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Performance Comparison of Some Common Thermocouples for Waste Heat Utilization

VINOD KUMAR, JASPAL SINGH and S S VERMA
Department of Physics S.L.I.E.T., Longowal, Distt.-Sangrur-148 106 (Punjab)
Email: ssverma@fastmail.fm

In the present scenario of energy crisis, conversion of waste heat into electricity with the help of thermoelectric devices is thought to be as an important resource of energy. This paper presents some results of the experimental research addressing the performance of some commonly available thermocouples: Cu-Fe, Cu-Al and Fe-Al. Coefficient of performance of these thermocouples was measured in a temperature range from room temperature to maximum operating temperature of 310^0C. The effect of static magnetic and electric field for its different orientations is also measured on the performance of these thermocouples. It is found that in normal conditions the coefficient of performance for Fe-Al thermocouple is better than other combinations. The effect of magnetic and electric field was favorable in parallel orientation as compared to other orientations.

Key Words: Thermoelectricity, coefficient of performance, waste heat utilization

INTRODUCTION

Research is underway to identify the techniques for reliable utilization of low grade waste heat[1-3]. More availability of low grade waste heat and sometimes along with the static electric and magnetic fields, always attract the scientists for its utilization. The technology of thermoelectricity is considered as one of the best options for this utilization due to many inherent advantages being associated with the technology of thermoelectric conversion of heat into electricity. This technology provides pollution free, compact, reliable and easily operatable devices as compared to other traditional technologies of energy conversion. Due to this, researchers[4-6] are busy in investigating theoretical concepts and developing efficient thermoelectric materials.

The performance of thermocouples described in terms of figure of merit is given by: $ZT=(\alpha^2\sigma/\lambda)T$; where '$\alpha$' is the Seebeck coefficient in μVK^{-1}; 'σ' is the electrical conductivity in Sm^{-1}; 'λ' is the thermal conductivity in $Wm^{-1}K^{-1}$ of thermoelectric material and 'T' is absolute temperature in Kelvin. Coefficient of Performance (COP) of any thermocouple basically depends on the thermal conductivity and electrical conductivity of thermoelectrical materials in use. For better COP, there is a need for materials with low thermal conductivity and higher conductivity. Though, both of these properties go hand by hand with materials characteristics. Many researchers[7-9] have directed their investigations to develop materials with low thermal conductivity and high electrical conductivity. Similarly, the effect of magnetic and electric field has also been studied by many workers[10-13].

In the present investigations, three easily available materials i.e., copper, iron and aluminum are selected to represent a significant variation in these properties as well as to take into account the magnetic and non-magnetic nature of these materials in order to investigate the effect of magnetic and electric field on their performance. The electrical and thermal conductivity of these materials in their purest form is in the order as: copper > aluminum> iron where copper & aluminum are non-magnetic and iron is magnetic in nature. In the present investigations, the performance of three thermocouples TC1 (Fe-Cu), TC2 (Cu-Al) and TC3 (Al-Fe) is studied in normal conditions. Out of these three thermocouples, TC3 was found to show good performance which is then studied under the effect of static electric and magnetic field under various orientations.

EXPERIMENTAL DETAILS

Thermocouple (TC1) is fabricated (without the use of third material as a binder) and TC2 and TC3 are just in twisted form because aluminum can not be welded under normal conditions. The specifications of all the three thermocouples are listed in table 1.

Table 1: Specification of thermocouples

Thermocouple	Material	Resitivity (ohm m)	Electrical conductivity (Sm^{-1})
TC1	Fe	$1.66x10^{-6}$	$6.024x10^{5}$
	Cu	$2.25x10^{-6}$	$4.4x10^{5}$
TC2	Cu	$2.8x10^{-7}$	$3.6x10^{6}$
	Al	$3.2x10^{-7}$	$3.13x10^{6}$
TC3	Al	$3.2x10^{-7}$	$3.096x10^{6}$
	Fe	$1.5x10^{-6}$	$6.7x10^{5}$

Experimental investigations for normal conditions (fig. 1a) and with magnetic (fig.b) or electrical field (fig.c) for their different orientations have been made according to the experimental details already discussed[14].

