ISSN : 0974 - 7486 Volume 11 Issue 1

Materials Science

An Indian Journal

Full Paper

MSAIJ, 11(1), 2014 [19-24]

Magnetic field dynamics of thermo-emf generation in the high temperature range

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ABSTRACT

This paper presents some results of experimental research addressing the influence of magnetic field dynamics on the Seebeck effect (i.e., performance) of some selected classical thermocouples namely: Cu-Fe, Fe-constantan, constantan-nichrome, Fe-nichrome and Cu-nichrome. Thermocouples were selected on the basis of their esay availability and low cost with an aim of their (thermocouples) suitability towards the conversion of waste heat into electricity, i.e. as generator thermoelements. Effect of magnetic field dynamics of thermo-emf generation was investigated in the temperature range from 30^0C to 350^0C. The generation of thermo-emf for these thermocouples was studied at different values of applied magnetic field for its three (i.e., parallel, anti-parallel and perpendicular) orientations w.r.t. thermocouple. The magnetic field dependence of the Seebeck voltage was found to be large. Results show not only the significant increase in the thermoemf generation in case of all these thermocouples but also indicate greater stability of thermoemf generation with temperature variation. Thus, highlighting the importance of presence of magnetic field not only in terms of increasing the thermoemf generation and stability, but also towards the need of accuracy concern about the thermocouple response in temperature measurements.

KEYWORDS

Classical thermocouples;
Waste heat recovery;
Magnetic field dynamics and thermo-emf.

INTRODUCTION

Seeback thermoelectric phenomenon is the conversion of heat into electricity with the advent of thermocouples. Where as a thermocouple is an assembly of two different materials, generally metals; joined at the two ends called junctions. When a temperature gradient is established at the two juctions there is the generation of thermo-emf due to the contact potential which depends on electron density. The general equation of thermoelectricity to explain the generation of thermo emf, is E = $\alpha T + \frac{1}{2}\beta T^2$ where α and β are the Seebeck constants in μV/^{0}C and μV/^{0}C^2 respectively and T is the temperature gradient (temperature difference between two junctions). Thermopower, the rate of change of magnitude of thermo emf w.r.t. the temperarure gradient, is given as: $\frac{dE}{dT} = \alpha + \beta T$. Hence, it is clear that the thermo power increases with increase in temperature gradient because "α" and "β" are the constants for a given material. Finally, the equation of thermo-emf generation is generally taken as $dE/dT = \alpha$[1] because β is very small as compared to α. Thermoelectric generation of electric power is also beneificial due to its pollution free nature, no moving parts and no complex designing. With such advantages it can play an important role to overcome the energy crisis and environmental degradation. This has always motivated the researchers for advancements of this field to look for increase in thermoemf generation with classical or advanced thermoelectric materials as well as to study the effect of other operating parameters[2-4].

Waste heat is an integral part of all the industrial applications/processes in general and of combustion in particular. Advancements in the utilisation of waste heat by thermoelectric materials is of great interest. With the improvements in the technologies: the efficiency, modeling, designing and selection of materials can vary but the wastage of energy (mostly in the form of heat) can't be completly eliminated. It is not availabe only in the domestic areas like in the kitchens but also in the industries i.e. generators, electric motors, computers and in the furnances also. Sometimes, waste heat in significant amount also originates from the data centres, rubing processes, welding technologies and in the heating cooling systems. This waste heat can be utilised by converting it into electricity with the advent of thermocouples i.e. thermogenerators[5-7]. The power generated by thermoelectric techniques can be recycled or stored for the use of same devices. So, a thermogenerator making use of efficient and cost effective thermocouples is always sought to recover waste heat by converting it into useful thermo power. The prospective use of low cost and easily availabile classical thermocouple materials in thermogenerator is the basic approach of present research work with an aim to investigate the enhancement of thermo-emf generation. Thus, we have selected the classical thermoelectric materials (copper, iron, nichrome and constantan). The elemental characterization of these market avialable thermoelectric materials was also done in order to find out their composition for quality comparision.

