International Journal of Futuristic Trends in Engineering and Technology
ISSN: 2348-5264 (Print), ISSN: 2348-4071 (Online)
Vol. 1 (05), 2014

Bimetallic Thermopile for Thermo - electricity Generation from Waste - Heat of flue gases

(Paper ID: 503006201412)

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***Abstract*:** As in any chemical process industries the area of concern is the usage of energy & efficiency of energy conversion systems. As in any chemical process industries energy losses in the form of waste heat occur to surrounding because of lower conversion efficiencies for conversion of heat to other form of energies. These heat losses or waste heat can be utilized to generate electricity using the concept of electricity generation. The paper focuses on the basic concept of converting the waste heat to thermoelectricity and the conceptual architecture design, as well as on the subcomponent manufacturing and assembly for the thermoelectric generator implementation on flue stacks. Finally it focuses on the theoretical and practical calculation of power generated from the proposed architecture for thermoelectric generators. The results from the analytical model shows that TEGs have good future scope in chemical process industries for thermoelectricity generation from the waste heat of flue gases.

Keywords: Thermoelectricity, waste heat, thermoelectric materials.

I. Introduction

Thermoelectricity is the electricity generated from the waste heat of flue gases. It is the energy generated from the waste heat of flue gases which are lost to surrounding flue gases stacks. It is generated based on the Seebeck principle which states that when there is a temperature difference between two junctions, the electricity is generated.

The cost of thermoelectric power generator essentially consists of the device cost. Waste heat is utilized as energy input which is free of cost so no need to consider its cost. There are many thermoelectric materials available but the material with higher Fig. of merit can be used to get maximum power output. The length of TEG leg and number of couples connected in series is the important factor for power output.

In this paper the basic theory of thermoelectricity generation and design of TEG with implementation and power calculation from proposed architecture is discussed in brief.

II. Basic Theory of a Thermoelectric Power Generator

The basic theory and operation of thermoelectric based systems have been developed for many years. Thermoelectric power generation is based on a phenomenon called "Seebeck effect" discovered by Thomas Seebeck in 1821[2].When a temperature difference is established between the hot and cold junctions of two dissimilar materials (metals or semiconductors) a voltage is generated which is called Seebeck voltage.

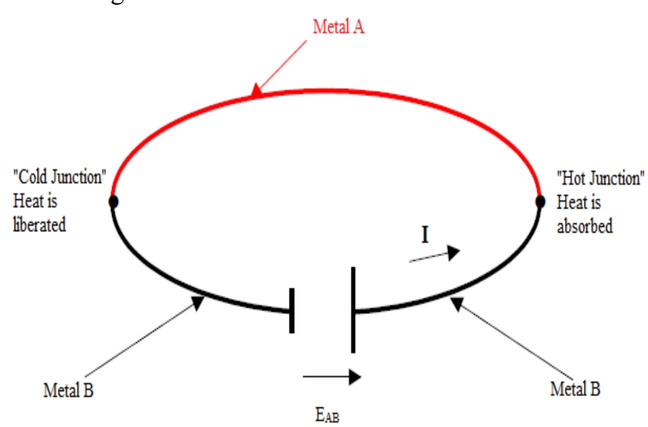

Fig. 1. Illustration of the Seebeck Effect[6]

$$E_{AB} = S_{AB} \times T (1)$$

Where S_{AB} is called the Seebeck co-efficient.

Based on this Seebeck effect, thermoelectric devices can act as electrical power generators. A simple thermoelectric power generator operating based on Seebeck effect is shown in Fig. (1).As shown in Fig. (1), The two junctions of a thermoelectric generator are kept at different temperature and based on Seebeck effect, as there is a temperature difference between the two junctions, current flow in the circuit and electrical power is produced. Using the first-law of thermodynamics (energy conservation principle) the difference between Q_H and Q_L is converted in to the electrical power W_e. As the temperature difference between the two junctions increases the output electrical power also increases. This concept can be utilized and such many thermoelectric generators are arranged in series and parallel on a flue stack to get large voltages.

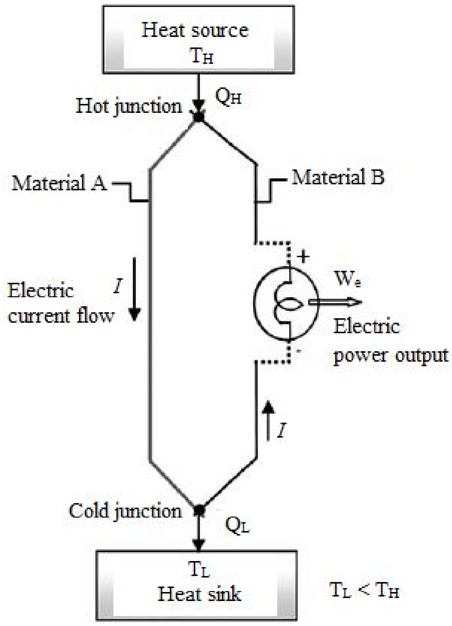

Fig. 2. Schematic Diagram Showing the Basic Concept of a Simple Thermoelectric Power Generator Operating based on Seebeck Effect[1]

