Thermocouples calibration and analysis of the influence of the length of the sensor coating

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Abstract. This paper presents the design and construction of a lab prototype, with a much lower cost compared to the ones commercially sold, enabling the manufacture of thermocouples which are then calibrated to verify their functionality and acceptance. We also analyze the influence of the external insulation over the wires, to determine whether it influences temperature measurement. The tested lengths ranged from 0.00 m up to 0.030 m. The thermocouple was compared against the behavior of a thermocouple of the same type that was purchased with a commercial supplier. The obtained measurement showed less than 1 °C difference in some points. This makes the built thermocouple reliable, since the standard allows a difference of up to 2.2 °C.

1. Introduction
Temperature is an important factor that should be taken into account in the majority of energy exchange processes, thermometers are instruments specifically designed to measure temperature, there is a wide variety of thermometers today and their operating principles are equally extensive. The thermometers are the instruments that are used for temperature measurement, a type of them, contact thermometers, should be placed in physical contact in the middle of the medium from which you want to know the temperature, for example: in production processes or exchange of energy, the medium can consist of an electric oven, in exhaust gases of a combustion engine, water at the entrance of a cooling tower, bioreactors, etc. These contact thermometers base its operation in thermal equilibrium that is established by direct contact of sensor and the medium of interest. Thermocouples are a type of contact temperature gauges; they are widely used in the industrial branch due to their capacity of measuring a wide range of temperatures, their reliability, easy operation and the possibility of registration of the measurement automatically. A thermocouple is composed of two conducting wires made of different material; these cables have a point in common. This union works as measuring point (sensing joint), which comes in contact with the medium in which you want to determine the temperature, at the other end, wires are connected to an electronic circuit that delivers a reference voltage (the voltage is usually associated with a temperature of 0 °C). When thermocouple wires are subjected to a difference in temperature between the measuring joint and the end connected to the reference circuit, there is a potential difference based on the change of temperatures (Seebeck effect). One of the most widely used thermocouples is the K-type, because of its low cost compared to other types of thermocouples. The commercial cost of these devices is high, although the material to build them is usually inexpensive; the cost of the commercial product rises considerably, up to eight times. The punctual
measurement of temperature has different key applications in laboratory work, especially when it comes to evaluating the thermodynamic behavior of some systems as for example in solar energy, heat transfer, thermal machines, etc. There are some prototypes which require up to 50 measurements in different sites at the same time, which makes the cost of this kind of experience rather high, considering the use of one or more thermocouples for each point.

In order to reduce costs, to the extent possible, in the area of Thermo-fluids, at UAM-A, it was decided to design and build an apparatus that would manufacture the thermocouples used in the instrumentation of the prototypes. We subsequently performed the calibration of the produced thermocouples. A question that arises when these instruments are evaluated is if the distance of coating that is removed to the thermocouple measuring wires influence on the precision of the measurement or not. The objectives of this work were to present the design and construction of the prototype for the thermocouples manufacturing and to investigate whether the distance that is removed from the wire coating had a significant impact on the temperature measurements.

2. Description of the manufacturing prototype and calibration of thermocouples

For the manufacture of thermocouples, type K (Chromel-Alumel) cable for thermocouple was used, the joint between the two metals that is required for the measurement of temperature was made producing a short circuit; this merged both metals forming an amalgam, and therefore the principle of operation of the prototype is to produce this phenomenon. The components of the device are: (A) a mechanical arm, (H) a ceramic rod, (D) a tip to join the thermocouple, (B, C) thermocouple attachment lugs, and (E, F) the power switch box.

One end of the lever arm is firmly fixed to a base (D) at the other end is placed a piece of charcoal which helps to close the electrical circuit with the tip of the thermocouple (C). This material was selected because it was the only one that would not leave residues and also it would not stick to the fused union of the temperature sensor; the ceramic bar (H) is fixed and its function is to serve as support and insulation when the short circuit between the carbon and the tip of the thermocouple occurs; the tip of the thermocouple to be joined is the type K-thermocouple cable. The power switch (F) is located in the switch box; it is a 10 A thermomagnetic switch, which must be activated before making any temperature measurement (F). Finally, there is a plug for connection to the Electric power supply. The diagram of the device is presented in Figure 1 and the built prototype, in Figure 2.

LabView software in which the instrumentation (ADAM modules) is integrated, was used in the registration of measurements. The proper programming for reading in real time and data storage for their subsequent management was performed.
A virtual instrument (program) which allows the measurement, registration and presenting the graphs for four temperatures on screen at the desired time, was created. The main window of this LabView program is shown in figure 3.

Fig. 3. Main window of the program.