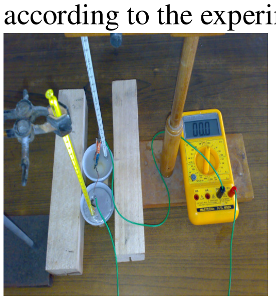

Figure 1(a)

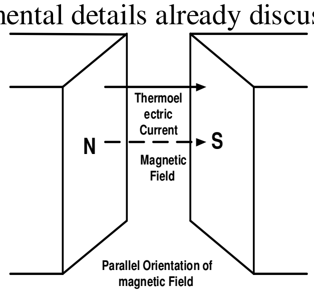

Figure 1(b)

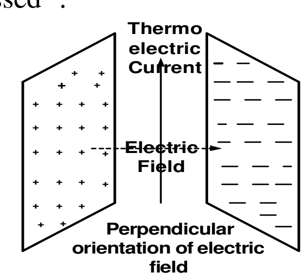

Figure 1(c)

When all the selected thermocouples are studied for their thermoemf generation with the temperature ranging up to 310^{0}C, the parabolic curves of thermo emf generation with temperature were obtained. Out of three thermocouples, thermocouple (TC3) has best performance for the selected temperature range as shown in fig 1(a). Then TC3 was studied for the strength of magnetic field (=120Gauss) in parallel, antiparallel and perpendicular orientation by keeping the complete thermocouple inside the poles of electromagnet. Use of magnetic field with low strength was decided due to the cost involved in generating the magnetic field as well as its low value availability with waste heat resources. The temperature of cold junction was always maintained at room temperature which was having minor changes on daily basis and is indicated in the respective graphs.

RESULTS AND DISCUSSION

Figure 2 shows that in normal mode, thermoemf with temperature is maximum for thermocouple (TC3) at all temperature ranges with its max. value at 1.6892mV at the temperature difference of 293^{0}C. Aluminum-iron thermocouple shows better performance as compared to other combinations (i.e.,copper-iron, TC1 & copper-aluminum TC2) indicating the importance of a combination of materials with low thermal conductivity and high electrical conductivity. Aluminum fulfills the requirement of high electrical conductivity where as iron has low thermal conductivity. Aluminum shows better prospects as one of the thermocouple material, however, difficulty arises with aluminum for the fabrication of its thermocouple as aluminum does not fuse with other materials under simple laboratory conditions.

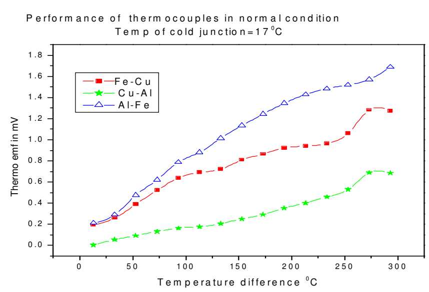

Fig. 2: Variation of thermo emf in normal mode

The effect of magnetic field (for 120G) is studied only for TC3 with its different orientations i.e., parallel, anti-paraellel and perpendicular. From fig. 3 it is found that up to a temperature difference of 126^{0}C the thermoemf is approximately same for all three orientations and then thermoemf generation for parallel orientation increases for max. of 1.898mV for the temperature difference of 286^{0}C.

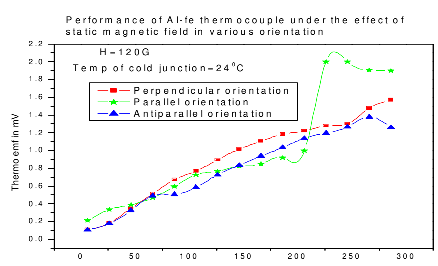

Fig. 3: Variation of thermo emf in static magnetic field (=120Gauss) for TC3

For the temperature difference of 226^0C to 286^0C, thermoemf for parallel orientation increases rapidly. Similarly, thermocouple (TC3) was studied in the effect of static electric field for three different orientations of electric field. It is found from fig. 4 that for applied electric field equivalent to 4volts, the effect of electric field on the generation of thermoemf is only significant at higher temperature variations. At higher temperature differences, parallel and perpendicular orientations also produce same results where as antiparallel orientation indicates generation of lower thermoemf. Theoretical explanation for the favourable orientations of magnetic and electric field is to be studied further.

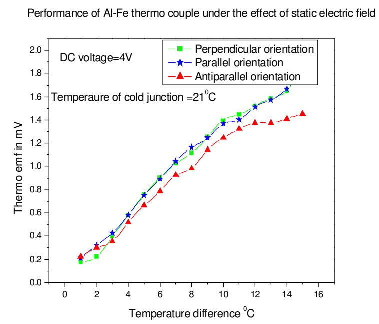

Fig. 4: Variation in thermo emf with static electric field for its different orientations

Conclusions

From the present investigations it is concluded that the performance of Al-Fe thermocouple is better than other thermocouples for normal mode of operation in lower as well as higher temperature range. For magnetic field, all the three orientations has approximately same performance for lower temperature range but parallel orientation is better for the higher temperature range. Parallel & perpendicular orientations of electric field also show promising effect on thermoemf generation. Thus, application of electric and magnetic fields enhance the generation of thermoemf which may help in the utilization of such fields present along the low grade waste heat.

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