltage generated at the junction of two different metals. The history begins in 1821 when Thomas Johann Seebeck found that an electric current would flow in a circuit made from two dissimilar metals, with the junctions at different temperatures. This is called the Seebeck effect. Apart from power generation, it is the basis for the thermocouple, a widely used method of temperature measurement. The voltage produces is proportional to the temperature difference between the two junctions. The proportionality constant α is called the Seebeck coefficient.

A series- connected array of thermocouples was known as a "thermopile", by analogy with the voltaic pile, a chemical battery with the elements stacked on top of each other. The Danish physicist Oersted and the French physicist Fourier invented the first thermoelectric pile in about 1823, using pairs of small antimony and bismuth bars welded in series. The thermopile was developed by Leopoldo Nobili (1784-1835) and Macedonio Melloni (1798-1854). It was initially used for measurements of temperature and infra-red radiation, but was also rapidly put to use as a stable supply of electricity for other physics experimentation.

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 [3].

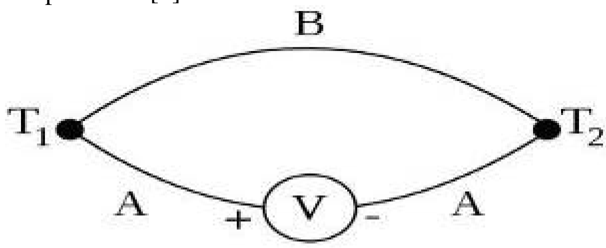

Figure. 1 Illustration of Seebeck Effect

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 (E_{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

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

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 2.

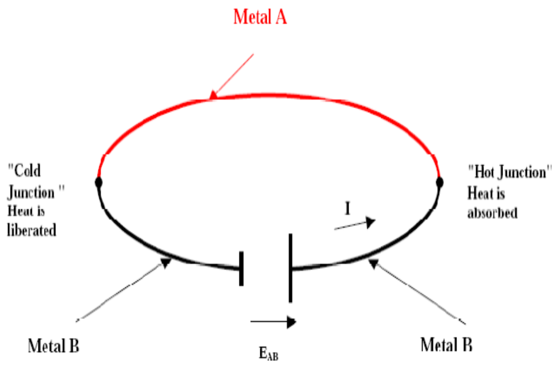

Figure.2 Illustration of Peltier Effect

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.

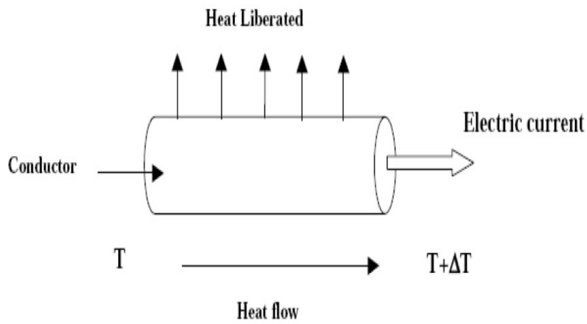

Figure.3 Illustration of Thomsan Effect

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 Thermocouple: There are several different recognized thermocouple types available. But the basic 3 types are

i. Base metal thermocouples
ii. Noble metal thermocouples
iii. 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.
So the research has been done on the Base metal thermocouple, for the evaluation of different types of thermocouple, the graph studied the different temperature ranges versus thermocouple voltage.

Base Metal Thermocouple: 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.
From the figure below we can find that the type E thermocouple gives the maximum thermocouple voltage for given temperature difference and that is 68 µV/°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 are famously called thermopiles [5].

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

In the fabrication there are basically 3 steps:
1. Gather required stuffs
2. Making thermocouple
3. Build a Thermopile

As shown in figure the E type thermocouple gives the maximum thermocouple voltage for given temperature difference.

The type E thermocouple is composed of a positive leg of chromel (nickel/10% chromium) and a negative leg of constantan (nickel/45% copper).So by joining the two thermocouple by shown in fig.5 [1].

