Asian Journal of Chemistry Vol. 21, No. 10 (2009), S056-061

Effect of Magnetic and Electric Field Dynamics on Copper-Iron Thermocouple Performance

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Paper presents an approach to the utilization of waste heat by the use of thermoelectricity with the advent of cheap and easily available Cu-Fe thermocouple. A significant novelty of present investigation is the generation of thermo-emf with low grade waste heat utilization along with the static-electric or -magnetic fields. The performance of thermo couple is examined under normal conditions over a wide temperature range and then in different orientations of static-electric or -magnetic fields.

Key Words: Thermoelectricity, Magnetic field, Electric Field, Waste heat utilization

INTRODUCTION

Electric energy is commonly generated using heat energy and this conversion with latest technological developments still comes about 50% at the maximum, thus, a large part of heat is being wasted. Thermoelectricity is a well known technology to convert heat into electricity. This technology at one hand when bestowed with number of advantages has a limited use due to its lower conversion efficiency. But in an era of energy crisis and environmental degradation by the generation of pollutants while meeting the growing energy demand, there is need to make thermoelectric conversion more efficient and user friendly so that at least low grade waste heat[1-3] can be put to a use by using cheap and easily available thermocouples in various regions of low grade wastes heat availability and sometimes, with the presence of static electric and magnetic fields.

Taking into consideration the importance of thermoelectric power generation, development of thermoelectric materials and theoretical studies in this field are keeping researchers[4-6] always busy. But, still the wide application of thermoelectric power generation has been limited due to its relatively low heat to electricity conversion efficiency and high temperature operations with costly thermocouples. Efforts[7-9] are directed to simulate and develop new materials with increasing electrical conductivity and decreasing thermal conductivity in order to have increased thermoelectric power coefficients. Effect of magnetic or electric fields are also being studied by many researchers[10-13] for long with different materials and other parameters keeping in view the presence of these effects with the heat sources or in order to see the possibility to improve on thermoelectric conversion efficiency.

Present experimental investigations are for a copper-iron thermocouple with and without the effect of magnetic and electric fields. The selection of Cu-Fe thermocouple is based on its easy availability and low cost. The market available common wires were used to make thermocouples by simple welding without introducing any third material. Experimental investigations were made for different situations (normal mode-without any effect of magnetic or electric fields), with static magnetic or static electric field (for different orientations) under a temperature range. All these investigations will help to implement a design of simplification, compactness and most important more electric power output. The equipments of such implementations can be employed as charging devices, efficiencies improve mentors, aerospace applications, commercially applications, and in other electronic devices.

EXPERIMENTAL

Thermocouple (TC1) was used for investigations in normal mode and for all electrical field orientations and parallel & anti parallel orientations of magnetic field where as thermocouple (TC2) was used in perpendicular orientation of magnetic field only. Thermocouple (TC1) was to be made small in order to accommodate it inside the poles of electromagnet which was easily maintained for parallel and anti-parallel orientation but not for perpendicular orientation as junctions were getting attracted towards the poles. Therefore, thermocouple (TC2) with long length of copper wire (bringing the junction outside the magnetic field region) was used for perpendicular orientation. It is clear from table 1 that the resistivity and electrical conductivity of both the thermocouples were not identical which means that the composition of the materials used for TC1 and TC2 were not same which shows the need for standardization of composition of thermocouple materials for better comparison and this will be taken care in further studies.

Table 1: Specifications of thermocouples

Physical Quantity	TC1		TC2	
	Copper	Iron	Copper	Iron
Length	8×10^{-2} m	15.5×10^{-2} m	16×10^{-2} m	2×10^{-2} m
Radius	0.58625 mm	1.075 mm	1.174 mm	1.01 mm
Area	1.0792 mm^2	3.63 mm^2	4.33 mm^2	3.2 mm^2
Resistance	0.0934 Ω	0.1015 Ω	0.083 Ω	0.11 Ω
Resistivity	1.3E-6 Ωm	2.4E-6 Ωm	2.25E-6 Ωm	1.66E-6 Ωm
Electrical Conductivity	7.7E5 Sm^{-1}	4.2E5 Sm^{-1}	4.4E5 Sm^{-1}	6.024E5 Sm^{-1}