Effect of magnetic field on the performance of thermocouples has been reported[8-14] for its role in significant enhancement of the thermo emf generation under different conditions and materials. Avialbility of waste heat can be accompained by the presence of magnetic field or can also be applied from outside. Presently, measurements of the change in Seebeck voltage were carried out with full length thermocouple in the magnetic field for parallel and anti-parallel modes and aplying magnetic field at the centre of thermocouple in perpendicular modes with temperature. Magnetic field strength dependence was investigated for its three lower values of 260, 360 and 460 Gauss. Being an energy dependent parameter, the magnetic field strength was selected in its lower range so that the ratio of energy produced to energy used should remain greater than one. It was found that the generation of thermo emf can be enhanced considerably for an optimum value of applied magnetic field which highlights towards better efficiency of thermo-emf generation from waste heat with cheap and easily available thermocouples under the effect of applied magnetic field.

EXPERIMENTAL

Measurement of physical parameter

The physical parameters like electrical conductivity of thermocouple wires and thermo-emf generation were measured with the help of a standard digital multimeter (make HP 34401A) with an accuracy of six decimal places. The measured physical parameters of different wires used to make thermocouples are given in TABLE 1.

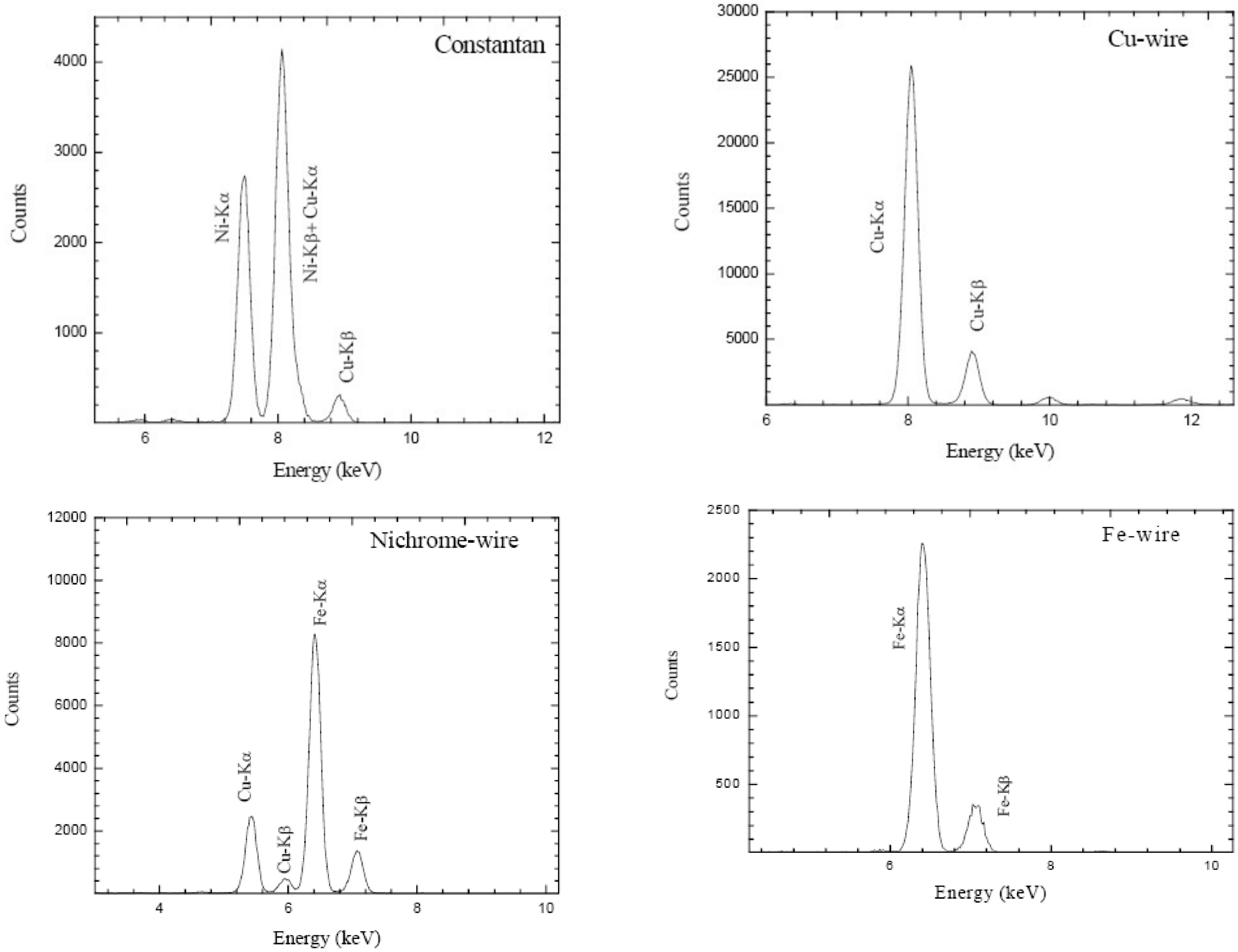
Characterisation of thermoelectric materials

