17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0126
CALIBRATION OF THERMOCOUPLE TYPE TEMPERATURE SENSORS BY COMPARISON WITH STANDARD INSTRUMENT USING LINEAR REGRESSION MATH METHOD

João Gabriel Bezerra da Silva
Edson Alves de Souza
Universidade Federal do Pará, Rua Augusto Corrêa, 1 - Guamá, Belém – PA
jgbsmec@gmail.com
edsonalves@ufpa.br

Hendrik Maxil Zárate Rocha
Universidade Federal do Pará, Rua Augusto Corrêa, 1 - Guamá, Belém – PA
hendrick@ufpa.br

Tainã Carvalho Garcia Miranda Filgueiras
Universidade Federal do Pará, Rua Augusto Corrêa, 1 - Guamá, Belém – PA
tai.filgueiras@gmail.com

Lucas Nagib de Freitas
Universidade Federal do Pará, Rua Augusto Corrêa, 1 - Guamá, Belém – PA
lucasn.defreitas@gmail.com

Luiz Claudio da Cunha Marques
Universidade Federal do Pará, Rua Augusto Corrêa, 1 - Guamá, Belém – PA
luizmar7@yahoo.com.br

Abstract: *This work has as an objective to evaluate in a experimental form, the calibration of temperature sensors, specifically, thermocouple K type, using a methodology as we can follow from the norm NBR 14610(Temperature indicator with sensor - Calibration by comparison with standard instrument) to do so we operated a linear regression in the commonly measured temperature range, in the Laboratory of Internal Combustion Engines of Universidade Federal do Para, with an estimated from the local temperature(ambient temperature 28°C) until 600° reached inside the combustion gases. For that purpose, it was build a bench of instruments with a series of integrated equipment in one whole system. The set is assembled by an electric oven with controlled temperature scale, data acquisition, and precision thermocouple, a computer unit equipped with software that supports the monitoring, recording, analysis and manipulation of the signals received by the data acquisitor. The results showed that the applied method is effective presenting acceptable errors within the ranges of uncertainties.*

Keywords: *calibration, temperature sensor, thermocouple, mathematical method by regression, uncertainties.*

1. INTRODUCTION

The temperature is a physical quantity used in the engineering segment as a parameter in several industrial processes, its control has a fundamental importance and is consistent with the final product quality (MOREIRA, 2002; SANTOS, 2011; VALÉRIO, 2017; DE MORAIS, 2010). Adopted as a control parameter, temperature is commonly monitored in a wide range of applications, defining maximum operating limits in processes and equipment for a given thermal load condition, providing important information that correlates the change of the physical state of matter, structural integrity of equipment in operation, and as a safety factor to prevent accidents.

Thermocouples are the most widely used sensors in the industry for measuring temperatures. In particular, robust construction and simplicity of application are indicated for measuring under severe conditions of high thermal loads. Due to the high temperature variations, the thermocouples change over time, resulting in reading errors, being necessary to go through a calibration routine (MOREIRA, 2002; OMEGA 2015).

According to the author (SINGH, et al., 2016), in real situations, calibration methods are used to improve accuracy and to reduce measuring errors of an instrument. Among the methods mentioned by the author, the linear regression calibration is an important mathematical technique capable of estimating a variable in relation to a reliable comparison data expressly correlated by the same measurement conditions within the range of interest.

By understanding the complexity of the studied subject, this research has as the general objective to evaluate in an experimental way the calibration of temperature sensors, type K thermocouples, adopting a methodology based on the norm NBR 14610 (Temperature indicator with sensor - Calibration by comparison with standard instrument) , using linear regression in the temperature range commonly measured in the Laboratory of Internal Combustion Engines of the Federal University of Pará, estimated from the local temperature (ambient temperature ± 28 ° C) to the 600 ° C reached in the combustion gases.

2. METODOLOGY

In order to reach the objective of the research, a bench was built using an electric heater adapted and controlled by a dimmer module (voltage regulator), model TRIAC SCR10-220VAC, with input voltage 220V, output voltage between 10-220V and power of 4000W, allowing the temperature to be varied to a desired scale. As reference base, an isolated junction type K thermocouple with stainless steel sheath was used in an operating range of -200 ° C to 1250 ° C, and a calibration and uncertainty certificate of ± 0.3% of the scale at 25 ° C, providing temperature indices for comparison of the out of calibration thermocouple sensors.