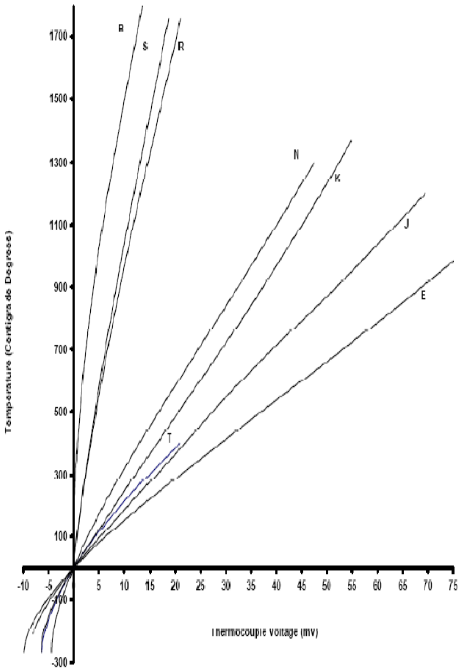

Figure.4 Voltage-Temperature Characteristics of B, E, J, K, N, R, S, and T Type Thermocouples

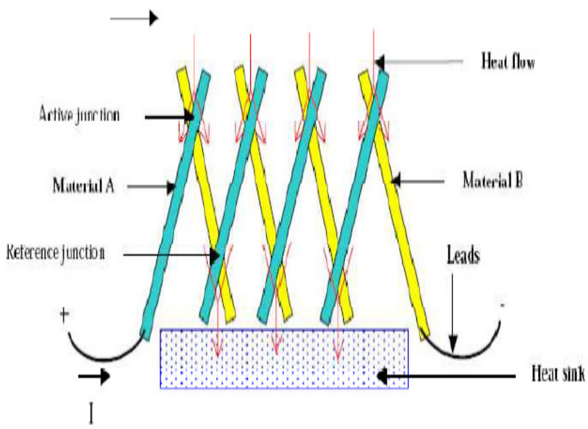

Figure.5 Schematic of Thermopile

IV: PROPOSED ARCHITECTURE CALCULATION:

In the power plants there is lots of the 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. 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.

We are trying to make section of the thermocouples having two thermopile sections within it which are connected in series. There are 50 sections like the same connected in parallel.

Each section has 2 rings (coils) connected in series. So we will be getting emf (voltage) as the series resultant of all the thermocouples in that section.

The final voltage will be combination of all the 50 sections connected in parallel.

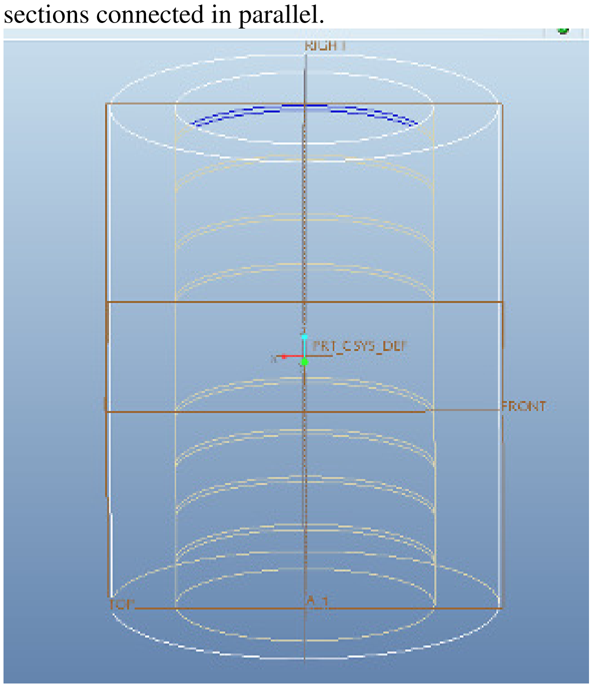

Figure.6 Schematic of Chimney mounted with thermopile

Calculation for Proposed Model:

Using the equation as below using cold junction compensation theory, the theoretical voltage created by the proposed model will be,

$$VTC_{T2-T1} = VTC_{T2} - VTC_{T1} \quad (a)$$

Where, T2 is the hot junction temperature which is 105°C and

T1 is the cold junction temperature which is 35°C

So for this case the VTC will be,

$$VTC_{105-35} = VTC_{105} - VTC_{35}$$

Equation below illustrates the power series model used for all thermocouples

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

(Here VTC in mV and temperature in °C)

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

Hot junction VTC: the flue gases temperature taking 105°C

$$\mathbf{VTC} = \sum_{k=0}^{3} C_i \times (T)^{i}$$

(Considering the coefficients up to the C_3 because after that there will not be much effect in the final value of the voltage)

$VTC_{105\text{-}0} = (C_0 \times (T)^0) + (C_1 \times (T)^1) + (C_2 \times (T)^2) + (C_3 \times (T)^3)$

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	

Figure.7 Coefficients Ci for the Type E Thermocouple [6]

Now putting the values of the temperature and the coefficient from the table above,

