

A STUDY OF INHOMOGENEITIES OF THERMOCOUPLES AND ITS CONTRIBUTION TO THE CALIBRATION UNCERTAINTY CALCULUS

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Abstract: This paper presents a study on the measurement of thermocouple inhomogeneity and its contribution to the calculation of the uncertainty of thermocouple calibration. This study evaluated 26 thermocouples, including noble metal thermocouples (type S, R and B) and base metal thermocouples (type N, K, T and J). The measurements were carried out in alcohol, oil and salt baths, at temperatures from $-40\text{ }^{\circ}\text{C}$ to $420\text{ }^{\circ}\text{C}$. In this paper we propose a correlation of inhomogeneity value for each thermocouple type evaluated, considering the temperature range and immersion depth.

Keywords: Thermocouple, inhomogeneities, calibration, uncertainty.

1. INTRODUCTION

One of the most important influences in thermocouple calibration is the inhomogeneities of the thermoelements which causes changing in Seebeck coefficient along the length of wires. It is recommended that this characteristic is taken into account in calculating the uncertainty of the thermocouple calibration [1, 2, 5].

The main objective of this work is to obtain results which may characterize the homogeneity of the thermocouple wires and consider it in the calculation of measurement uncertainty [3]. This study evaluated 26 thermocouples from different manufacturers, including mineral insulated thermocouples (type N, K, T and J) and noble metal thermocouples (type S, R and B).

In this study we tested 5 N-type thermocouples, mineral insulated, isolated junction, outer diameter 1.6 mm, stainless steel sheath; 6 N-type thermocouples, mineral insulated, grounded junction, outer diameter 1.0 mm, stainless steel sheath; 5 T-type thermocouples, mineral insulated, isolated junction, outer diameter 1.6 mm, stainless steel sheath; 4 K-type thermocouples, mineral insulated, isolated junction, outer diameter 1.6 mm, stainless steel sheath; 2 J-type thermocouples, mineral insulated, isolated junction, outer diameter 5.0 mm, stainless steel sheath; 1 N-type thermocouple, mineral insulated, isolated junction, outer diameter 6.0 mm, stainless steel sheath; 1 type B, S and R thermocouple, assembled in ceramic protection tubes and diameter wires of 0.5 mm.

2. PROCEDURE

This study was performed in alcohol, oil and salt baths in the temperature range $-40\text{ }^{\circ}\text{C}$ to $420\text{ }^{\circ}\text{C}$, at different immersion depths. The stable and uniform region of the baths was used to carry out the measurements. The baths were previously evaluated and the maximum temperature gradient measured was less than $0.02\text{ }^{\circ}\text{C}$. During the thermocouples tests the temperature of the baths were monitored with a platinum resistance thermometer connected to a measuring system of $8\frac{1}{2}$ digits.

The thermocouples type B and type S were previously “used” for measurements up to $1100\text{ }^{\circ}\text{C}$. Prior to the tests of inhomogeneity, these two thermocouples were annealed in air by circulation of an electrical current of 12 A [4, 9]. After annealing, the thermocouples were assembled in ceramic tubes and heat treated at $1100\text{ }^{\circ}\text{C}$ for 6h. All N-type thermocouples are new and measurements were made in the state as received, without heat treatment. Thermocouples type T, J and K are “used”. They have been used in measurements up to $350\text{ }^{\circ}\text{C}$, $500\text{ }^{\circ}\text{C}$ and $900\text{ }^{\circ}\text{C}$ respectively, and have not been heat-treated before this study [4, 7].

The thermocouples were inserted into the bath and after stabilization of the readings; they were gradually withdrawal and placed at each depth previously defined for evaluation, which correspond to intervals of 25 mm. The immersion depth in which the thermocouples were placed in the calibration baths was between 75 mm to 270 mm.

The measurements were carried out with a data acquisition system of $6\frac{1}{2}$ digits, connected to a computer where the data were stored. The reference junctions of the thermocouples were maintained in an ice bath (0°C).