The data collection was made by a CONTEMP A202 acquirer with reading accuracy ± 0.3%, providing 8 channels and allowing to use up to 7 thermocouples simultaneously. Subsequently, the signals collected by the CONTEMP A202 passed through a USB converter, and were sent to the computational unit responsible for the storage and treatment of the collected temperature results.

With the help of DAQFactory software that enables and supports process monitoring, registry entriess, data analysis and even allows the user to change the setpoints to the desired temperature. Moreover, the software allows direct entry with the equations of calibration curves obtained by linear regression [5].

The figure 1 shows a sketch of the bench used to adjust the temperature sensors, identifying the equipment already presented.

Attached to the top of the oven, a removable base (thermocouple bench) has been adapted to remove and fix the thermocouples so that the sensor ends, immersed in the oven chamber (thermal medium), are leveled in the same position, ensuring that the temperatures are approximate for all sensors. Likewise, in order to ensure the most uniform approximation of thermocouple temperatures, the thermal resistances of the electric furnace were positioned in the lower part of the heater chamber so that the surfaces between the resistor bank and the sensor ends are parallel, maintaining uniformity in the thermal environment, ie in the region where the standard instruments and the indicator sensor are inserted, according to NBR 14610.

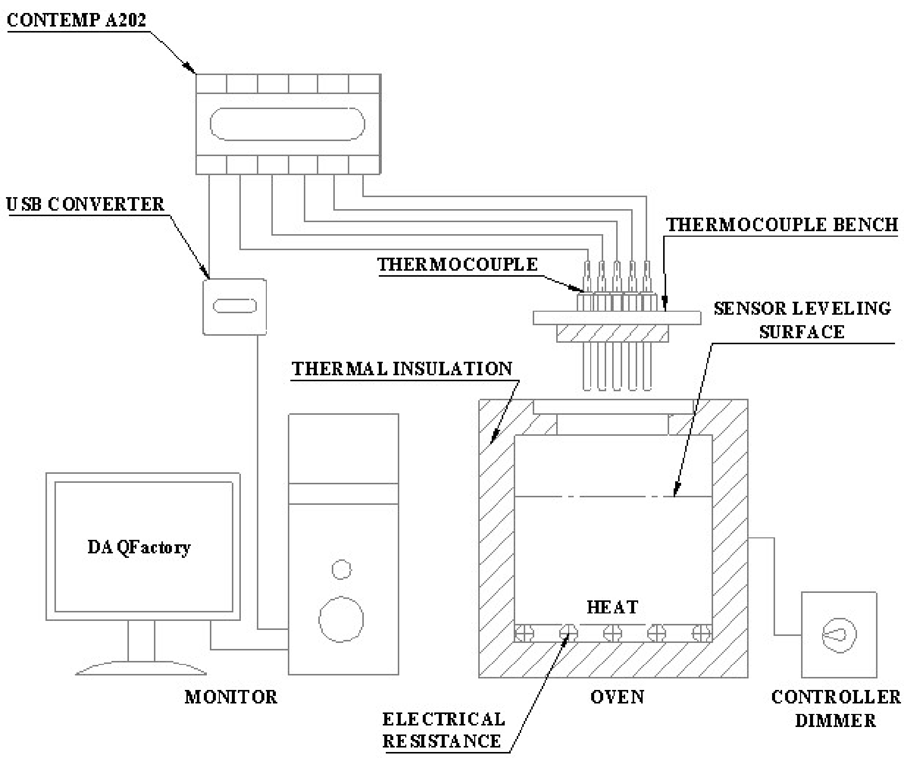

Figure 1 - Technical sketch of the bench developed for temperature adjustment

The thermocouple bench, shown in the diagram in figure 1, integrates part of the wall of the heater and, in order to maintain the homogeneity of the insulation, the surface of the bench in contact with the thermal chamber is covered by an insulating layer of the same material of the rest of the walls of the heater, in this case, refractory bricks and thermal wool. The cracks formed by the coupling are also filled with thermal wool.

