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 easy availability and low cost with an aim of their (thermocouples) suitability towards the conversion of waste heat into electricity, i.e. as generator thermo-elements. 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.

Keywords Classical thermocouples, waste heat recovery, magnetic field dynamics and thermo-emf.

1. 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 junctions 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). Thermo-power, the rate of change of magnitude of thermo-emf w.r.t. the temperature 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 = α [1] because β is very small as compared to α. Thermoelectric generation of electric power is also beneficial 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 thermo-emf generation with classical or advanced thermoelectric materials as well as to study the effect of other operating parameters [2-3].

Sometimes, waste heat in significant amount also originates from the data centers, rubbing processes, welding technologies and in the heating cooling systems. This waste heat can be utilized by converting it into electricity with the advent of thermocouples i.e. thermo-generators [4]. Effect of magnetic field on the performance of thermocouples has been reported [5] for its role in significant enhancement of the thermo-emf generation under different conditions and materials.

2. 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.

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}

3. Characterization of Thermoelectric Materials

The characterization of the selected thermoelectric materials was carried out using the XRF technique at the Tata Institute of Fundamental Research (TIFR) Bombay (India). The characterization graphs are shown in Figure 1 (a), 1 (b), 1 (c) and 1 (d):

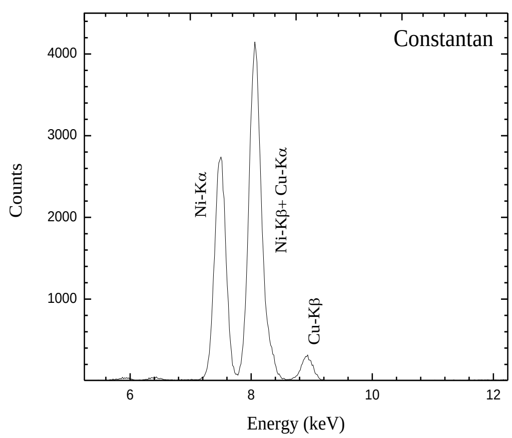

Figure 1 (a)

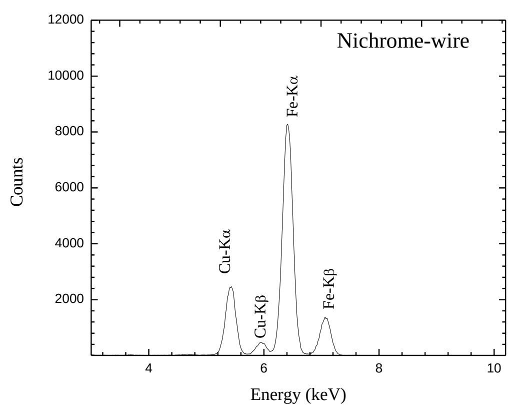

Figure 1 (b)

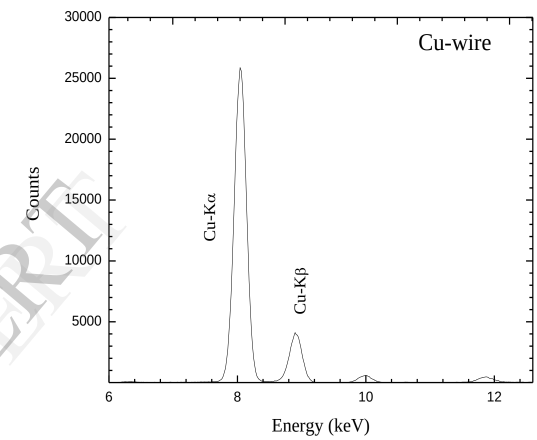

Figure 1 (c)

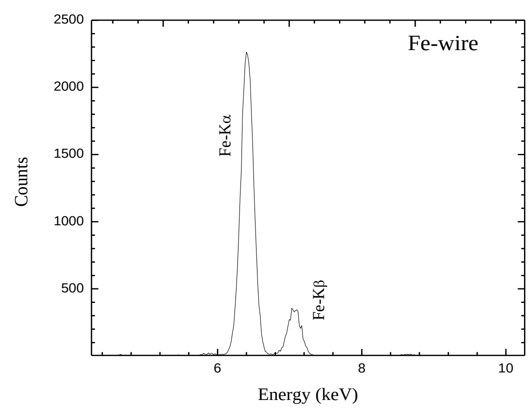

Figure 1 (d)

4. 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 300C to 3500C were made with digital multimeter HP34401A. The electromagnets were used to provide the required magnetic field strength. The magnetic field in two orientations i.e. parallel and perpendicular is applied on the each thermocouple by electromagnets. The variation of magnetic field strength as a function of the length of the thermocouple is shown in Figure 2.