3. RESULTS AND DISCUSSION

Figures 1 to 11 present the *emf* profile results of thermocouples for several immersion depths and temperatures. Some thermocouples, as type K, T, J and N (1 mm, O.D.), were tested at more than one temperature. The $E - E_{ref}$ difference correspond to the *emf* deviation, where E is the *emf* measured and E_{ref} is the *emf* from the thermocouple reference table.

Figure 1 shows the inhomogeneities results of a type K thermocouple (TPK2007-1), measured at different immersion depths and temperatures.

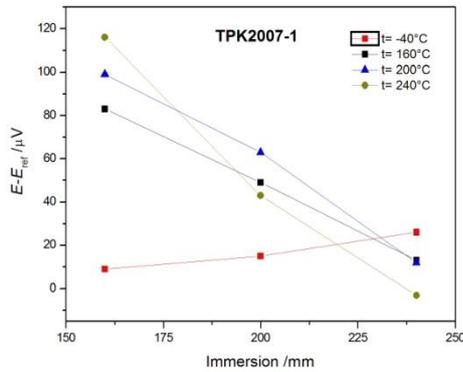


Figure 1. Inhomogeneities of K-type thermocouple (TPK2007-1).

Figure 2 shows the inhomogeneities results of a type N and R thermocouples (TC N6#01 and TC R#02), measured at different immersion depths and temperature of 300°C.

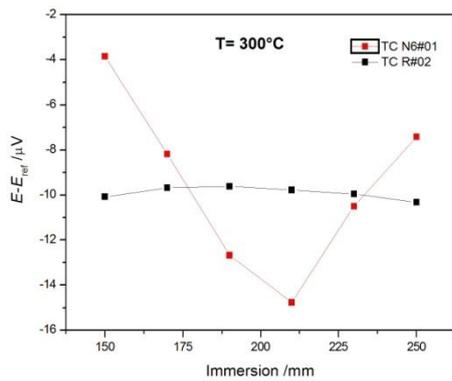


Figure 2. Inhomogeneities of N and R-type thermocouples.

Figure 3 shows the inhomogeneities results of a type B and S thermocouples (TC B#02 and TC S#03), measured at different immersion depths and temperature of 420°C.

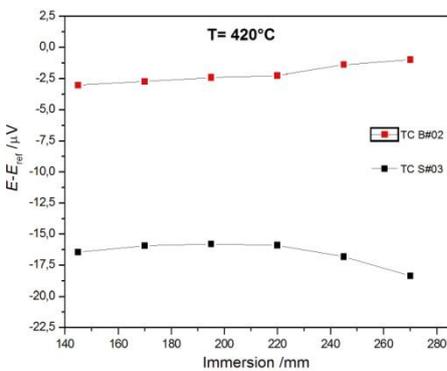


Figure 3. Inhomogeneities of B and S-type thermocouples.

Figure 4 shows the inhomogeneities results of a two type J thermocouples (TC J#07 and TC J#08), measured at different immersion depths and temperature of 420°C.

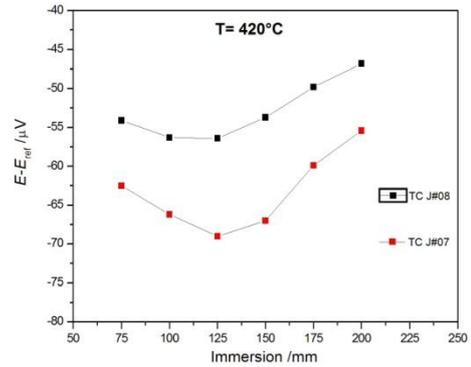


Figure 4. Inhomogeneities of J-type thermocouples and temperature of 420°C.

Figure 5 shows the inhomogeneities results of a two type J thermocouples (TC J#07 and TC J#08), measured at different immersion depths and temperature of 100°C.