The tests are conducted in the following steps:

It is important to notice that to maintain the uniformity of the whole calibration process, once the thermocouples are coupled in the oven, they can not be moved until the end of the calibration process, ie in order words, until all 6 steps described below are completed.

Step 1 - The thermocouples are fixed to the base (thermocouple bank) and are leveled in the same position of the thermocouple with calibration certificate. The base is then coupled in the oven to maintain the same uniformity for all sensors.

Step 2 - The oven is switched on and the temperature is set to the desired value. This is a time meant for the thermal medium to enter steady state, to which it is recognized by the temperature stability as a function of time.

Step 3 – after the temperature is stable, the data provided by the indicator sensors and the standard sensor are started.

Step 4 - Repeat steps 2 and 3 by varying the temperature on an increasing scale within the desired temperature range, ie between the local ambient temperature (± 28 ° C) until reaching the temperature of 600 ° C.

Step 5 - with the data collected, data will be treated and adjusted using the linear regression technique in relation to the standard reference data, obtaining the mathematical equations of calibration.

Step 6 - The calibration equations are reconditioned in DAQFatory software. New tests will be performed to collect the new data and check the ranges of uncertainties to evaluate the adopted calibration method

3. RESULTS

Initially, experimental tests were performed with the linear regression temperature adjustment methodology. In the results, the temperature range is limited to ambient temperature (approx. 28 ° C) with elevation up to 100 ° C.

