Analysis of The Seedbeck Effect of Some Thermocouples

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Abstract: A thermocouple is a temperature-measuring device that consists of two dissimilar conductors that are joined at each end. In this experiment, two junctions were created between two different materials; Nichrome and Constantan, Copper and Constantan, and Nichrome and Copper, by twisting the wires firmly together. The voltmeter leading to the two free ends was set to the most sensitive DC voltage (200 mV). The voltage was measured and recorded with both junctions at room temperature. One junction was inserted into an ice block at 0°C, while the other junction was inserted into hot liquid maintained at 100°C and the voltage was measured and recorded. The procedure was repeated using different pairs of materials to create the junctions with various lengths and diameters of the wires, with a view to determining the pair that will generate the highest voltage. It was observed that the combination of Nichrome and Constantan generated the highest value of voltage, ranging from 1.73 mV – 7.13 mV, than that of Copper and Constantan and Nichrome and Copper, ranging from 0.2 mV- 4.0 mV and 0.2 – 1.67 mV respectively. The combination of Nichrome and Constantan is therefore the best thermocouple material.

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1. Introduction

A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors or semiconductors (Kerlin and Johnson, 2012). It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control, and can also convert a temperature gradient into electricity.

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple (Burns and Scroger, 1989).

In order to use a thermocouple to measure temperature directly, one junction must be maintained at a known temperature. This junction is commonly called the reference junction and its temperature is the reference temperature. The other junction which is normally placed in contact with the body of unknown temperature is called the measurement junction (Baker, 2000).

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered major appliances (Wang, 1990).

There are three ways to investigate properties of electrical materials. The first way is applying an electric field to a material with no temperature gradient. This defines the electrical conductivity (σ) of the materials by taking the ratio between the current density and the applied electric field. The second way is applying a temperature gradient and measuring the heat flow. This defines the thermal conductivity (k) of the material by taking the ratio of heat flow to unit area. The third way is applying a temperature gradient across two dissimilar homogeneous conductive materials. This defines the Seebeck coefficient (thermo-power, thermoelectric power) by taking the ratio between the voltage produced (Seebeck voltage) and the temperature difference (Rowe, 2006).

The Seebeck effect, aside from Peltier and Thompson effect, is one of three thermoelectric phenomena. Seebeck effect was firstly discovered in 1821 by Thomas Seebeck while investigating thermal effect on galvanic arrangement (Callen, 1948). Seebeck accidentally connected parts of bismuth and copper which induced a thermoelectric electromotive force (EMF) that disturbed a compass nearby. Seebeck described this phenomenon as thermo-magnetism. Later on, the Seebeck effect was proven as one of the fundamental electrical properties of a conductor. Not until 1851 by W. Thompson that a theoretical approach to thermoelectric properties was proposed (Thompson, 1851). The Seebeck effect describes the voltage or electromotive force (EMF) induced by the temperature difference (gradient) along a wire. The change in the electromotive force of the material with respect to a change in temperature is called the Seebeck coefficient or thermoelectric sensitivity. This coefficient is usually a non linear function of temperature.

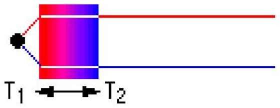
This paper will focus on the determination of the thermocouple pair that will generate the highest voltage along its gradient, that is, the best thermocouple pair from a linear combination of Nichrome, Constantan and Copper wires when their lengths and diameters are varied.

Theory of Thermocouple

A thermocouple circuit has at least two junctions: the measurement junction and a reference junction. Typically, the reference junction is created where the two wires connect to the measuring device. This second junction is really two junctions: one for each of the two wires, but because they are assumed to be at the same temperature (isothermal) they are considered as one (thermal) junction. It is the point where the metals change - from the thermocouple metals to whatever metals are used in the measuring device - typically copper.

The output voltage is related to the temperature difference between the measurement and the reference junctions. This is phenomena is known as the Seebeck effect. The Seebeck effect generates a small voltage along the length of a wire, and is greatest where the temperature gradient is greatest. If the circuit is of wire of identical material, then they will generate identical but opposite Seebeck voltages which will cancel. However, if the wire metals are different the Seebeck voltages will be different and will not cancel (Disalvo, 1999).

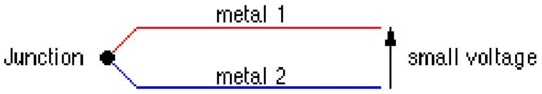
In practice the Seebeck voltage is made up of two components: the Peltier voltage generated at the junctions, plus the Thomson voltage generated in the wires by the temperature gradient.



Signal Generated by Temperature Gradient

The Peltier voltage is proportional to the temperature of each junction while the Thomson voltage is proportional to the square of the temperature difference between the two junctions. It is the Thomson voltage that accounts for most of the observed voltage and non-linearity in thermocouple response (Disalvo, 1999).