The thermoelectric materials selected in present investigations were chracterised to find out their compo-

TABLE 1 : Experimental parameters of the selected thermoelectric materials

S. No.	Parameter	Copper	Iron	Constantan	Nichrome
1.	Resistance (Ohm)	0.1918	0.7062	0.5174	1.6874
2.	Area of Cross-Section (m^2)	1.51×10^{-6}	9.5×10^{-7}	1.112×10^{-6}	9.7×10^{-7}
3.	Length (m)	48×10^{-2}	48×10^{-2}	48×10^{-2}	48×10^{-2}
4.	Resistivity ρ (Ohm-m)	6×10^{-6}	1.4×10^{-6}	1.2×10^{-6}	3.41×10^{-6}
5.	Electrical Conductivity σ (Sm^{-1})	1.67×10^{6}	7.143×10^{5}	8.33×10^{5}	2.933×10^{5}

sition for the sake of performance comparison with the other versions of these thermoelectric materials avilable in the market. The characterisation was carried out using the XRF technique at the Tata Institute of Fundamental Research (TIFR) Bombay (India). The characterization graphs are given below :



Experimental set-up

The temperature gradient is established at the two junctions of the thermocouples by the heating and cooling arrangements. The generated thermo-emf measurements in the temperature range of 30^0C to 350^0C were made with digital multimeter HP34401A. The experimental set up is shown in Figure1. The electromagnets were used to provide the required magnetic field stength. The variation of magnetic field strength as a function of the length of the thermocouple is shown in Figure 2.

Form the Figure 2, it is very clear that the length-magnetic field curve is parabolic i.e. magnetic field has its highest concentration at the centre of thermocouple whereas it decreases with increase in length. The parallel/antiparallel and perpendicular orientations of magnetic field w.r.t. thermocouples were obtained by keeping the thermocouple and electromagnets with due consideration to variation of magnetic field along the length of the thermocouple.

RESULTS AND DISCUSSION

Normal & parallel mode

The graphical comparison of thermo-emf generation as a function of temperature gradiant for all selected classical thermocouples in various modes is shown in Figure 3. Figure 3a shows the results in the normal mode (i.e., without any applied magnetic field). From Figure 3a, it is very clear that Fe-constantan thermocouple generates maximum thermo-emf whereas Cu-Fe generates minimum. The values of generated thermo-