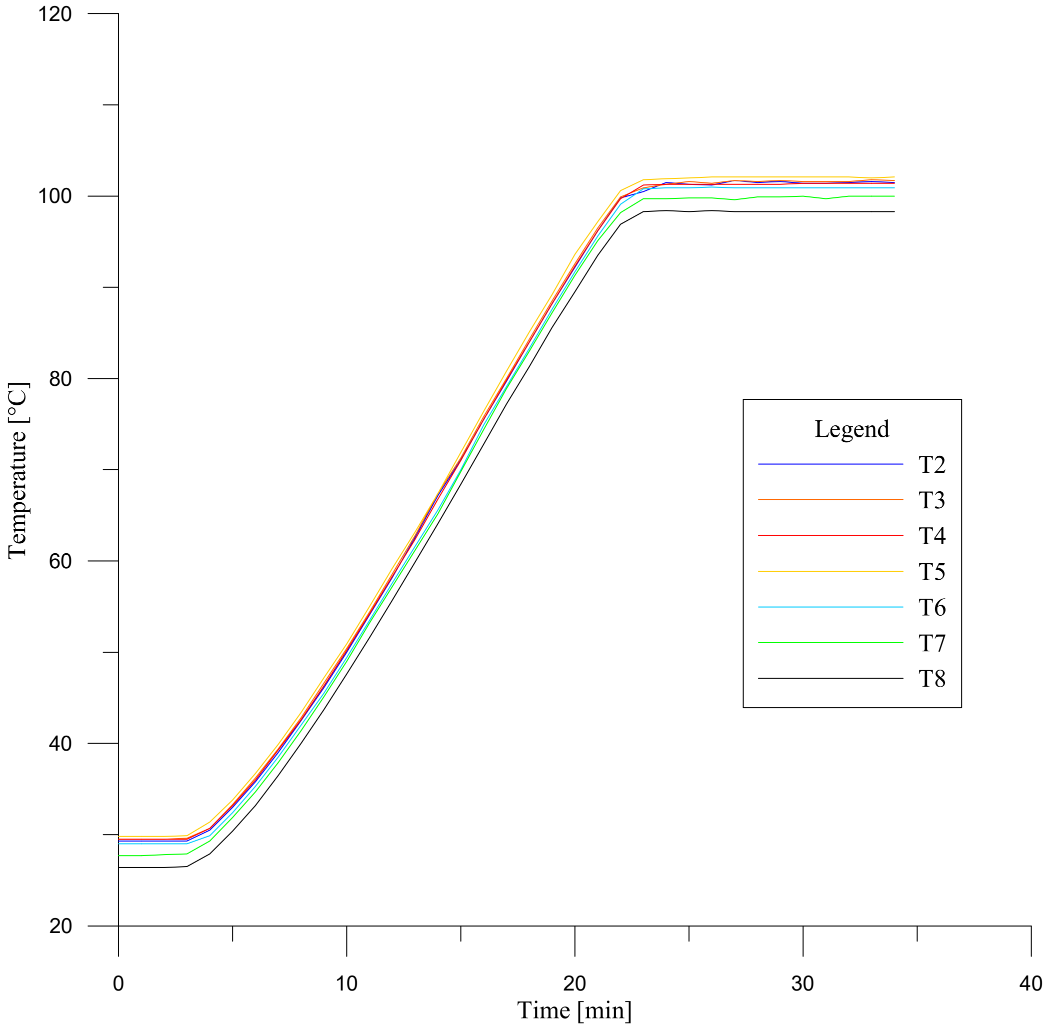

Figure 2 - Results with the out of calibration sensors.

The curve obtained with the precision thermocouple was designated T4, the other references as: T2, T3, T5, T6, T7 and T8 are thermocouples with deviations in their measurements. Figure 2 presents the results in the normal condition of each sensor at different temperature levels. We can see the deviation of the curves obtained in relation to the T4 curve designated with the thermocouple with calibration certificate. The calibration zone using the mathematical regression technique was used as the region where the temperature increase is linear for all indicators, as exemplified in figure 3.

