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Influence of electric field dynamics on the generation of thermo emf by some advanced thermocouples in the high temperature range

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ABSTRACT

This research work reports about the energy conversion characteristics of advanced thermoelectric materials like Platinum, Rhodium, Constantan, Chromel and Alumel (of types B, E, R, K and S) in the influence of applied electric field dynamics. These kinds of the materials are generally taken as the temperature measuring tools in the critical molten states of certain materials and other high temperature conditions. But here, their response only to Seebeck effect is analyzed as the functioning of thermo generator elements. This is an approach of their use in those conditions where the waste heat is available along with the electric fields. The generation of thermo emf is investigated in the normal mode to the temperature range of 330^{0}C and then compared with their similar performances under the effect of applied electric field in various orientations (parallel & perpendicular) for different magnitudes at the same temperature range.

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KEYWORDS

Thermocouples;
Thermo-emf generation;
Field mode;
Characterization.

INTRODUCTION

In the recent years energy crisis introduces a large number of techniques and materials due to their energy conversion efficiencies. Due to environment issues like global warming, free from pollutants and toxic materials the thermoelectric technology becomes very advantageous. The thermoelectric generators are taken as the energy tool of green technology. Thermoelectric devices becomes more popular from the last decades in domestic and industrial areas due to their simple and safe size, easy operation, environment friendly nature and reliable in all conditions and their position independent nature[1,2]. Majority of the electrical and electronic instruments having low efficiencies causes a large content of input as the waste heat. The low and high grade waste is available in all the domestic, industrial, technical and engineering fields. The waste heat energy can be converted in to electrical energy with the utilization of thermocouples; an assembly of dissimilar thermoelectric materials[3,4]. The waste heat in vehicles can be recycled by its conversion with the appropriate design and size of thermoelectric devices as they extend from micro to macro dimensions. The cooling of car seats, heating of residential systems and refrigeration are major applications on these days[5,6]. The semiconductor