The heating of one end was carried out by heating mercury (Hg) up to 340^{0}C in a crucible (THIASIL®) on an electric hot plate and then immersing hot junction into it. Cold junction was maintained at room temperature by using normal tap water in a crucible (THIASIL®) and fresh water was continuously poured at cooling end to maintain the temperature of cold junction. Mercury was used instead of water because of its high boiling point (357^0C) and its heating is smooth. Measurements for resistance of the thermocouple was firstly measured with the help of meter bridge and then verified by Digital Multimeter (HP34401A). Thermo-emf generated was measured with Digital Multimeter (MASTECH$^{®}_{CE1010}{}^{IEC}$ M92A). Thermometers of different ranges were used to measure temperature(s) of hot and cold junctions.

Different modes of experimentation

Thermocopule (TC1) in normal mode as shown in fig. 1(a) was investigated up to the temperature range of 140^0C. It was also investigated in parallel and anti parallel orientations of static magnetic field using an electromagnet as shown in fig. 1(b) by keeping the copper wire inside the magnetic field. All orientations were examined for magnetic field strengths of 120, 2780, and 5485 Gauss for which the electromagnet available in the laboratory was calibrated. The cooling and heating arrangement is same as for normal condition of investigations.

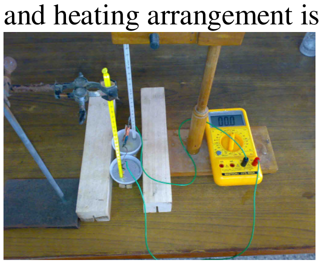

Fig. 1(a): Normal Mode

Fig.1(b)Using electromagnet

Fig. 1(c): Using Electric field

To study the effect of electric field an experimental set up as shown in fig. 1(c) was fabricated. Two aluminum plates (each of area 25 cm X 22.6 cm) were arranged in the form of parallel plate capacitor. For perpendicular orientations the separation between plates was 13.5 cm and for parallel & anti-parallel the separation was 17 cm. The plates were connected to a DC battery (to produce static electric field) and were mounted on to an adjustable wooden base parallel to each other.

RESULTS AND DISCUSSION

Figure 2 shows the variation of thermo-emf generation (mV) as well as thermo power coefficient (TPC) ($\mu V/^0C$) for Cu-Fe thermocouple (TC1) under normal mode of investigations. The temperature difference of thermocouple junctions was varied upto 120^0C. Temperature of cold junction was maintained at 23^0C i.e., room

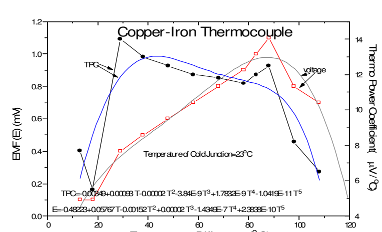

Fig.2: Normal mode

temperature. The maximum emf was obtained as 1.1mV for a temperature difference of 88^0C between the hot and cold junctions

Magnetic Field Effect

Effect of static magnetic field (B) for its different values was investigated on the performance of thermocouple (TC1). Figure 3 shows the variation of thermo-emf generation as a function of temperature difference for different values of B in the ‖orientation of thermocouple. Temperature of cold junction was maintained equal to 20^0C i.e., room temperature. The parabolic behaviour of thermocouple is extended to a large temperature difference under the effect of all values of B but thermo-emf generation was found to decrease for higher values (i.e., 5485Gauss) of magnetic field and there was also not a significant change in thermo-emf for fields of 120 to 2780 Gauss. Inversion temperature is also influenced to decrease with the increase in magnetic field. It is clearly evident from the fig. 3 that magnetic field does influence the power generation but higher strength is not of much use. The thermo-emf was found to almost double as compared to normal mode and generation was also without fluctuations. For B=120G & B=2780G max emf was 2.2mV at the temperature difference of 270^0C where as for B=5485G it was 1.9mV at a temperature difference of 230^0C.