3. Manufacture of thermocouple

The thermocouple manufacturing was carried out with a section of 0.40 m type K-cable, a length of 0.02 m of the insulating material at one end was withdrawn, this side should be placed in the hold-down shoe of the prototype for the manufacture of thermocouples; a length of 0.005 m of the insulation material is removed from the end of wires, then both wires are united with a rat-tail type lashing; this would be the temperature sensor. This end was placed in the ceramics holding of the positive pole of the apparatus and then the soldering thermocouple wires by the action of short-circuit proceeded. The thermocouple was withdrawn from the device making sure that the molten tip was perfect, i.e. that a small ball with both wires, free of any kind of fracture, had been formed. For details on the design and use of the available equipment, [2] can be consulted. For the first test the length of the insulation removed at the thermocouple was considered null, i.e., the thermocouple had two wires covered completely, then lengths of 0.003 m, 0.005 m, 0.010 m, 0.015 m, 0.020 m 0.025 m and 0.030 m were withdrawn, and each test was repeated four times to verify that there was no significant variation in the measurements, or in its case, to obtain an average of them. A commercial thermocouple of the same type was employed as reference, and served as a pattern for measurements.

4. Experimental procedure.

The experiment was conducted by placing 750 mL of water at 0 °C, in a beaker of 1 liter of volume, where two thermocouples were inserted into the center of the bowl and exactly at the same depth, to ensure that both were in the same isothermal region and to avoid, to the extent possible, variations in temperature due to the flow currents. The vessel was warmed on an electrical thermal plaque until the water reached boiling point. At the same time both ends of thermocouples were connected to the ADAM module and the LabView program was started on the computer and the registration of measurements, performed every second, begins. The employed array is shown in Figure 3.
5. Results
All the tests that were conducted began at 0 °C and ended at approximately at 92 °C, in each experiment the average of the four tests was obtained, most of the results were almost equal, and the duration of each time was approximately 26 minutes. The graph of temperature against time obtained when the two wires of the thermocouple were completely covered with plastic is presented in Figure 4. There are some differences of maximum 1 °C in some spots. In all tests no greater value difference was observed.

In the case of the thermocouple for which 0.030 m of the insulating cover was withdrawn, the variation of temperature for some points did not exceed 1 °C, as shown in the graph of Figure 5. According to the ASTM E230/E230M-12 standard [1], in the temperature range of 0 °C to 760 °C a difference of up to 2.2 °C is allowed, therefore the built thermocouple was considered acceptable for measurements in the specified temperature range. Subsequently, the described procedure was repeated several times to this same thermocouple, i.e., a length of 0.003 m of plastic was removed and four tests were performed, until it a final length of 0.030 m of cover was withdrawn.
Figure 6, shows the graph of the temperature of the thermocouple to be calibrated against the temperature of the reference thermocouple, in order to find the percentage of error between two measurements and the value of $R^2$ of each of the performed experiences. In the case of both wires completely covered the $R^2 = 0.9996$, the percentage of average error found was 1.2%, which makes it acceptable.

The values of the percentage of error and the value of $R^2$ for every experienced thermocouple are presented in Table 1. The maximum value of the percentage of retrieved error was observed when we withdrew a length of 0.030 m of the insulating material and the value of $R^2$ in all cases was very close to the unit.

The conclusion from these results is that the insulating material of a thermocouple can be removed up to 0.025 m length and readings obtained will be within the recommendation mentioned in the corresponding ASTM standard.
6. Conclusions.
An economical lab prototype that enables the production of thermocouples which are subsequently calibrated for its functionality and acceptance has been built. The influence of the insulation covering of the wires in temperature measurement was analyzed. The experienced lengths of the uncovered portion of the wire ranged from 0.00 m up to 0.030 m, and were compared against the behavior of a thermocouple of the same type that was purchased with a commercial distributor. The obtained measurements presented a variation on some points of less than 1 °C, which confirms the built thermocouple as reliable, since the standard allows a difference of up to 2.2 °C.

Table 1. Error percentage and value of $R^2$ p for each evaluated condition of the thermocouple.

| Non-insulated length [m] | % Error | $R^2$    |
|--------------------------|---------|----------|
| 0.000                    | 1.10    | 0.99967  |
| 0.003                    | 0.71    | 0.99972  |
| 0.005                    | 1.27    | 0.99967  |
| 0.010                    | 0.43    | 0.99969  |
| 0.015                    | 0.65    | 0.99977  |
| 0.020                    | 1.90    | 0.99976  |
| 0.025                    | 0.60    | 0.9997   |
| 0.030                    | 2.90    | 0.99944  |

References
[1] ASTM E230/E230M-12 2012
[2] López C.R., Morales G. J., Vaca M. M., Lizardi R. A., Terres P. H, Lara V. A. 2013. Equipo para Laboratorio: Fabricación y Calibración de Termopares UAM-Azcapotzalco