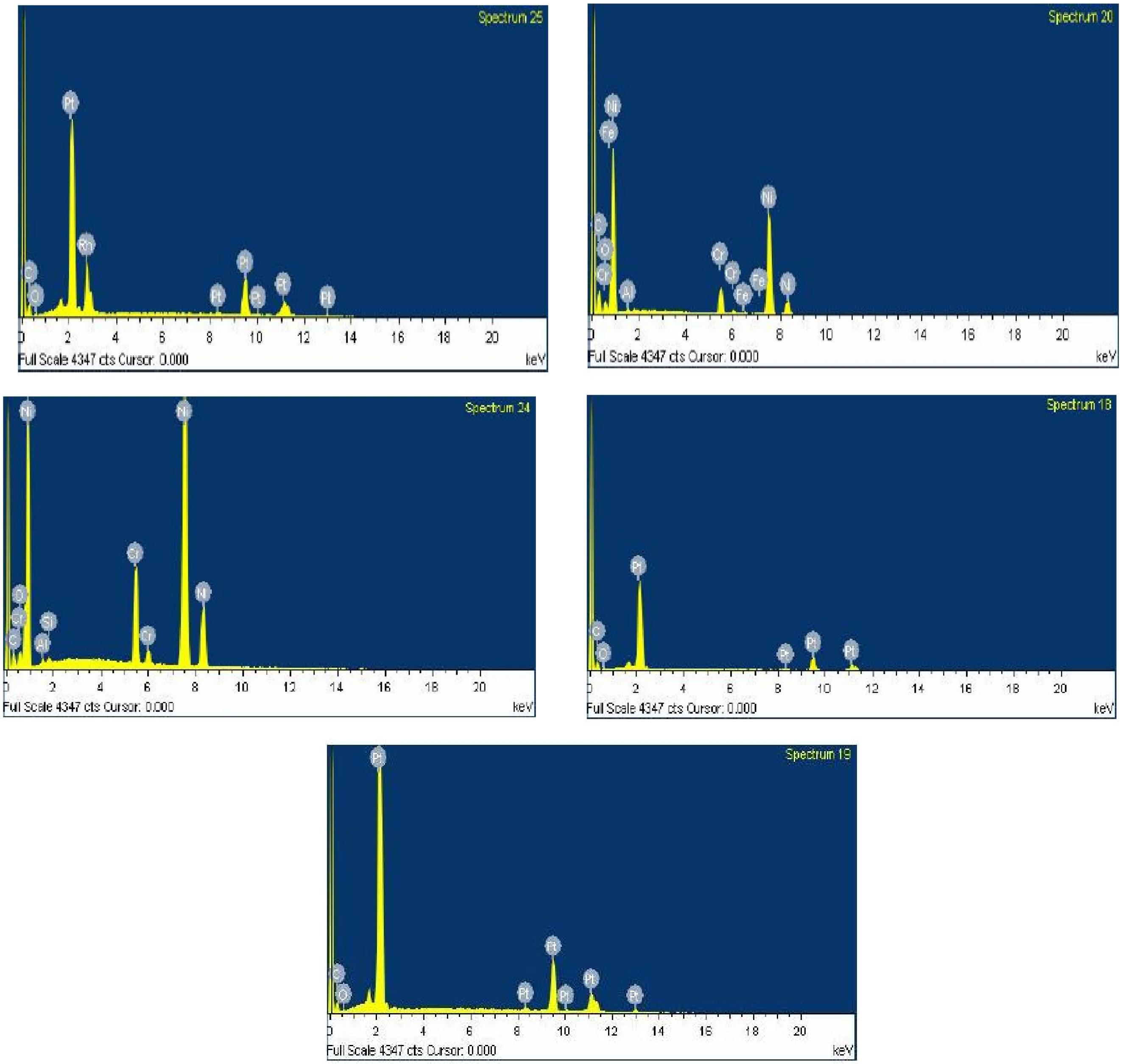

Figure 1 : XRD composition analysis of Type-B, Type-E, Type-S, Type-K, Type-R thermocouples

materials like Bi_2Te_3 and Pb_2Te_3 are known as the better thermoelectric due to their improved figure of merit and energy conversion characteristics. Nowadays, the researchers oriented on these materials in some advanced era for the implementation of better thermoelectric devices[7,8].

Selection of thermocouples

The thermocouples of types K, E, B, R and S which are the alloys of Platinum, Rhodium, Chromel, Constantan and Alumel are selected here for the generation of thermo emf. In fact these thermocouples are used as the temperature measuring tools (RTD) in a very high temperature range[9,10]. But here we are interested to investigate their energy conversion efficiencies[11] from the response of Seebeck effect. The Elemental Diffraction Spectroscopy (EDS) studies of all thermocouples are also carried out[12] and shown in Figure 1.

Normal mode

This mode indicates the normal conditions in which thermocouple experiments are performed for the generation of thermo emf. This is a mode which is free from all external parameters. This mode plays a significant role for the investigations and comparisons of the applied electric and magnetic field modes[12,13].

Electric field dynamics

The electric field also has a significant effect on the thermoelectric properties[14-15], which directly affect the magnitude of Seebeck coefficient. In this research work, we apply the electric field strengths in parallel and perpendicular orientations by the different potential difference magnitudes i.e. 4V, 8V and 12V to seek the effects on thermo power, which my results to improve the figure of merit. The electric field for different potential difference strengths is shown in TABLES 1 and 2.

Performance of thermoelectric materials

The performance of thermoelectric materials can be expressed by:

TABLE 1 : Strength of applied electric field (Perpendicular orientation)

Sr. No.	Applied Potential Difference (Volt)	Strength of Electric Field ($V\ m^{-1}$)
1	4	22.2
2	8	44.4
3	12	66.7

TABLE 2 : Strength of applied electric field (Parallel orientation)

Sr. No.	Applied Potential Difference (Volt)	Strength of Electric Field($V\ m^{-1}$)
1	4	10.7
2	8	21.3
3	12	32

$$Z = \frac{\alpha^2}{KR} \quad (1)$$

Where Z is the figure of merit of the thermoelectric material and α is the Seebeck Coefficient[16] given by:

$$\alpha = -\frac{\Delta V}{\Delta T} \quad (2)$$

In the above relations R is the Specific Resistance and K is the thermal conductivity of the material. For a thermocouple the figure of merit[17] can be given by:

$$Z = \frac{(\alpha_a - \alpha_b)^2}{[(\rho_a\lambda_a)^{1/2} + (\rho_b\lambda_b)^{1/2}]^2} \quad (3)$$

Here α_α and α_b are the Seebeck constants of two thermoelectric materials; p_α, p_b and λ_α, λ_b are specific resistances and thermal conductivities of the thermoelectric materials respectively.

