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GENERATION OF ELECTRICITY FROM FLUE GASES

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Abstract

Flue gas is the gas exiting to the atmosphere via a flue, which is a pipe or channel for conveying exhaust gases from a fireplace, oven, furnace, boiler or steam generator. Quite often, the flue gas refers to the combustion exhaust gas produced at industries or by heavy duty vehicles. These flue gases carry a large amount of heat which is of no use. Here, in this paper we are going to discuss a setup from which the waste heat of flue gases can be easily converted into electrical energy.

Introduction

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates 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 charge carriers in the material to diffuse from the hot side to the cold side. 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 can be used as temperature controllers. The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

The Seebeck effect is the conversion of temperature differences directly into electricity and is named after the Baltic German physicist Thomas Johann Seebeck. Seebeck, in 1821, discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the junctions. This was because the metals responded to the temperature difference in different ways, creating a current loop and a magnetic field.

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named for French physicist Jean Charles Athanase Peltier, who discovered it in 1834. When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction.

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.

Thermocouple

A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit.

A thermopile is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel. Thermopiles do not respond to absolute temperature, but generate an output voltage proportional to a local temperature difference or temperature gradient.

Thermopiles are used to provide an output in response to temperature as part of a temperature measuring device, such as the infrared thermometers widely used by medical professionals to measure body temperature. The output of a thermopile is usually in the range of tens or hundreds of mill volts.

Thermopiles are also used to generate electrical energy from, for instance, heat from electrical components, solar wind, radioactive materials, or combustion. The process is also an example of the Peltier Effect (electric current transferring heat energy) as the process transfers heat from the hot to the cold junctions.

Types of thermocouple

Different types of thermocouple are available for various purposes. Some are listed below:

Type K thermocouple

The type K is most common type of thermocouple. It's inexpensive, accurate, reliable, and has a wide temperature range. The type K is commonly found in nuclear applications because of its relative radiation hardness. Maximum continuous temperature is around 1,100C.

Global Journal of Engineering Science and Research Management

Type J thermocouple

The type J is also very common. It has a smaller temperature range and a shorter lifespan at higher temperatures than the Type K. It is equivalent to the Type K in terms of expense and reliability.

Type T thermocouple

The Type T is a very stable thermocouple and is often used in extremely low temperature applications such as cryogenics or ultra-low freezers. It is found in other laboratory environments as well. The type T has excellent repeatability between –380F to 392F (–200C to 200C).

Type N thermocouple

The Type N shares the same accuracy and temperature limits as the Type K. The type N is slightly more expensive. The type N has better repeatability between 572F to 932F (300C to 500C) compared to the type K.

Type B thermocouple

The Type B thermocouple is used in extremely high temperature applications. It has the highest temperature limit of all of the thermocouples listed above. It maintains a high level of accuracy and stability at very high temperatures.

Type E thermocouple

The Type E has a stronger signal & higher accuracy than the Type K or Type J at moderate temperature ranges of 1,000F and lower. The type E is also more stable than the type K, which adds to its accuracy.

Theoretical calculation

If the hot junction temperature is T1°C and cold junction temperature T2°C then,

$$\mathrm{VG}_{\mathrm{T1-T2}} = \mathrm{VG}_{\mathrm{T1}} - \mathrm{VG}_{\mathrm{T2}}$$

If the temperature of the hot junction is 70°C and ambient is 40°C. So applying above equation, generated Voltage (VG) will be

$$\mathrm{VG}_{70-40} = \mathrm{VG}_{70-0} - \mathrm{VG}_{40-0}$$

Equation below illustrates the power series model used for all thermocouples

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

Here VG in mV and temperature in °C and Ci is the co-efficient for the thermocouple type E.

The set of coefficients used in Eqn. to model E Type thermocouple is shown in the table below,

Global Journal of Engineering Science and Research Management

Table for Type E thermocouple (Reference junction 0oC)

°C	0	1	2	3	4	5	6	7	8	9	10
	Thermoelectric Voltage in mV										
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420
40	2.420	2.482	2.545	2.607	2.670	2.733	2.795	2.858	2.921	2.984	3.048
50	3.048	3.111	3.174	3.238	3.301	3.365	3.429	3.492	3.556	3.620	3.685
60	3.685	3.749	3.813	3.877	3.942	4.006	4.071	4.136	4.200	4.265	4.330
70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319
100	6.319	6.386	6.454	6.522	6.590	6.658	6.725	6.794	6.862	6.930	6.998

Using above discussed equation and the value of coefficient from the table, the value of generated voltage can be found easily,

$VG_{70-0} = 4.330$ mV And $VG_{40-0} = 2.420$ mV

Now the net voltage generated will be,

$VG_{70-40} = 1.91$ mV per single thermocouple loop.

For a normal size thermocouple, there will be 25 numbers of loops. Hence, total voltage generated will be,

$VG = 25 \times 1.9 = 47.75$ mV

In industries and power plant large amount of flue gases is being produced, carrying large amount of heat energy. In chimneys the temperature of flue gases is about 140oC which can be our hot junction and the air whose temperature will be about 30oC can work as a cold junction. This temperature difference will result in generation of voltage in few mili-volts from one thermocouple loop. Further on adding these in series, an applicable amount of electricity can be produced.

Conclusion

The thermal energy of flue gases goes waste as there is no such system is being adapted to make use of it. By applying the simple concept of thermoelectricity the heat energy can be converted into electricity. The proposed model can be applied in different industries, power plants and also in the vehicles. By increasing number of loops in the thermocouple one can increase the amount of electricity to be generated. It is an efficient way of conserving the thermal energy which goes waste in the atmosphere due to unavailability of appropriate system.

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