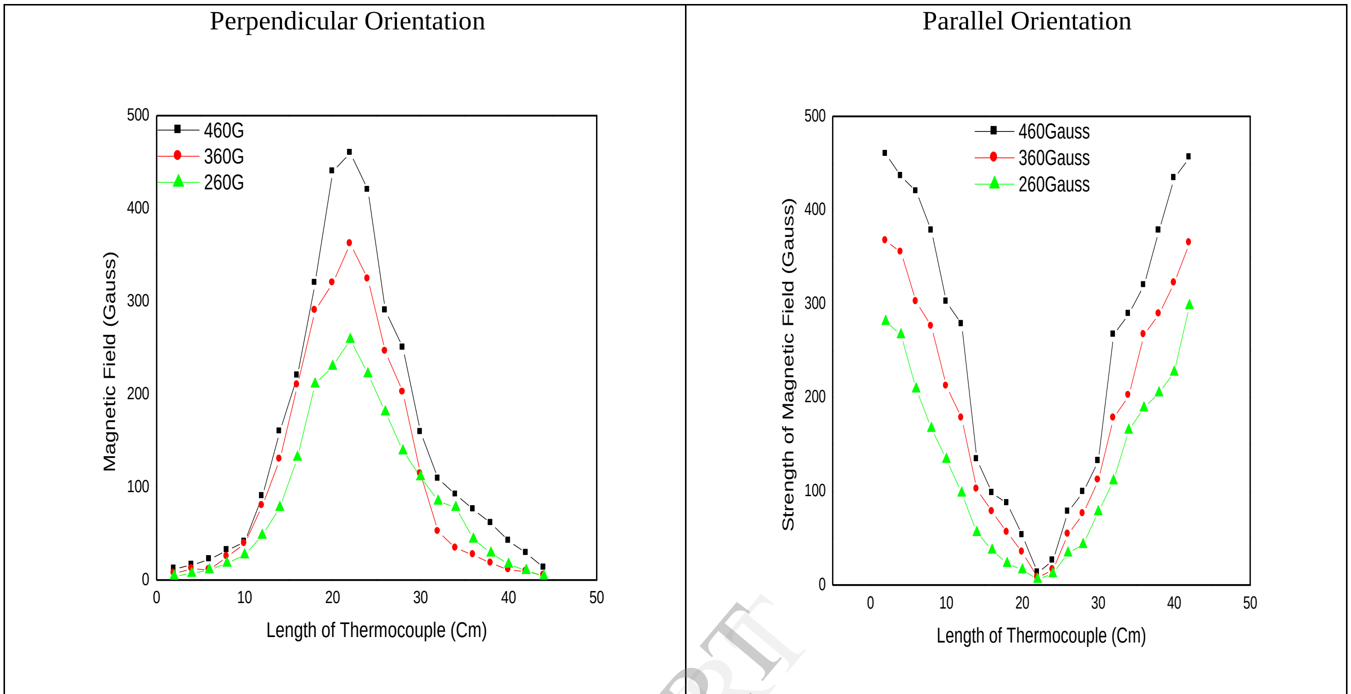

Figure 2. The variation of magnetic field strength as a function of the length of the thermocouple

5. Result and Discussion

Normal & Parallel Mode

The graphical comparison of thermo-emf generation as a function of temperature gradient for all selected classical thermocouples in various modes is shown in Fig. 3. Figure 3a shows the results in the normal mode (i.e., without any applied magnetic field). From Fig. 3a, it is very clear that Fe-constantan thermocouple generates maximum thermo-emf whereas Cu-Fe generates minimum. The values of generated thermo-emf at the maximum temperature gradient 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 comparison to normal mode for all the thermocouples with temperature gradient not only enhances but also shows more generation stability. Figure 3b, c & d show the thermo-emf generation with temperature gradient 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 Fig. 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.