EXPERIMENTAL PROCEDURE

Normal mode set up

*E*lectric furnace and fresh tap water respectively obtain the heating and cooling arrangements. The digital multi-meter of HP 34401A is used for thermo emf and other measurements with an accuracy of six decimal places.

Measurement of physical parameters

The physical parameters of all the thermoelectric materials are measured by the digital multi-meter of HP 34401A is used for thermo emf and other measurements with an accuracy of six decimal places. All these

TABLE 3 : Physical parameters of all thermoelectric materials for considered thermocouples

S. No.		Material	Length (m)	Area of Cross Section (m^2)	R(Ω)	Resistivity (Ω m)	Electrical Conductivity (Sm^{-1})
1.	Type-S	Pt	80×10^{-2}	3.2×10^{-7}	0.175	7×10^{-8}	14.3×10^{6}
		Rh-Pt	80×10^{-2}	3.02×10^{-7}	0.179	7×10^{-8}	14.3×10^{-8}
2	Type-K	Chromel	80×10^{-2}	3×10^{-7}	0.288	10.8×10^{-8}	9.3×10^{-8}
		Alumel	80×10^{-2}	3×10^{-7}	0.220	8.3×10^{-8}	12×10^{-8}
3	Type-E	Chromel	80×10^{-2}	1.02×10^{-7}	0.501	6.4×10^{-8}	15.6×10^{-8}
		Constantan	80×10^{-2}	1.02×10^{-7}	0.512	7×10^{-8}	14.3×10^{-8}
4	Type-R	Pt	80×10^{-2}	3×10^{-7}	0.350	13×10^{-8}	7.7×10^{-8}
		Rh-Pt	80×10^{-2}	3×10^{-7}	0.421	15×10^{-8}	6.7×10^{-8}
5	Type-B	Pt	80×10^{-2}	3.42×10^{-7}	0.224	9.6×10^{-8}	10×10^{-8}
		Rh-Pt	80×10^{-2}	3.42×10^{-7}	0.240	10.3×10^{-8}	9.7×10^{-8}

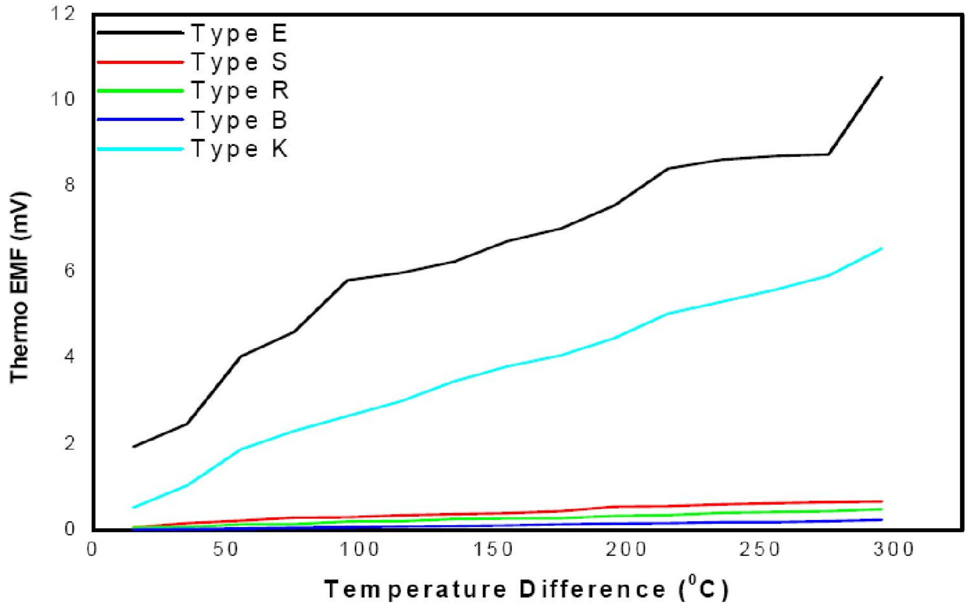

Figure 2 : Shows thermo-emf generation as a function of temperature difference for normal mode

measurements are mention in the TABLE 3.