III. COMPOSITION AND SPECIFICATIONS OF A TEG

Fig. 3 shows a schematic diagram illustrating components and arrangement of a conventional single-stage thermoelectric power generator. As shown in Fig. (3), it is composed of two ceramic plates (substrates) that serve as a uniform surface area for hot and cold junctions and electrical insulation for n-type (heavily doped to create excess electrons) and p-type (heavily doped to create excess holes) semiconductor thermo elements. In thermoelectric materials, electrons and holes operate as both charge carriers and energy carriers. The ceramic plates are used for keeping the thermoelements thermally in contact but electrically separated. The semiconductor thermo elements (e.g. silicon-germanium SiGe, lead-telluride PbTe based alloys) that are sandwiched between the ceramic plates are connected thermally in parallel and electrically in series to form a thermoelectric device (module).More than one pair of semiconductors are normally assembled together to form a thermoelectric module and within the module a pair of thermo elements is called a thermocouple(1). The junctions connecting the thermo elements between the hot and cold plates are interconnected using highly conducting metal (e.g. copper) strips. See Fig. (3).

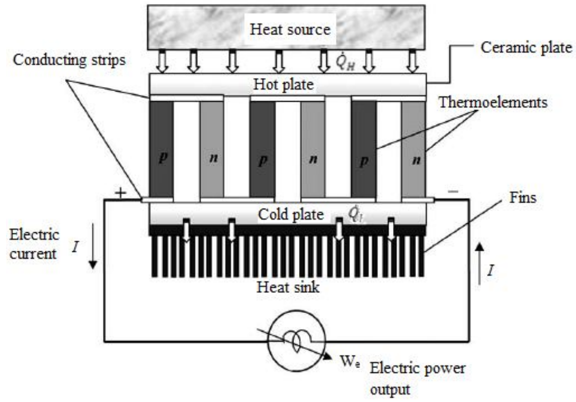

Fig. 3. Schematic Diagram Showing Components and Arrangement of a Typical Single-Stage Thermoelectric power Generator[1]

The sizes of conventional thermoelectric devices vary from 3 mm^2 by 4 mm thick to 75 mm^2 by 5 mm thick. Most of thermoelectric modules are not larger than 50 mm in length due to mechanical aspect. The height of single stage thermoelectric modules ranges from 1 to 5 mm. The modules contain from 3 to 127 thermocouples[2].

IV. DESIGN AND FABRICATION OF A TEG

In the fabrication there are basically 4 steps:
1. Gather required stuffs
2. Optimize the BWG size
3. Making thermocouple
4. Build a Thermopile

Step 1 Gather Required Stuffs

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

Step 2 Optimize the BWG size

Based on practical observation the optimum BWG size for the Nichrome/Constantan thermo element is 18 BWG.

Table 1. The Experimental Results

BWG	Length (cm)	Temp. of Junction (°C)		Voltage Generated (mV)	Ampere Generated (mA)
		HOT	COLD		
18	2	100	35	4.3	58.85
20	2	100	35	4.3	37.39
22	2	100	35	4.3	23.39
24	2	100	35	4.3	14.84

Step 3 Making thermocouple

A thermocouple is made by connecting two dissimilar metals forming two junctions. If these two junctions are kept at different temperature based on Seebeck effect a tiny voltage is generated. Cut and solder a positive P leg of metal nichromeand a negative leg of constantan of same length. Solder them to form two junctions and with the help of heat source just heat one of the junction and kept the other junction at room temperature. There is a tiny voltage in the circuit. If such a many thermocouples are connected in series to form a thermopile it can give large voltage.

Step 4 Build a Thermopile

A single thermocouple can give a very tiny voltage but if such a thermocouples are connected in series than it can give a measurable amount of voltage. Thermocouples connected in series is called a thermopile.

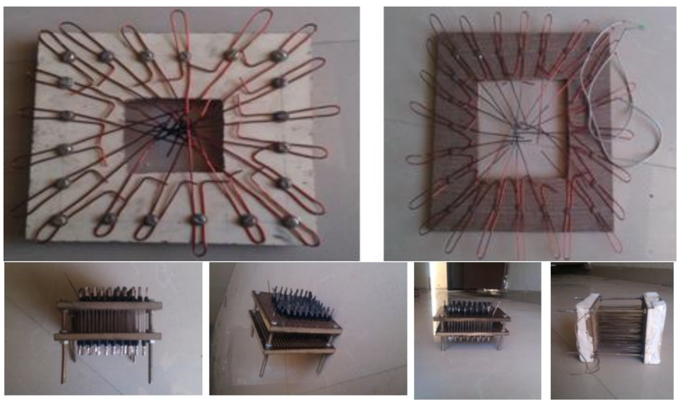

Fig. 4. Different types of thermopiles.