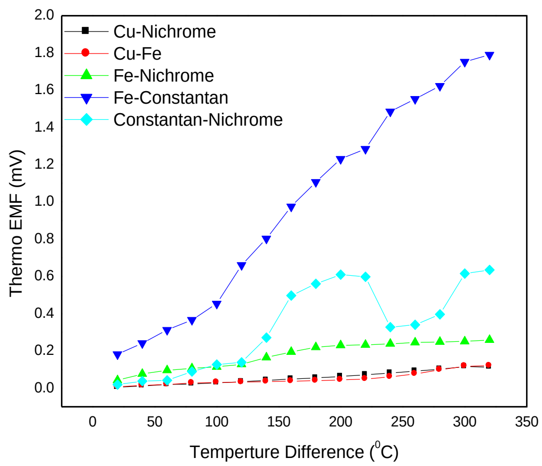

Figure 3(a): Normal mode

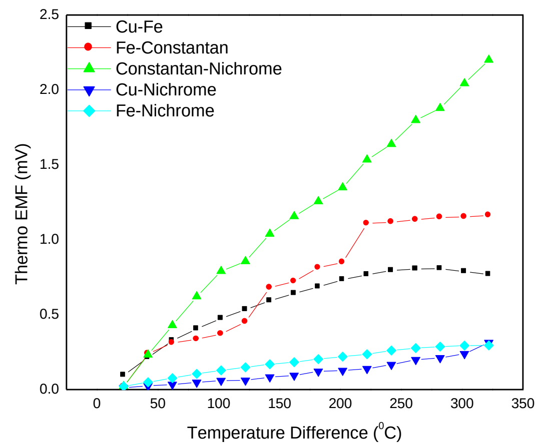

Figure 3 (b):Parallel Mode (for B = 260 Gauss)

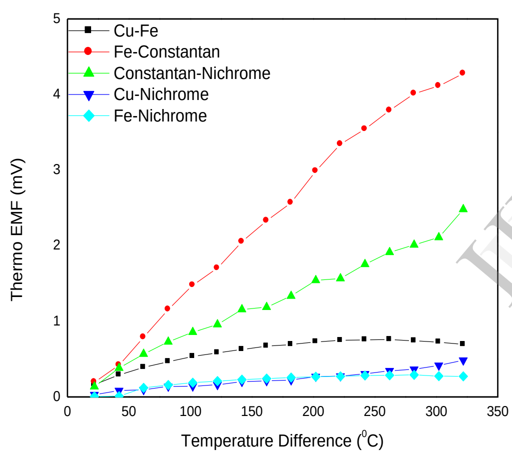

Figure 3 (c): Parallel Mode (for B = 360 Gauss)

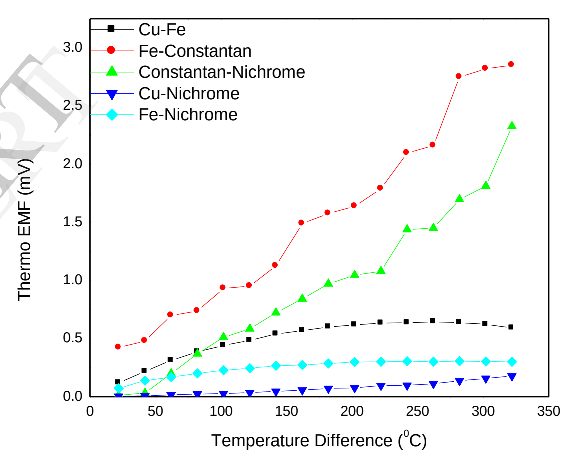

Figure 3 (d): Parallel Mode (for B = 460 Gauss)

6. Perpendicular Mode

Figure 4a, b & c give the graphical representation of thermo-emf generation as a function of temperature gradient 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 gradient and applied magnetic field strength with more stability as compared 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.

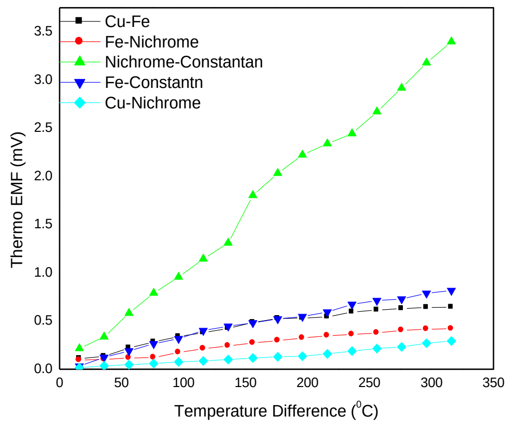

Figure (4a): Perpendicular mode (for B=260 Gauss)

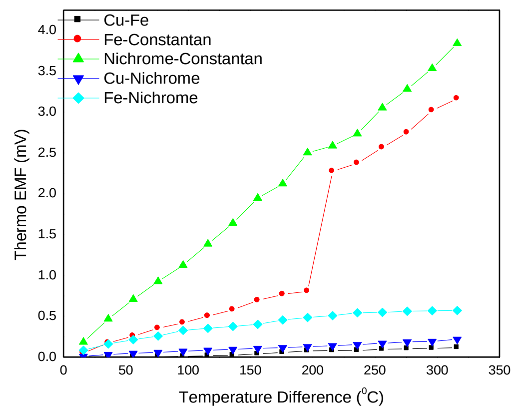

Figure (4b): Perpendicular mode (for B=360 Gauss)

7. 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 especially in perpendicular mode where as in parallel mode there is an optimum value of magnetic field.

5. References

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