Applying electric field

The electric field is applied in parallel and perpendicular orientations on the selected thermocouple with the help of two aluminum plates (25cm×22.6cm) of parallel plate capacitor set up. The parallel and perpendicular orientations are just the configurations of applied field and thermocouple. The potential difference applied for both the orientations is 4V, 8V and 12V. The separation between aluminum plates for parallel and perpendicular orientation is 37.5cm and 18 cm respectively

RESULTS AND DISCUSSION

Normal mode investigations

In this mode the thermocouples can be easily classified for the generation of thermo emf. In this mode the thermocouples of type E is best among the all because it generates maximum thermo emf for the entire temperature range. Its maximum thermo emf at the maximum temperature gradient of 295^0C is 11mV; whereas for the minimum temperature gradient of 15^0C is about 2mV. This can be expected as the performance of Fe and Ni which are the ferromagnetic materials along with the paramagnetic materials (Al, Cr) it can be analyzed from the elemental diffraction spectroscopy peaks of type E thermocouple. The second class thermocouple is the Type K thermocouple, for which the maximum and minimum thermo emf generations are 6mV and 0.4mV for the maximum and minimum temperature gradients respectively. This can be viewed as the Seebeck response of non-magnetic materials. The normal mode behavior of all thermocouples is shown Figure 2.

All the other thermocouples (of types B and R) having low emf generations at all temperatures. Their maximum thermo emf magnitudes are only in the range of 0.5mV corresponding to the maximum temperature gradients of 295^0C. This means the response of non magnetic materials (Pt, Rh, C and O) is least as compared with the magnetic materials. The type S thermocouple is an alloy with the contents of ferromagnetic and paramagnetic materials (Ni, Cr and Al) shows the weak response for emf generations.

Influence of electric field

Parallel electric field mode

Applied potential difference of 4V

This is the case of applied electric field of magnitude 10.7 Vm^{-1}. In this mode the performance order of thermocouples is Type E > Type K > Type R >Type S and B (Figure 3(a)). The magnitude of maximum thermo emf for the first three thermocouples (E, K and R) is about 11mV, 3.6mV and 1mV respectively; whereas for type S and B it limits only to 0.5mV at the maximum temperature gradient of 295^0C. The behavior of type E

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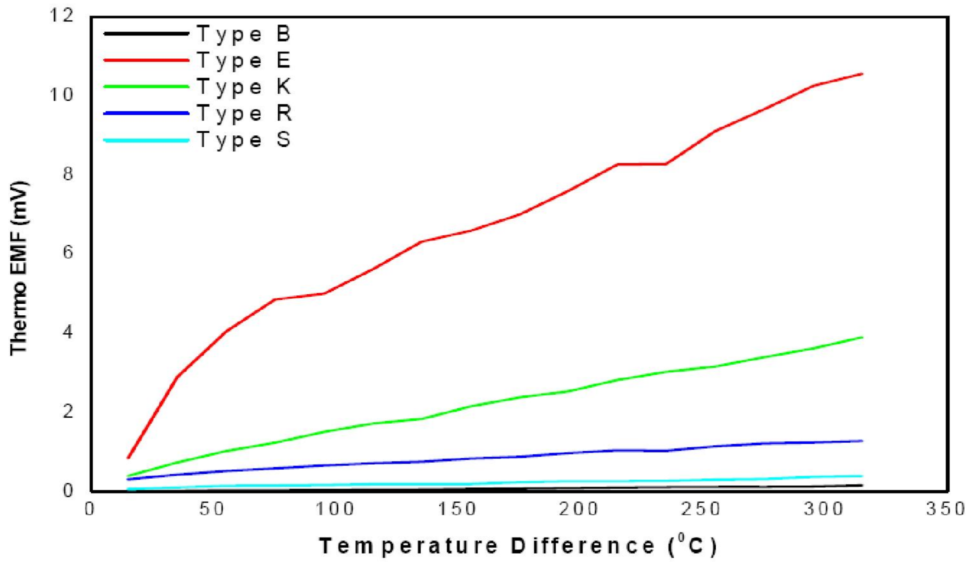