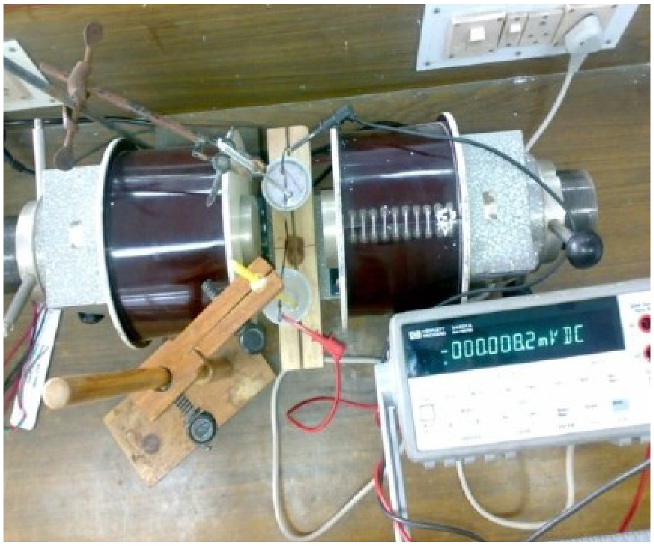


Figure 1

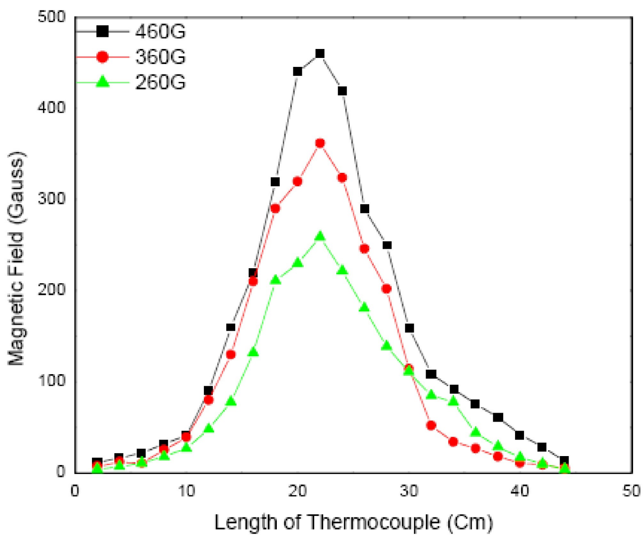


Figure 2

emf at the maximum temperature gradiant of 330^{0}C are 1.8mV and 0.1mV respectively for these thermocouples. With parallel mode of applied magnetic field, thermo-emf generation in comparision to normal mode for all the thermocouples with temperature gradiant not only enhances but also shows more generation stability. Figure 3b,c & d show the thermo-emf generation with temperature gradiant for the applied magnetic field strengths of 260, 360 and 460 gauss in parallel mode. Thermo-emf generation is more stable as compared to that in normal mode and it increases linearly with increase in temperature difference. The maximum values of thermo-emf generated with 260, 360 and 460 gauss applied magnetic field strength in parallel mode are 2.3mV, 4.2mV and 2.7mV respectively at the maximum temperature difference. From Figure 3b,c & d, it is very clear that Fe-constantan and constantan-nichrome thermocouples turn up to be better thermoelectric materials. Besides, it is also found that thermo-emf generation under similar conditions for same thermocouples for parallel mode is a function of magnetic field strength and a value of 360 gauss magnetic field strength gives the best thermo-emf generation results as compared to 260 and 460 gauss.

Perpendicular mode

Figure 4a, b & c give the graphical representation of thermo-emf generation as a function of temperature