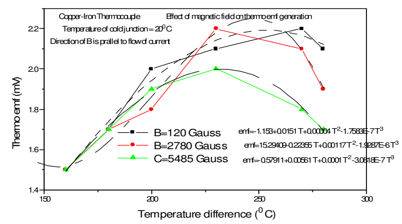

Fig. 3: Parallel orientation of B

Similar investigations were performed for anti-‖ orientation of magnetic field with thermocouple (TC1) shown in fig.4 and for ⊥ orientation with thermocouple (TC2) shown in fig.5. In case of anti-‖orientation thermo-emf generation

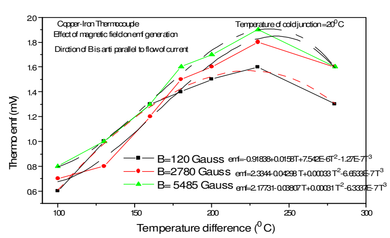

Fig.4: TC1 for ant-parallel orientation of B

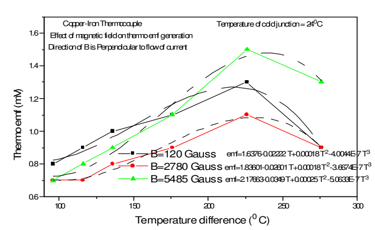

Fig.5: TC2 for perpendicular orientation of B

increases with the increase in the strength of B but the increase was less as compared to ‖orientation mode. No change was found in the inversion temperature with the strength of B and increase in operating temperature range was as usual to the effect of B in ‖ orientation. For B=120G max emf was 1.6mV where as for B=2780G & B=5485G max emf was 1.8mV & 1.9mV respectively at temperature difference of 230^{0}C. In case of ⊥ orientation therm-emf generation shows an erratic behaviour with the strength of B applied. It deceases with the increase in B from 120G to 2780G and then increases for 5485G. Inversion temperature almost remains un-affected with B in this orientation.

Electric field effect

Similar experimental investigations were carried out to study the effect of electric and its orientations (parallel, anti-parallel & perpendicular) on the thermo-emf generation. Inversion temperature range was found to increase with the increase in electric field but there was in-significant change in thermo-emf generation for each orientation with the electric field strength. Figure 6 shows the comparison of thermo-emf with temperature difference for all orientation of electric field (equivalent to 4V). The thermo-emf was found to almost double as compared to normal mode (i.e., without electric field application) and generation was also without fluctuations. Thermo-emf generation was less for parallel (1.9mV at temperature difference of 267^{0}C) and anti-parllel (1.1mV at temperature difference of 227^{0}C) orientations of electric field as compared to perpendicular orientation (2.1 mV for the temperature of difference of 267^{0}C). However, for lower temperature range (suitable to normal mode), the thermo-emf generation was better without any electric field, therefore, electric field in its perpendicular orientation will only help to get more thermo-emf at higher temperature range.

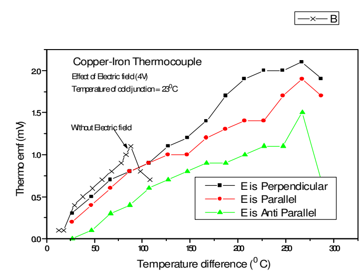

Fig.6: Electric field in Normal mode

Conclusions

From the present investigations it is concluded that for normal mode, the curve is limited to small temperature range i.e., only up to 140^{0}C where as thermo-emf generation in this range is better in comparison to electric or magnetic field with any orientation. Electric and magnetic field presence enhanced the thermo-emf generation and also widen the operating temperature range up to 310^{0}C which will help to make use of low grade waste heat with higher temperature. The thermo-emf generation is better for electric field with its ⊥ orientation and for B with its ∥ orientation. The another aspects for various temperatures, electric fields, magnetic field and their orientations can be easily examined and compared from graphs.

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