Figure 3(a) : Shows thermo-emf generation as a function of temperature difference for parallel electric field of 4V

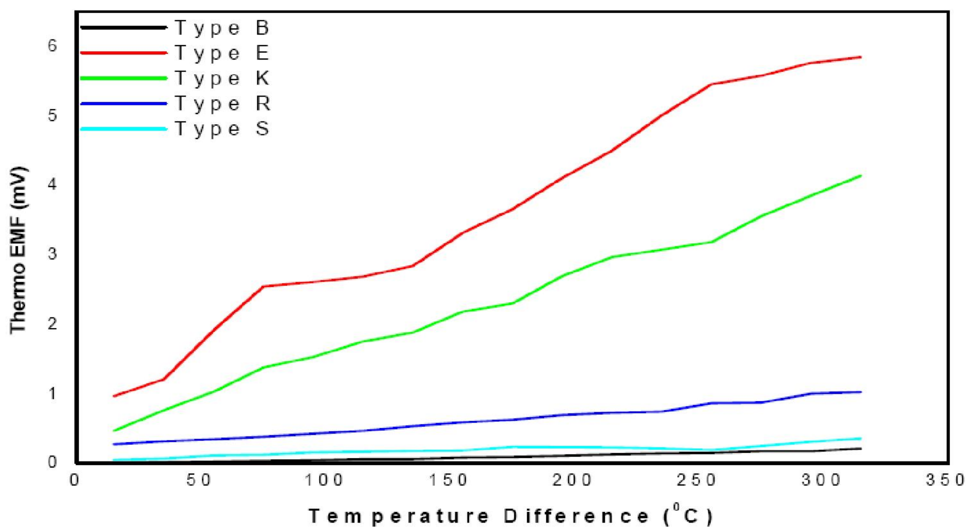

Figure 3(b) : Shows thermo-emf generation as a function of temperature difference for parallel electric field of 8V

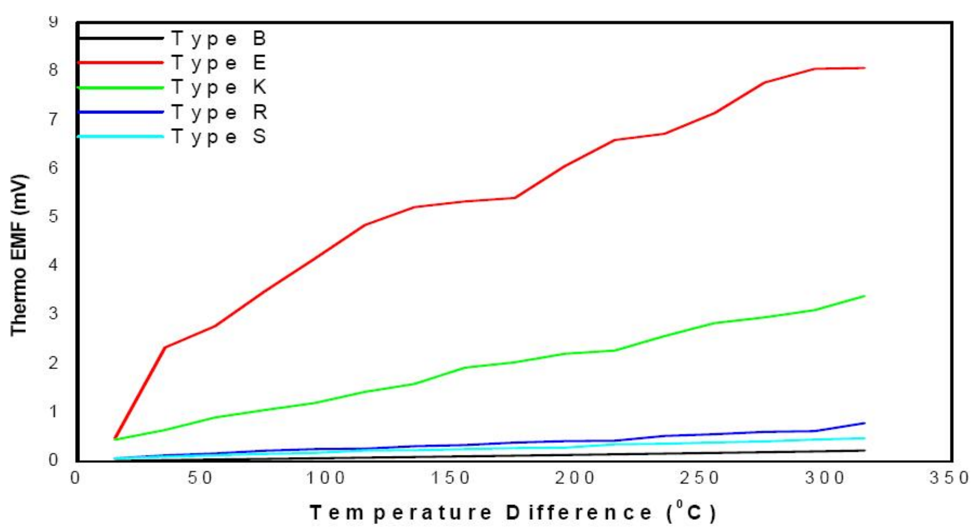

Figure 3(c) : Shows thermo-emf generation as a function of temperature difference for parallel electric field of 12V