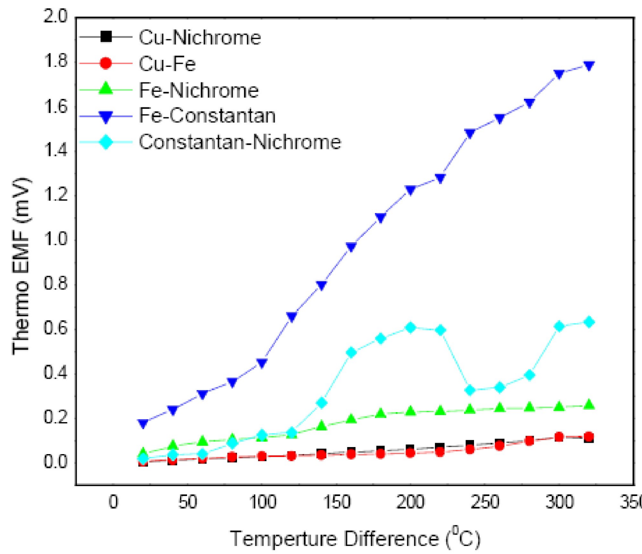


Figure 3a : Normal mode

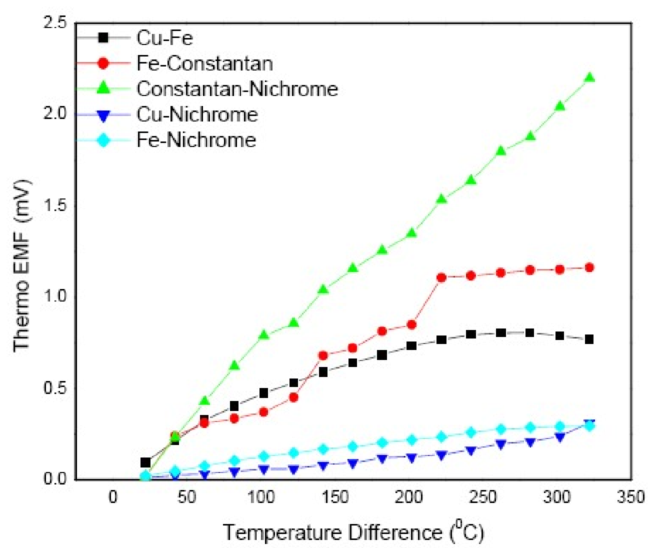


Figure 3b : Parallel mode, for B = 260 gauss

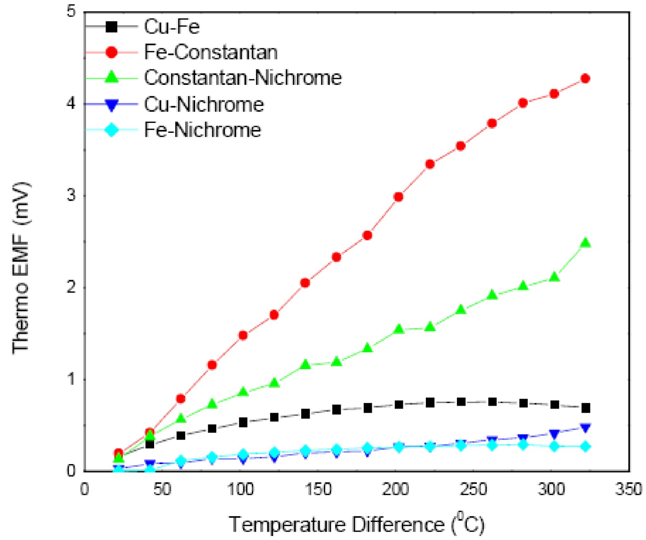


Figure 3c : Parallel mode (for B = 360 gauss)

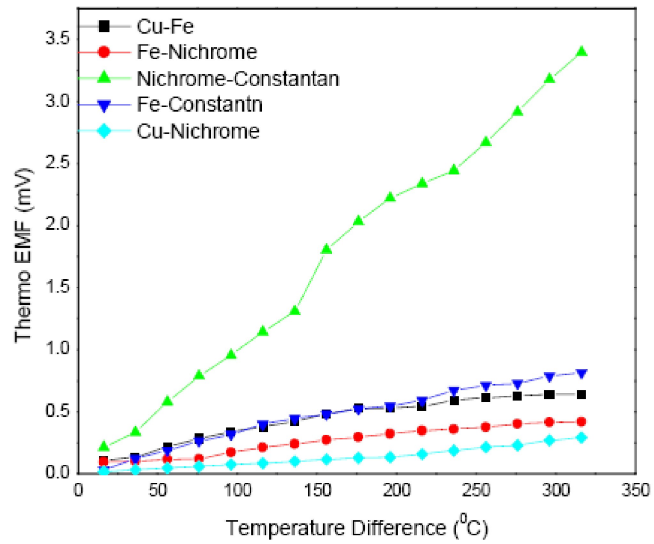


Figure 4a : Perpendicular mode (for B=260 gauss)

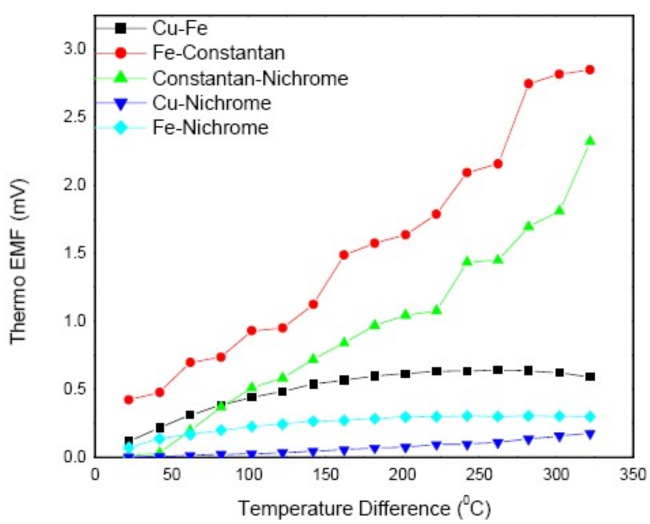


Figure 3d : Parallel mode (for B = 460 gauss)