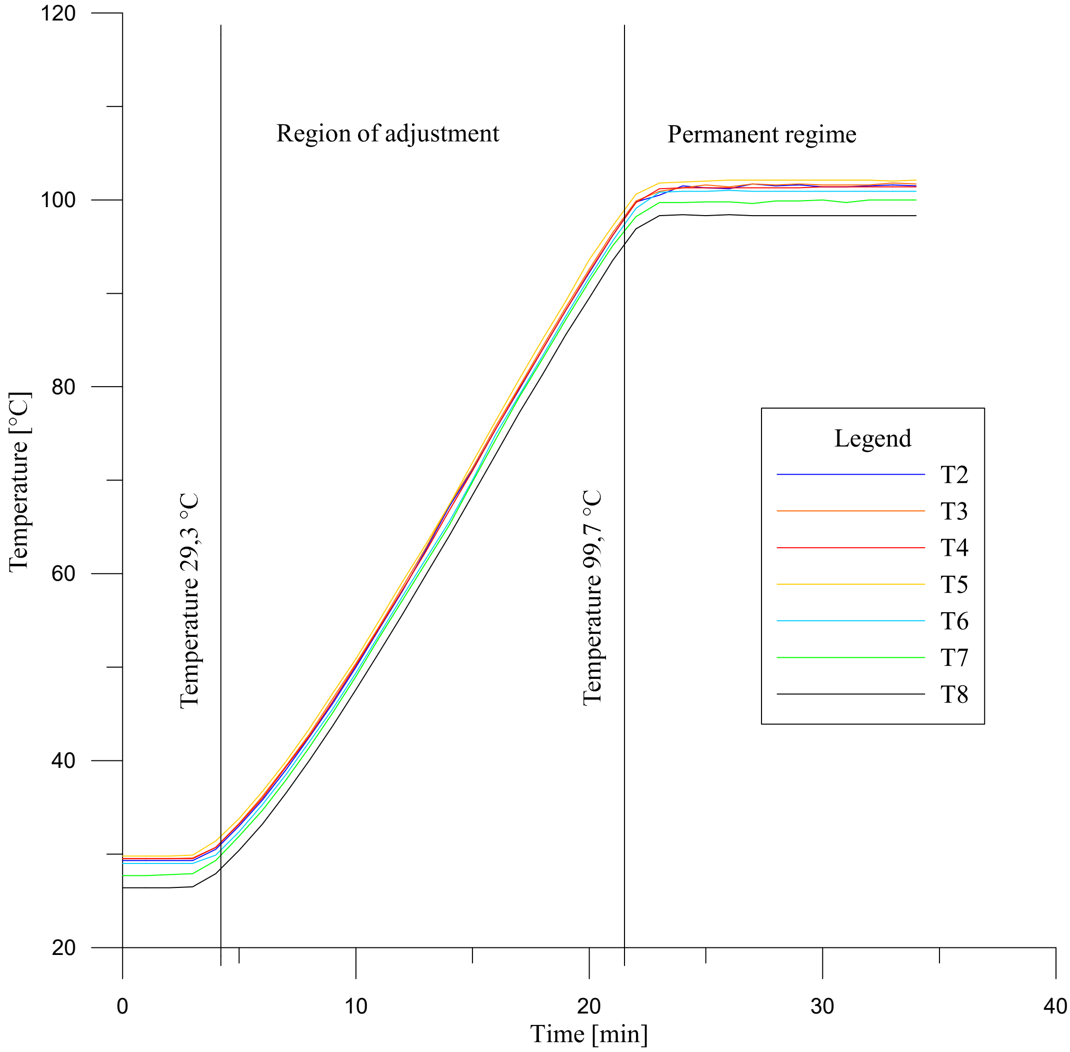

Figure 3 - Temperature adjustment zone.

The equations obtained with the linear regression method are presented in Table 1. These equations were inserted in the layout configuration developed with the DAQFactory program.

Curve	**Linear Regression**	**R²**
T2	y = 0,996011x + 0,305785	0,99996
T3	y = 0,997395x - 0,086531	0,999975
T5	y = 0,993817x - 0,454685	0,999972
T6	y = 0,997831x + 0,878271	0,999958

T7	y = 0,996998x + 1,381797	0,99994
T8	y = 0,999649x + 2,700295	0,999981

Table 1 - Mathematical regression calibration equations obtained for each thermocouple

The new results collected under the same conditions of the initial test and with the equations inserted in the program are presented in figure 4. By making a direct comparison with the first results, the linear regression calibration method of the recorded temperature curves approaches the reference curve obtained by the reliable thermocouple, curve T4.