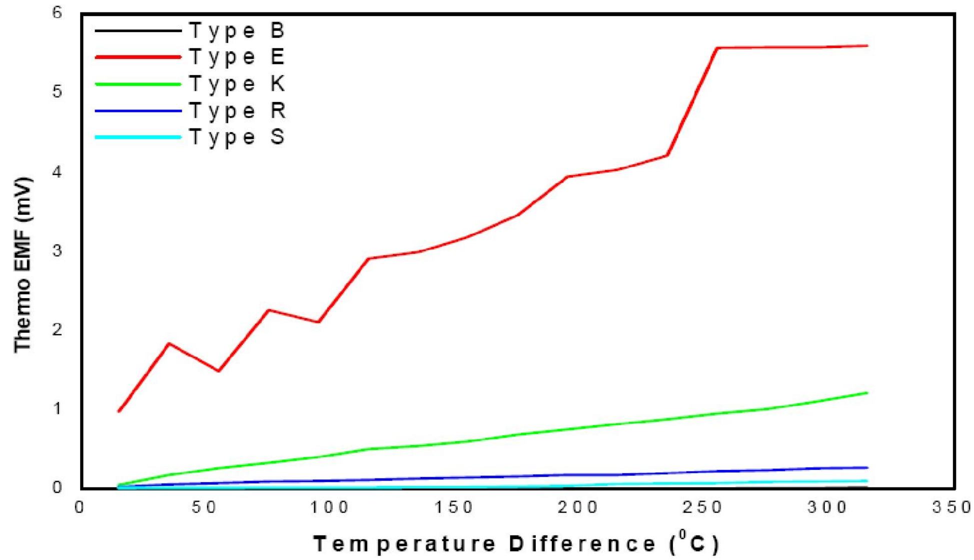

Figure 4(a) : Shows thermo-emf generation as a function of temperature difference for perpendicular electric field of 4V

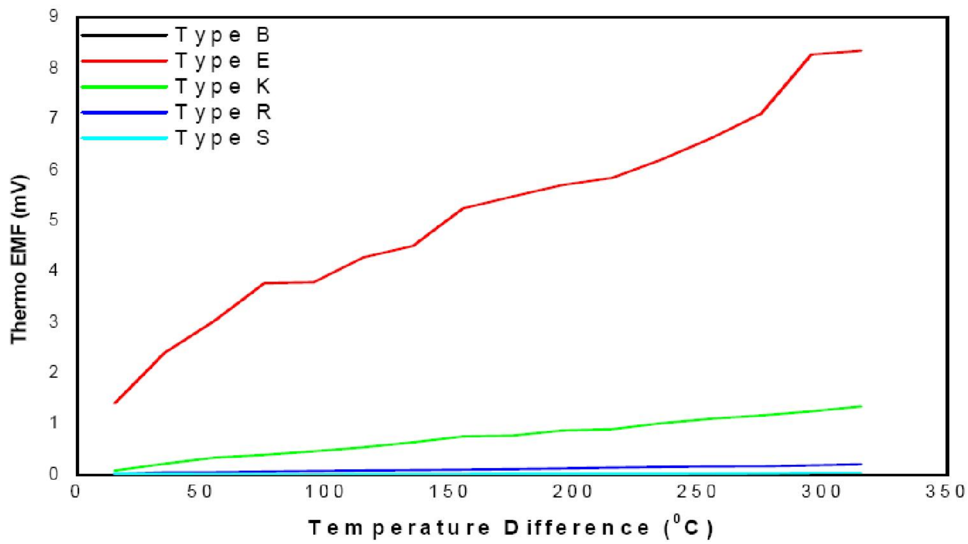

Figure 4(b) : Shows thermo-emf generation as a function of temperature difference for perpendicular electric field of 8V