Each thermocouple type has its characteristic Seebeck voltage curve. The curve is dependent on the metals, their purity, their homogeneity and their crystal structure. In the case of alloys, the ratio of constituents and their distribution in the wire is also important. These potential inhomogeneous characteristics of metal are why thick wire thermocouples can be more accurate in high temperature applications, when the thermocouple metals and their impurities become more mobile by diffusion (Charles, 1953).



The Thermocouple

2. Material and Methods

One of the major aims of this research work is to determine the best thermocouple materials among a selected set of materials. At high temperatures, thermocouple wire can undergo irreversible changes in the form of modified crystal structure, selective migration of alloy components and chemical changes originating from the surface metal reacting to the surrounding environment. With some types, mechanical stress and cycling can also induce changes. Increasing the diameter of the wire where it is exposed to high temperatures can reduce the impact of these effects.

The highlighted points below sum up the reasons for this choice of the metals used:

Copper was selected because it has a very low electrical resistance therefore, as current flows, there is very small voltage drop along the cable and only a small degree of heating occurs in the wire.

Nichrome is useful for heating purposes and when the stability of the resistance value is not important. Nichrome can be run up to very high temperature where the wire can become bright red in colour. The electrical resistance rises with temperature.

Constantan and Nichrome are alloys; Constantan contains 56% Copper and 44% Nickel while Nichrome contains 80% Nickel and 20% Chromium. This factor makes them perform better as thermocouple materials.

Procedure

1. Copper, Constantan and Nichrome wires were selected as the thermocouple materials.

2. The standard wire gauges, SWG of the wires which represent a variation in diameter and ranging from 24 to 32 at an interval of 2 were used.

3. Equal lengths of the same gauge of dissimilar wires were coupled and the lengths were varied from 10 cm to 40 cm at an interval of 10 cm.

4. Two junctions were created between two different materials by twisting wires firmly together.

5. The voltmeter which leads to the two free ends was set to the most sensitive DC voltage (200 mV).

6. The voltage was measured and recorded with both junctions at room temperature.

7. One junction was inserted into an ice block at 0 degrees Celsius while other junction was inserted in hot liquid maintained at 100 degrees Celsius and the voltage was also measured and recorded.

8. The experiment was repeated using different pairs of materials to create the junctions.

3. Results

Table 2 – Results of Copper –Constantan pair

S/N	SWG	D(mm)	L (cm)	V_1 mV)	V2(mV)	V3(mV)	Vave(mV)
1	24	0.56	10	3	3.2	3.0	3.17
2	26	0.46	10	4	3.6	3.8	3.73
3	30	0.32	10	0	0.5	0.4	0.43
4	32	0.27	10	0	0.3	0.2	0.23
5	24	0.56	20	4	3.7	3.8	3.73
6	26	0.46	20	3	3.7	3.9	3.67
7	30	0.32	20	3	2.6	2.4	2.50
8	32	0.27	20	0	0.2	0.2	0.20
9	24	0.56	30	4	3.7	3.6	3.63
10	26	0.46	30	3	2.6	2.4	2.50
11	30	0.32	30	Reading fluctuates			
12	32	0.27	30	4	4.0	4.1	4.00
13	24	0.56	40	3	3.1	3.1	3.13
14	26	0.46	40	3	2.6	2.7	2.67
15	30	0.32	40	Reading fluctuates			
16	32	0.27	40	3	3.5	3.7	3.53

Table 1- Results of Nichrome-Constantan pair

S/N	SWG	Diameter(mm)	Length(cm)	V1(mV)	V2(mV)	V3 / mV	Vaverage(mV)
1	24	0.56	10	4	3.7	3.8	3.83
2	26	0.46	10	7	7.1	7.1	7.13
3	28	0.38	10	4	3.6	3.3	3.47
4	30	0.32	10	Reading fluctuates			
5	32	0.27	10	4	4.2	4.2	4.23
6	24	0.56	20	4	3.9	4.0	3.97
7	26	0.46	20	4	3.9	4.1	4.00
8	28	0.38	20	3	2.5	2.7	2.67
9	30	0.32	20	4	4.1	3.8	3.97
10	32	0.27	20	4	3.8	3.9	3.77
11	24	0.56	30	4	3.8	3.9	3.87
12	26	0.46	30	2	1.9	2.1	2.00
13	28	0.38	30	2	1.8	1.6	1.73
14	30	0.32	30	3	2.8	2.7	2.77
15	32	0.27	30	2	2.4	2.2	2.23
16	24	0.56	40	3	2.7	3.0	2.83
17	26	0.46	40	3	3.4	3.1	3.23
18	28	0.38	40	3	3.3	3.3	3.33
19	30	0.32	40	3	2.7	2.4	2.57
20	32	0.27	40	3	3.1	2.9	3.00