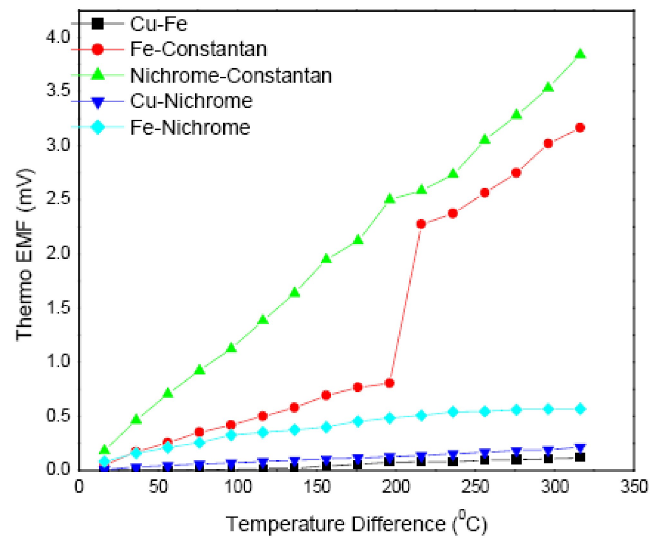


Figure 4b : Perpendicular mode (for B=360 gauss

gradiant for all selected classical thermocouples in perpendicular mode of applied magnetic field. The perpendicular mode was found to generate higher thermo-emf under same temperature gradiant and applied magnetic field strength with more stability as compraed to even parallel mode of applied magnetic field. In this mode for a magnetic field strength of 260 gauss, constantan-nichrome thermocouple generates about 3.4mV thermo-emf at the maximum temperature difference of 330^{0}C. Whereas, for 360 gauss and 460 gauss the maximum thermo-emf generated at the maximum temperature difference was 3.7mv for nichrome-constantan and 10.2mV for Cu-Fe thermocouple respectively.

Investigations indicate that in perpenicular mode, higher magnetic field strength gives better results in terms

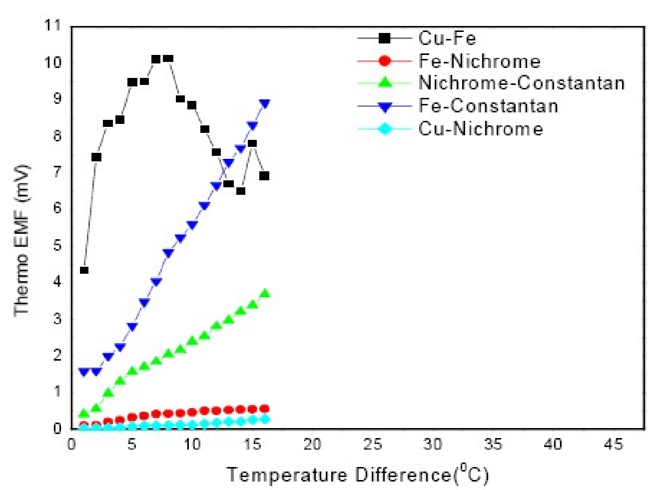


Figure 4c : Perpendicular mode(for B=460 gauss)

of thermo-emf generation. But generation of higher magnetic will again need more energy, therefore, its optimum value has to be chosen. The lower value of magnetic field i.e. 260 gauss is not that effective either in parallel or in the perpendicular orientations, however some thermocouples do generate slightly more thermo-emf at some temperature differences for this value of magnetic field also as compared to the normal mode. A comparison of thermo-emf generation at the minimum and maximum temperature difference in the normal, parallel and perpendicular modes of applied magnetic field for all presently investigated classical thermocouples are given in TABLE 2 for their suitability as thermogenerator elements for waste heat utilization.

TABLE 2 : A comparison of thermo-emf generation with temperature gradiant and magnetic field

Sr. No.	Mode	Temp.Diff (^{0}C)	Cu-Fe (mV)	Fe-constantan (mV)	Cu-nichrome (mV)	nichrome-constantan (mV)	Fe-nichrome (mV)
1.	Normal	30	0.0076	0.1819	0.0046	0.0191	0.0423
		350	0.1201	1.7906	0.11305	0.6349	0.2591
2.	Perpendicular (460 gauss)	30	4.3293	1.5839	0.0112	0.4139	0.1023
		350	6.9161	8.9185	0.2791	3.6865	0.5567
3.	Parallel (360 gauss)	30	0.1651	0.1975	0.0309	0.137	0.0058
		350	0.6935	4.2771	0.4867	2.4798	0.2742

CONCLUSION

It was found that the generation of thermo emf not only enhances considerably with increasing temperature gradient under the applied magnetic field but makes the generation a more stable process which highlights towards better efficiency of thermo-emf generation from waste heat with cheap and easily available thermocouples under the effect of applied magnetic field. The paper concludes that the thermo-emf generation enhanced in both the parallel and perpendicular modes of applied magnetic field than the normal mode and higher the value of applied magnetic field is better specially in perpendicular mode where as in parallel mode there is an optimum value of magnetic field. From the present experimental investigations, Fe-constantan and nichrome-constantan thermocouples emerged as better choices as thermoelements of a thermogenerator to convert waste heat into electricity under all the modes of applied magnetic field and other operating parameters in the high temperature range.

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