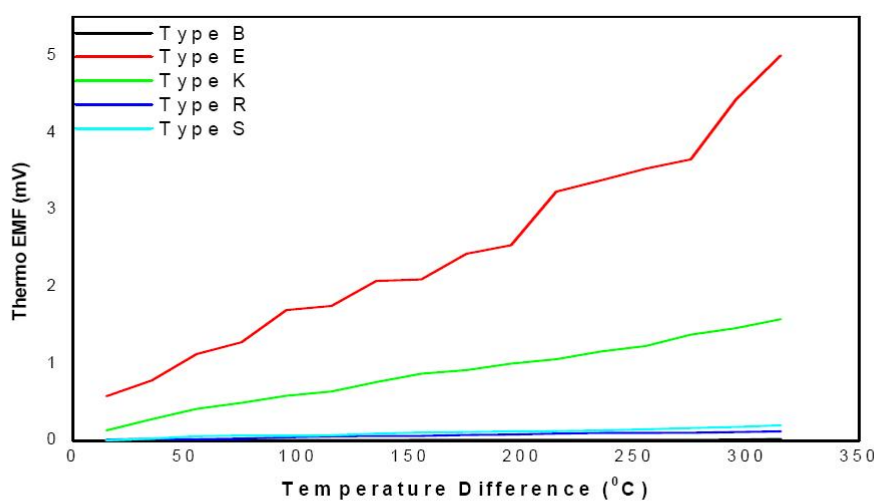

Figure 4(c) : Shows thermo-emf generation as a function of temperature difference for perpendicular electric field of 12V

thermocouple is not linear with the temperature variations as compared to all other thermocouples.

Applied potential difference of 8V

The corresponding electric field is of the magnitude of 21.3Vm^{-1}. The performance order is same as of the 4V but the emf magnitudes decreases than that case. The first rank thermocouple of type E generates only 6mV maximum thermo emf at the maximum temperature gradient; whereas type K and R limits only to 4.2mV and 0.8mV respectively at the same temperature difference (i.e. 295^{0}C). But the last rank thermocouples (type S and B) generate only 0.6 mV thermo emf as the maximum value (Figure 3(b)).

Applied potential difference of 12V

At this potential difference the electric field applied is 32 Vm^{-1} the exact order of the performances of thermocouples is Type E > Type K >Type R >Type S > Type B which generates the maximum thermo emf 8mV, 3mV, 0.5mV, 0.4mV and 0.2mV respectively at the maximum temperature gradient of 295^{0}C (Figure 3(c)). The behavior of all the thermocouples except of type E is linear.

Perpendicular electric field mode

Applied potential difference of 4V

For the 4V applied potential difference the strength of electric field is 22.2Vm^{-1}. The order of performance for maximum thermo emf generation is Type E > Type K > Type R > Type S and B (Figure 4(a)). For the thermocouple of type E maximum thermo emf is 5.7mV only where as it is 11mV in the parallel mode of 4V applied potential difference. Similarly for the type K and R it reduces to 1mV and 0.2mV respectively corresponding to the maximum temperature gradient. As of the previous mode the S and B type thermocouples again shows same performance of 0.1mV; which is less than all of the parallel modes. The type E thermocouple having large variations in the entire temperature range but all the other is in a linear manner.

Applied potential difference of 8V

For this 8V applied potential difference the magnitude of electric field is 44.4Vm^{-1}. The order of thermo emf generations is same as of the previous mode. The first three ranked thermocouples of Type E, K and R generates 8.4mV, 1.1mV and 0.2mV as the maximum thermo emf at the maximum temperature gradient respectively (Figure 4(b)).; which is enhanced for type E than the 4V of perpendicular mode. The other thermocouples of type S and B again limits to maximum emf of 0.1mV. The variations are less in this mode as compared to all of the previous modes.

Applied potential difference of 12V

The applied electric field is 66.7 Vm^{-1} and the order of thermo emf generations is slightly different from all the other modes, that is Type E > Type K > Type S >Type R and B. The variations for type E thermocouple are also reduced. At the maximum temperature gradient of 295^{0}C the maximum thermo emf is 5mV, 1.4mV, 0.2mV and 0.1mV for the above the order respectively (Figure 4(c)). All the other corresponding results can be compared from the graphical data.

CONCLUSION

Thermocouples of type E (Chromel-Constntan) and K (Chromel-Alumel) are the two better thermocouples not only in normal mode but also in both orientations of applied electric field. For type E thermocouple; the maximum thermo emf is 11mV at the maximum temperature gradient (in normal mode and 4V Parallel) but it is only 5mV for the 12V of perpendicular electric filed mode. So the energy conversion characteristics of ferromagnetic materials (Fe and Ni in type E thermocouple) are better than any other thermocouple. Hence this research work is able to provide the merit of RTD (Resistive Temperature Detector) materials as the thermo generator elements.

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