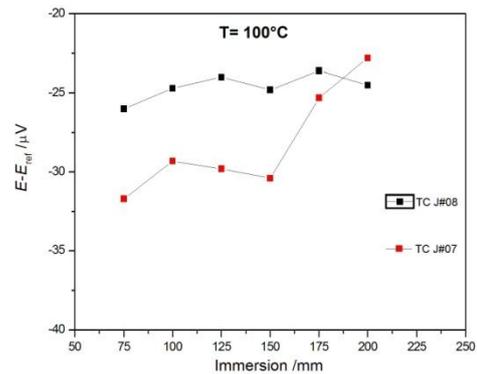


Figure 5. Inhomogeneities of J-type thermocouples and temperature of 100°C.

Figure 6 shows the inhomogeneities results of a six type N thermocouples (TC N1#01 to TC N1#06), measured at different immersion depths and temperature of 420°C.

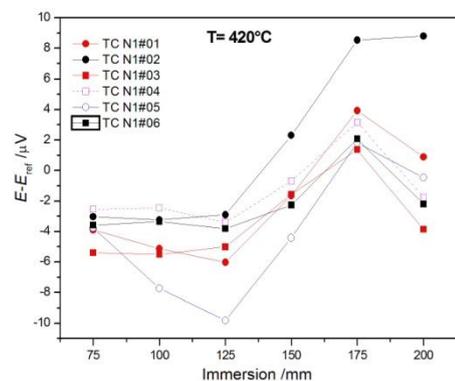


Figure 6. Inhomogeneities of N-type thermocouples (1mm, o.d.) and temperature of 420°C.

Figure 7 shows the inhomogeneities results of a six type N thermocouples (TC N1#01 to TC N1#06), measured at different immersion depths and temperature of 100°C.

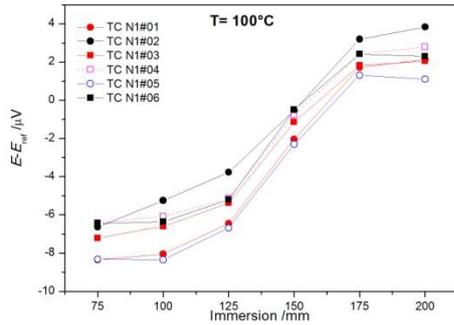


Figure 7. Inhomogeneities of N-type thermocouples (1 mm, o.d.) and temperature of 100°C.

Figure 8 shows the inhomogeneities results of a five type N thermocouples (TC N#01 to TC N#05), measured at different immersion depths and temperature of 420°C.

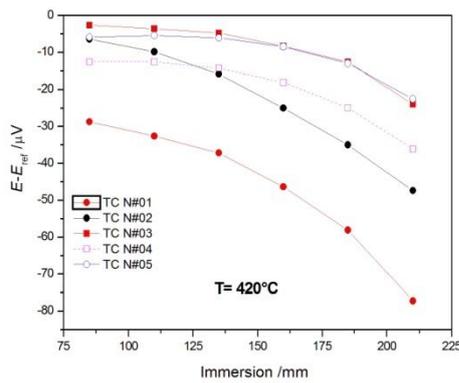


Figure 8. Inhomogeneities of N-type thermocouples (1.6 mm, o.d.) and temperature of 420°C.

Figure 9 shows the inhomogeneities results of a five type T thermocouples (TC T#01 to TC T#05), measured at different immersion depths and temperature of 310°C.

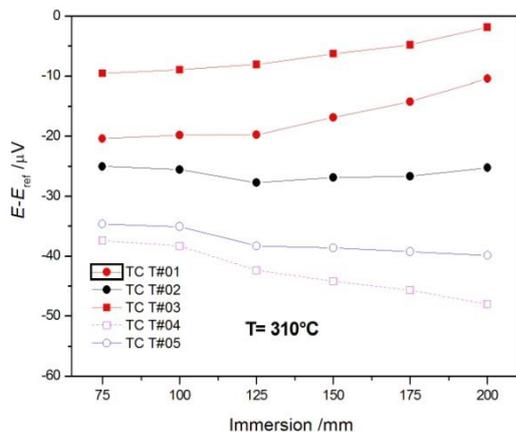


Figure 9. Inhomogeneities of T-type thermocouples (1.6 mm, o.d.) and temperature of 310°C.