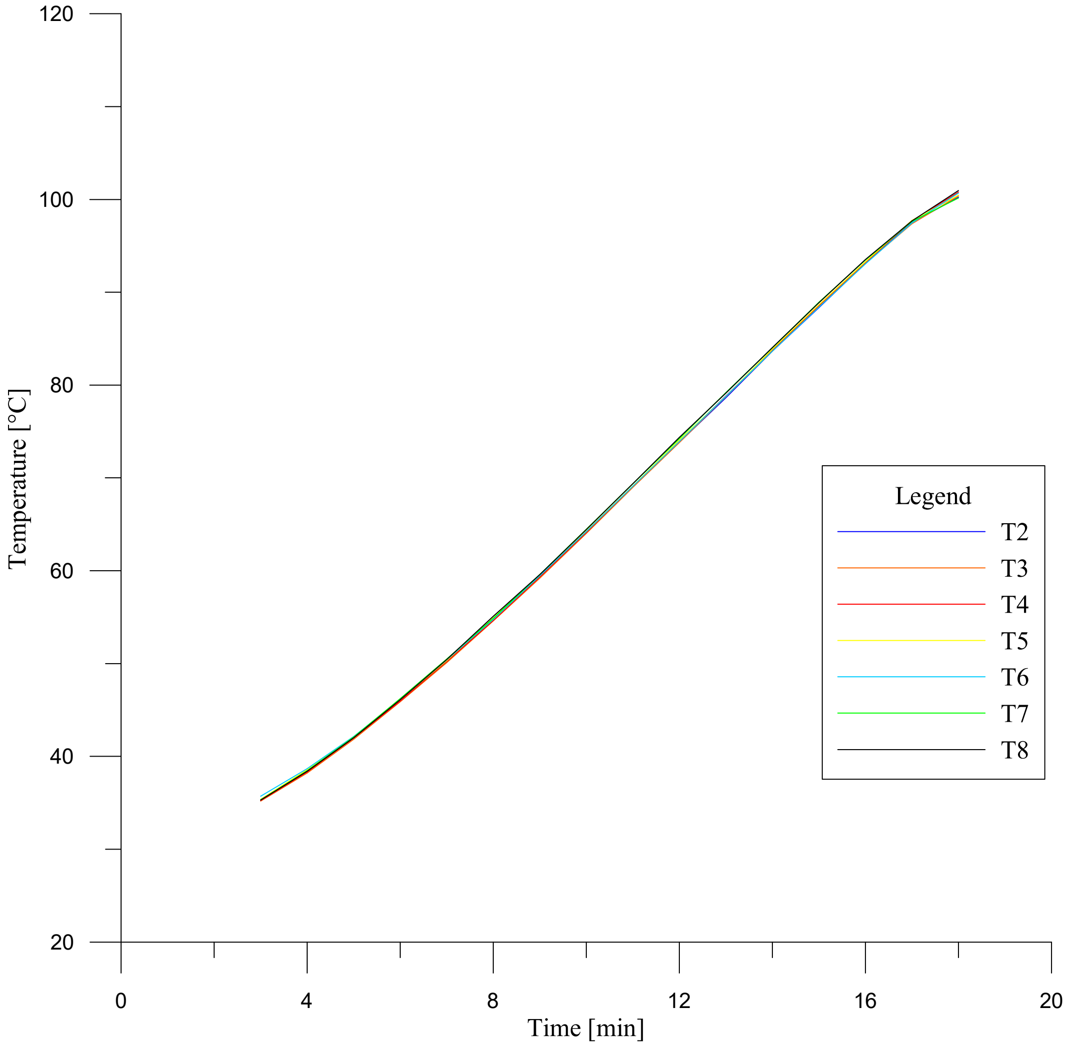

Figure 4 - Temperature curves adjusted by the mathematical regression method.

Through the observation of the following tables and comparing the results obtained in the two test modules, the general values are shown in Table 3 along with the calculated relative errors.

Curve	Maximum error [%]	Minimum error [%]	Mean [%]
T2	0,66	0,01	0,15
T3	0,54	0,00	0,14
T5	0,41	0,00	0,14
T6	0,69	0,00	0,15

T7	0,62	0,00	0,19
T8	0,36	0,03	0,16

Table 2 - Comparison of maximum and minimum errors.

Table 2 shows the maximum, minimum and mean error values of all the tests. It is observed that the maximum relative error was reached with the T6 sensor, with a value of 0.69% acceptable within the uncertainty range considering a temperature of 100 ° C.