Table 3 – Results of Nichrome and Copper pair

S/N	SWG	Diameter(mm)	Length(cm)	V1(mV)	V2(mV)	V3(mV)	Vaverage(mV)
1	24	0.56	10	0.3	0.3	0.3	0.30
2	26	0.46	10	0.5	0.5	0.5	0.50
3	30	0.32	10	1.0	1.1	1.3	1.13
4	32	0.27	10	0.4	0.3	0.4	0.37
5	24	0.56	20	0.2	0.2	0.2	0.20
6	26	0.46	20	0.3	0.3	0.3	0.30
7	30	0.32	20	1.7	1.7	1.6	1.67
8	32	0.27	20	0.2	0.2	0.2	0.20
9	24	0.56	30	0.3	0.4	0.3	0.33
10	26	0.46	30	0.4	0.4	0.4	0.40
11	30	0.32	30	Reading fluctuates			
12	32	0.27	30	0.4	0.4	0.4	0.40
13	24	0.56	40	0.3	0.3	0.4	0.33
14	26	0.46	40	0.3	0.3	0.3	0.30

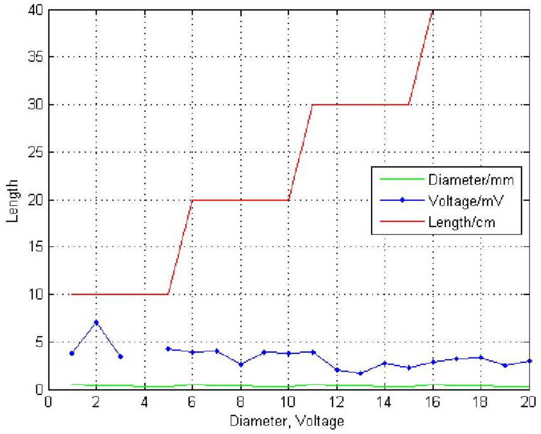


Figure 1 – Nichrome and Constantan

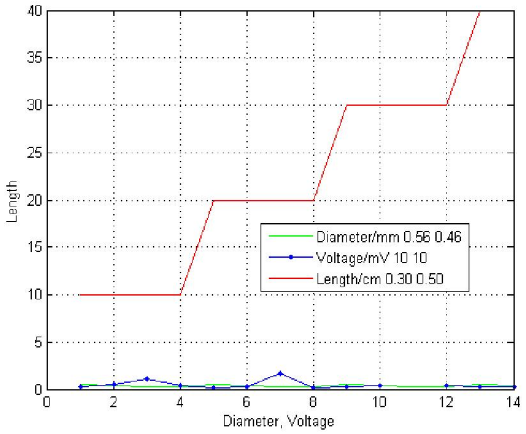


Figure 3 – Nichrome and Copper

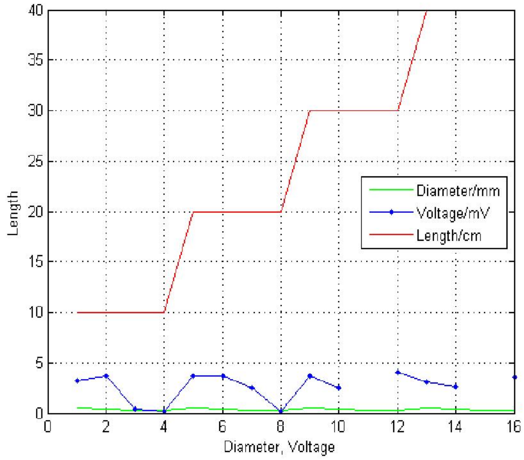


Figure 2 – Copper and Constantan

Discussion

Figures 1 – 3 show the plots of the diameter, length and mean voltage resulting from the temperature difference of the thermocouples. On a general consideration, all the plots except that of mean voltage of thermocouple showed similar characteristic patterns. A thorough observation of figures 1 – 3 revealed that the thermocouples made with Nichrome and Constantan gave higher voltage values compared to the one made with Copper and Constantan and Nichrome and Copper. This is because both materials are alloys; Nichrome is an alloy of Nickel and Chromel while Constantan is an alloy of Nickel and Copper. Another good reason for this is the fact that, Nickel a constituent of the two alloys has the lowest ionization energy of all the metals used. Hence, it is expected to generate the largest voltage.

Since the combination of Nichrome and Constantan gave a higher value of voltage (1.73 – 7.13 mV) than that of Copper and Constantan (0.2 –

4.0 mV) and invariably Nichrome and Copper (0.2 – 1.67 mV), the combination of Nichrome and Constantan is the best among the three thermocouples.

Conclusion

In thermoelectrics there is something called a Seebeck Coefficent. The Seebeck Coefficent is the thermoelectric sensitivity of each metal. Ionization energies are directly linked with Seebeck Coefficents. The larger the difference between the Seebeck Coefficients of the paired metals, the higher the voltage. The results are consistent with what is predicted by Seebeck theory. The combination of Nichrome and Constantan is the best thermocouple as seen from the results of the experiment.

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