A) Proposed Architecture For Implementation

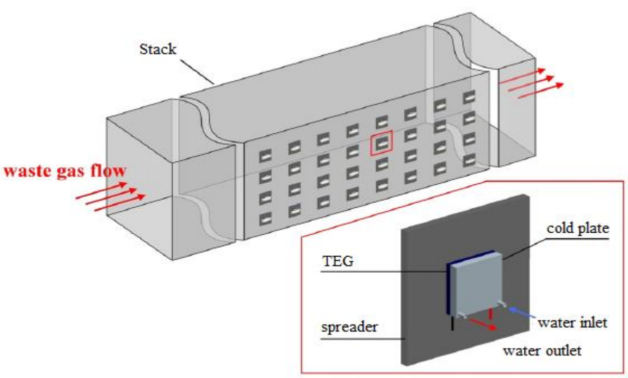

Fig. 5. Schematic Diagram of the Thermoelectric Module with a for Waste Heat Recovery

The schematic diagram of a system for thermoelectricity generation from the waste heat of flue gases is shown in Fig. 9. The thermoelectric model consists of a hot plate, a TEG and a cold plate based on air cooling. The dimensions of the assembled square TEG unit are 70mm×70mm×20mm. Its material is Nichrome-Constantan. A TEG is the major component of the thermoelectric module in which 100 pairs of p-type and n-type semiconductor legs composing the generator
are connected thermally in parallel between the hot waste gas and the cold plate and electrically in series to power the load circuit.

V. Analytical Model for Theoretical Power Calculation

This analytical model is used for calculating the theoretical voltage generated using TEG from waste heat of flue gases.
If the two junctions of a TEG are kept at different temperature voltage is generated according to the temperature differences. So now if the hot junction temperature is T_2°C and cold junction temperature T_1°C then by cold junction compensation principle

$$VTC_{T2-T1} = VTC_{T2} - VTC_{T1} \quad (8)$$

The temp of the hot junction by thermometer is 100°C and ambient is 34°C.so applying above equation theoretical voltage generated (VTC) will be

$$VTC_{199-34} = VTC_{100-0} - VTC_{34-0} \quad (9)$$

The equation below illustrates the power series model used for all thermocouples

$$VTC = \sum_{i=1} C_i \times (T)^i \quad (10)$$

Here VTC in mV and temperature in °C and Ci is the co - efficient for the thermocouple type E. The set of coefficients used for this model is shown for 3 significant digits in the Table below [9].
Using the above analytical model the theoretical and practical power obtained from the proposed architecture model can be calculated.

Table 2. Coefficients Ci for the Type E Thermocouple[6]

C_i Coefficients	Value -270 to 0°C (mV/°C)	Value 0 to 1000°C (mV/°C)
C_0	0.00E+00	0.00E+00
C_1	5.87E-02	5.87E-02
C_2	4.54E-05	4.54E-05
C_3	-7.80E-07	2.89E-08
C_4	-2.58E-08	-3.31E-10
C_5	-5.95E-10	6.50E-13
C_6	-9.32E-12	-1.92E-16
C_7	-1.03E-13	-1.25E-18
C_8	-8.04E-16	2.15E-21
C_9	-4.40E-18	-1.44E-24
C_{10}	-1.64E-20	3.60E-28
C_{11}	-3.97E-23	
C_{12}	-5.58E-26	
C_{13}	-3.47E-29	

VI. Results

A) Theoretical:

Voltage generated (V)= 1.72 V
Current generated (I)= 0.747 A
Power generated (P)= 1.28 W

B) Practical:

Voltage generated (V)= 1.68 V
Current generated (I)= 0.730 A
Power generated (P)= 1.22 W

The difference in theoretical and practical results is due to the additional contact resistance in the thermoelectric generators while doing practicals.
The electricity generated using the designed TEG is from only 20 modules connected in series-parallel connections. If such a 1000 modules are connected in series-parallel connection on a stack at industries, it will generate electricity in KV from the waste heat of flue gases. So its a green technology to generate electricity from the waste heat of flue gases. So TEGs have a very good scope in future as alternative green technology.

VII. Conclusion

Based on practical work it is concluded that thermoelectric generators can be used for electricity generation from the waste heat of flue gases and other process waste heat. As thermoelectric generator efficiency can be improved by optimizing the parameters affecting it, it can be applicable for generating thermoelectricity from industrial waste heat.As module efficiency improvements are achieved, thermoelectric will have an expanding range of both commercial and house hold applications as efficiencies improve and costs are reduced.

Acknowledgment

Authors would like to acknowledge the Department of Chemical Engineering, Vishwakarma Government Engineering College, Gujarat Technological University, Chandkheda for their kind support and correspondence. I would also thankful to principal Dr. A. M. Prabhakar and Head of the Department Prof. N. M. Patel for their encouragement and kind support for this research.

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