T4 [°C]	T2 [°C]	T2 cal. [°C]	Relative error [%]	T3 [°C]	T3 cal. [°C]	Relative error [%]	T5 [°C]	T5 cal. [°C]	Relative error [%]	T6 [°C]	T6 cal. [°C]	Relative error [%]	T7 [°C]	T7 cal. [°C]	Relative error [%]	T8 [°C]	T8 cal. [°C]	Relative error [%]
30,7	30,5	30,9	0,05	30,7	30,5	0,54	31,4	30,8	0,17	29,9	30,7	0,04	29,3	30,6	0,35	27,9	30,6	0,36
33,2	33,0	33,4	0,08	33,3	33,1	0,22	33,8	33,1	0,19	32,4	33,2	0,02	31,9	33,2	0,04	30,4	33,1	0,33
36,0	35,8	36,2	0,10	36,2	36,0	0,05	36,7	36,0	0,05	35,3	36,1	0,28	34,7	36,0	0,06	33,2	35,9	0,31
39,3	39,0	39,4	0,38	39,4	39,2	0,23	39,9	39,2	0,26	38,5	39,3	0,01	37,9	39,2	0,34	36,5	39,2	0,29
42,6	42,5	42,7	0,09	42,8	42,6	0,00	43,4	42,7	0,18	42,0	42,8	0,44	41,4	42,7	0,14	40,0	42,7	0,20
46,3	46,1	46,4	0,17	46,6	46,4	0,20	47,2	46,5	0,33	45,5	46,3	0,04	45,1	46,3	0,10	43,7	46,4	0,18
50,2	50,0	50,3	0,19	50,4	50,2	0,04	50,9	50,1	0,14	49,4	50,2	0,06	49,0	50,2	0,07	47,6	50,3	0,17
54,2	54,1	54,3	0,02	54,4	54,2	0,05	55,0	54,2	0,01	53,5	54,3	0,11	53,2	54,4	0,41	51,6	54,3	0,15
58,3	58,2	58,4	0,05	58,6	58,4	0,10	59,2	58,4	0,14	57,6	58,4	0,09	57,2	58,4	0,19	55,7	58,4	0,14
62,4	62,6	62,5	0,41	62,8	62,5	0,24	63,2	62,4	0,07	61,6	62,3	0,09	61,2	62,4	0,00	59,9	62,6	0,29
66,8	67,2	66,8	0,66	67,4	67,1	0,51	67,4	66,5	0,41	65,6	66,3	0,69	65,2	66,4	0,62	64,1	66,8	0,03
71,0	71,1	71,0	0,17	71,3	71,0	0,04	71,9	71,0	0,00	70,0	70,7	0,39	69,8	71,0	0,04	68,4	71,1	0,11
75,5	75,5	75,5	0,01	75,8	75,5	0,02	76,4	75,5	0,04	74,9	75,6	0,15	74,4	75,6	0,08	72,8	75,5	0,03
79,8	79,7	79,8	0,14	80,0	79,7	0,12	80,8	79,8	0,06	79,1	79,8	0,01	78,9	80,0	0,31	77,2	79,9	0,09
84,0	84,0	84,0	0,03	84,3	84,0	0,01	85,1	84,1	0,14	83,3	84,0	0,00	83,0	84,1	0,16	81,3	84,0	0,03
88,2	88,2	88,2	0,05	88,5	88,2	0,02	89,2	88,2	0,01	87,6	88,3	0,10	87,2	88,3	0,14	85,6	88,3	0,08
92,3	92,2	92,2	0,18	92,6	92,3	0,03	93,6	92,6	0,29	91,7	92,4	0,09	91,3	92,4	0,12	89,5	92,2	0,14
96,2	96,2	96,1	0,08	96,5	96,2	0,04	97,2	96,1	0,06	95,6	96,3	0,07	95,1	96,2	0,00	93,5	96,2	0,03
99,7	99,8	99,6	0,01	99,9	99,6	0,15	100,6	99,5	0,18	99,1	99,8	0,06	98,2	99,3	0,41	96,9	99,6	0,13

Table 3 - General results of temperatures and relative errors.

4. CONCLUSION

After the tests with the bench of temperature adjustments, the results showed that the calibration method by temperature indicator by comparison with standard instrument and using mathematical regression is highly effective besides extremely practical, being applicable in several occasions to record temperature values within the range of uncertainty.

5. REFERENCES

Moreira, L. Medição de temperatura usando-se termopar. Cerâmica Industrial, v. 7, n. 5, p. 51-53, 2002.

Santos, D.S., Vieira, H.D., Santos, P.R.F.,Texeira, R.N., Andrade, J. C. “Relatório final da comparação interlaboratorial com termopar tipo K de-40 a 300° C”. Ministério Do Desenvolvimento, Indústria E Comércio Exterior. (Relatório final - nº 007/2011).

Valério, B.G., Bastos, L.S.. Estudo da transferência de calor em um forno mufla. 2016. xx, 79 f., il. Trabalho de conclusão de curso (Bacharelado em Engenharia de Energia)—Universidade de Brasília, Brasília, 2016.

Morais, D. S. G. “Otimização dos processos de calibração na grandeza temperatura.” Monografia de graduação. Departamento de Engenharia Mecânica, Universidade Federal do Rio Grande do Norte, 2009.

OMEGA - Sensing Incredible Things (2015). Disponivel em: < https://br.omega.com/artigos-tecnicos/calibracao-dispositivos-medicao-de-temperatura.html > .

Singh, D., Kumar, P., Prasad, S.C. Calibration of thermocouples for low temperature applications. In: Recent Advances and Innovations in Engineering (ICRAIE), 2016 International Conference on. IEEE, 2016. p. 1-4.

NBR 14610 -Indicador de temperatura com sensor - Calibração por comparação com instrumento-padrão

6. ACKNOWLEDGMENT

This work was developed with the support of the Federal University of Pará - UFPA at the Laboratory of Internal Combustion Engines of UFPA - Labmotor. We have to honor all the support given by Professor Dr. Hendrik Maxil Zárate Rocha and for the dedication and contribution of the authors of this work.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.