Figure 10 shows the inhomogeneities results of a five type T thermocouples (TC T#01 to TC T#05), measured at different immersion depths and temperature of 100°C.

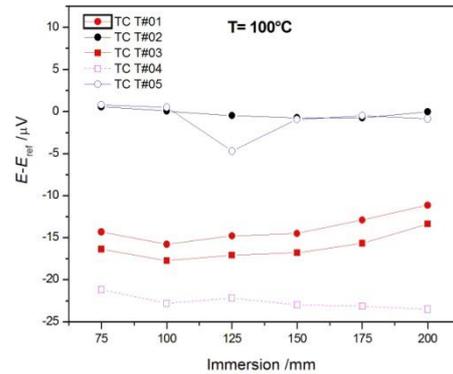


Figure 10. Inhomogeneities of T-type thermocouples (1.6 mm, o.d.) and temperature of 100°C.

Figure 11 shows the inhomogeneities results of a three type K thermocouples (TC K#01 to TC K#03), measured at different immersion depths and temperature of 420°C.

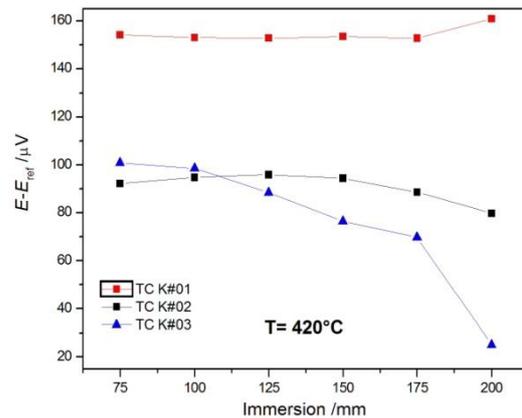


Figure 11. Inhomogeneities of K-type thermocouples (1.6 mm, o.d.) and temperature of 420°C.

The inhomogeneity/% is defined as the percentage of the average amplitude (Δemf) divided by the measured emf (E_{meas}) at a given temperature. It was calculated considering the maximum emf difference ($E_{max}-E_{min}$) obtained for all depths of immersion.

$$\text{inhomogeneity}/\% = \frac{\Delta emf}{E_{meas}} \times 100$$

Table 1 shows the average emf difference (Δemf (μV)) and inhomogeneity percentage for each group of thermocouples at temperatures of 100 °C, 300 °C and 310 °C.

Table 1. Inhomogeneity results

Temperature	100°C			310°C	300°C	
	T	N (1)	J	T	N (6)	R
Δemf (μV)	3.9	9.7	6.3	8.5	10.9	0.7
Inhomogeneity (%)	0.09	0.35	0.12	0.06	0.12	0.03

Table 2 shows the average emf difference (Δemf (μV)) and inhomogeneity percentage for each group of thermocouples at temperature of 420 °C.

Table 2. Inhomogeneity results

Temperature	420°C					
	K	B	S	N (1.6)	N (1)	J
Δemf (μV)	39.7	2.0	2.6	30.3	8.9	13.0
Inhomogeneity (%)	0.23	0.24	0.07	0.22	0.06	0.06

From the experimental results, an average percentage of inhomogeneity of the thermocouples can be proposed [10]. For thermocouples types J and T the value is 0.09%, for thermocouples types K and N the value is 0.21% and for thermocouples types R and S the value is 0.05% from the emf measured.

The uncertainty contribution from the inhomogeneity can be estimated as a rectangular distribution.

4. CONCLUSION

The present study led to know experimentally the behavior of thermocouples with respect to inhomogeneities of the wires at different temperatures and immersion depths. The results are important in the calibration of thermocouples, especially in the calculation of the uncertainty of calibration.

From the experimental data a percentage of thermovoltage inhomogeneity is proposed for the different types of thermocouples studied, in relation to the emf value measured at a given temperature. Although a small amount of thermocouples were studied, the results were satisfactory and very close to the publications dealing with this subject.

5. REFERENCES

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