$VTC_{105-0} = \{(0.00E + 00) \times (105)^0\} + \{(5.87E - 02) \times (105)^1\} + \{(4.50E - 05) \times (105)^2\} + \{(2.89E - 08) \times (105)^3\}$

VTC105-0 = 6.694 mV

Cold junction VTC: Ambient air temperature taking 35°C

$$\mathbf{VTC} = \sum_{k=0}^{3} C_i \times (T)^i$$

(Considering the coefficients up to the C_3 because after that there will not be much effect in the final value of the voltage)

$VTC_{105\text{-}0} = (C_0 \times (T)^0) + (C_1 \times (T)^1) + (C_2 \times (T)^2) + (C_3 \times (T)^3)$

Now putting the values of the temperature and the coefficient from the table above,

$VTC_{35-0} = \{(0.00E + 00) \times (35)^0\} + \{(5.87E - 02) \times (35)^1\} + \{(4.50E - 05) \times (35)^2\} + \{(2.89E - 08) \times (35)^3\}$

$VTC_{35\text{-}0}$ = 2.11 mV

Now using equation (a) the resulting voltage will be

$VTC_{105\text{ - }35} = VTC_{105\text{-}0} - VTC_{35\text{-}0}$

$VTC_{105\text{ - }35}$= 6.694 – 2.11 = 4.583 mV

The ring consists of no. of thermocouples in series. The thermocouple wires are constantan and chromel (type E thermocouple).
Total no. of loops formed in one coil (ring) - 2000
So resulting output voltage (of one ring) will be
V = no. of loops × VTC105-35
= 2000 × 4.583 = 9166 mV

So V=9.166 V

Now as per the proposed model there are 2 rings in series so the resultant voltage will be sum of both rings VTC. But as they are of same thermocouples and same no. of loops so the resultant voltage will be 2 times of one ring VTC

So voltage for one section will be = 2 × 9.166 = 18.332 V

Now there are 50 sections like that connected in parallel. In parallel connection the resultant voltage will be same as of one section. So the voltage will be same as of that of the one section that is 18.332 V.

So the VTC calculated for whole structure will be 18.332 V.

Current (I)

For calculating the current we will follow basic ohm's law

V = I × R

Where, I is the current developed and R is the resistance in ohm.
Taking wire of gauge 14 and from the use of the standard table, resistance for the type E thermocouple is 0.1753 ohm per foot.
The length of wire is 0.1 m in one thermopile loop. So the total length of the thermoelectric system will be,

Total length = length of one thermopile loop × no. of loops in one thermopile
= 0.1 × 2000 = 200 meter

Now, 1 meter = 3.28 feet
Total length in feet = 3.28 × 200 ≈ 656 feet

So the total resistance of one coil (ring) is
R_{total} = total length of one ring × resistance per foot
= 656 × 0.1753 = 114.9968 ≈ 115 ohm

So the resistance of one section which is having 2 rings connected in series

$$R_{section} = 2 \times 115 = 230 \text{ ohm}$$

Now for 50 parallel section resulting resistance,

$$\frac{1}{R_{structure}} = \sum_{i=1}^{5} \frac{1}{R_i}$$

$$R_{structure} = \frac{230}{50} = \mathbf{4.6\ ohm}$$

The current (I) will be

$$I = \frac{\text{voltage by single section}}{R_{structure}}$$

$$= \frac{18.332}{4.6} = 3.985 \text{ A}$$

So for whole structure resultant theoretical voltage and current will be 18.332 V and 3.985 A current respectively.

V: RESULT AND DISCUSSION

This thermoelectric system one can generate applicable amount of electricity from the high temperature difference and it is available at low cost.

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 up to certain limit. In heavy duty vehicles the smoke coming out of the exhaustion system will form the NOx 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 NOx 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[7].

Thermoelectric concept is considered to be a new concept for heat recovery in systems and energy conservation.

REFRENCES

[1]Jaydeep. V. Joshi and N. M. Patel, "Thermoelectric system to generate electricity from waste heat of the flue gases" Advances in Applied Science Research, 2012, 3 (2):1077-1084

[2]H.L Kalsi , Electronics instrumentation, Tata McGraw-Hill, 3rd edi, pg no.465-470

[3]http://www.aqpl143.dsl.pipex.com/MUSEUM/PO W ER/thermoelectric/thermoelectric

[4] http://en.wikipedia.org/wiki/thermoelecric_effect

[5]http://www.sensortecinc.com/docs/technical_resources/Thermocouple_Theory.pdf

[6] http://www.dataforth.com/catalog/pdf/an107.pdf

[7] http://en.wikipedia.org/wiki/Flue_gas