# METROLOGICAL EVALUATION OF A TEMPERATURE`S MEASUREMENT SYSTEM FOR POWER GENERATOR ENGINE


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**Abstract:** This present work aims at metrological evaluation of a measurement system of temperature for power engine generator based on NBR 13770 standardization, which regulates the calibration methodology for temperature sensors by comparing with a reference resistance thermometer. This measurement system is composed by four "K" thermocouples, signal conditioners, digitalization and signal processing platform. The data acquisition was automated by using a software for G programming



**Key words:** measurement system, thermocouples, metrological evaluation.


## 1. INTRODUCTION

Energy demand is growing on the worldwide scope. It is consequence of the population increasing and the worldwide economy. Brazil, as a developing country, follows that course. Studies with several energetic matrices in national territory are already very widespread. As [1] shows, despite the insertion of new sources in Brazilian matrix, the composition of energy sources still presents high dependence of petroleum when compared with the worldwide energetic matrix (41,9% in 2009 in the country and 33,1% in 2008 in the world). Among the petroleum derivates, diesel oil continues representing an essential source to Brazilian economy (16,7% of total energy consumption), due to its exclusive use on the loads transportation area – terrestrial and maritime – and on passengers' public transportation. According to [2] electric energy generation with diesel oil as energetic source can be mainly found in thermoelectric, industries and in isolated regions far from the concessionaries. Power Engine generators are used as emergency systems and peak demand, to increase reliability and saving. The variety of national energetic matrix is essential to the progress of the country and the independence from non-renewable sources.

Electric energy generation with power engine generator was studied in several researches either with Otto Cycle Engines or Diesel Cycle Engines. On these diesel cycle engines, [3] conducted studies using diesel oil working in a dual mode with natural gas and ethanol. The operation of a power engine generator using pure diesel oil and Biodiesel with several compositions and percentages was researched by [4]. From the data of the studies made with Diesel Cycle Engines, it was observed the potential of cogeneration for the units using exhaust gases.

The temperature measurement in air admission of the internal combustion engines serves as parameter to establish the relation air/fuel at the combustion moment and to define the best relation to the best burn. The temperature measurement of exhaust gases is used to determine the energetic potential of these gases so as to use them to improve the engine thermal efficiency, as seen in [5].

On any measurement, it is necessary to determine the data reliability. The equations which determine the measurements uncertainty level of any magnitude and the propagation of these errors along the measurement system are showed in [6].

## 2. OBJECTIVES

The purpose of this work is to study the metrological system of temperature measurement developed at the Power Generation Laboratory - LabGE - *PUC-Minas* for a power engine generator. This system shall attend a maximum uncertainty of ± 2,00°C to achieve the required reliability of temperature data collected in future experiments.

This study is intended to know the real conditions that the current equipment is under. This equipment is used to read and validate the temperature measurement system based on the NBR 13770 standardization in order to respect the uncertainty set for the unit.

This study will serve as a basis for immediate adequacies or possible improvements and future expansion which may be needed in the measurement system.

## 3. EXPERIMENTAL PLATFORM

The unit is in Power Generation Laboratory - LabGE - integrating the Research Center of *Coração Eucarístico campus* in Pontifical Catholic University of Minas Gerais.

### 3.1. Diesel Power Engine Generator

The power engine generator consists of a Diesel Cycle Engine produced by MWM coupled with an electrical generator by produced CROMACO whose characteristics are in Tables 1 and 2. Fig. 1 shows the power engine generator installed at the Power Generation Laboratory – LabGE.

**Table 1. Engine data**

| PARAMETER | TIPE OR VALUE |
|---|---|
| Construction type | DIESEL – four-stroke in line |
| Injection type | Direct |
| Diameter x course | 102 x 120 mm |
| Cylinder displacement | 0,980 liters |
| Number of cylinders | 4 |
| Total displacement | 3,922 |
| Aspiration | Natural |

**Table 2. Generator Data**

| PARAMETER | VALUE |
|---|---|
| N° of poles | 4 |
| Voltage (V) | 220 |
| N° of phases | 3 |
| Continuous Power (kVA) | 55 |
| Frequency (Hz) | 60 |

**Fig. 1. Diesel power engine generator**

### 3.2. Measurement System

The temperature measurement system consists of four "K" type thermocouples; *voltage amplifiers* using the *I.C. AD595* suitable for thermocouples as shown in Fig. 3. These are able to amplify the signal in variations of 10 mV / °C; *low-pass active filters* with approximately 1 Hz cutoff frequency as shown in Fig. 4; a *data acquisition module* – model *DAQ USB-6229* – developed by *National Instruments* as seen in Fig. 5; for data processing it was used the *LabVIEW* software, also developed by *National Instruments*. Fig. 2 shows the block diagram of the measurement system.

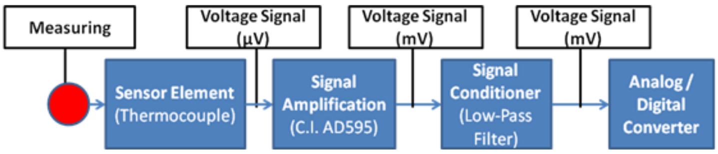


**Fig. 2. Block Diagram of temperature measurement system**

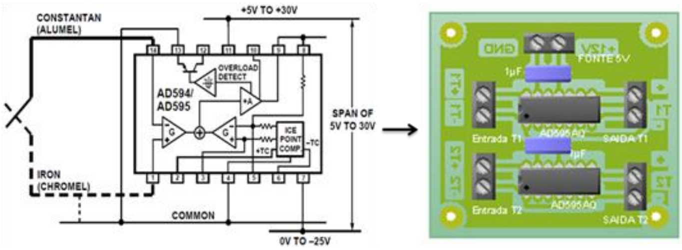


**Fig. 3. Signal Amplifier Circuit**

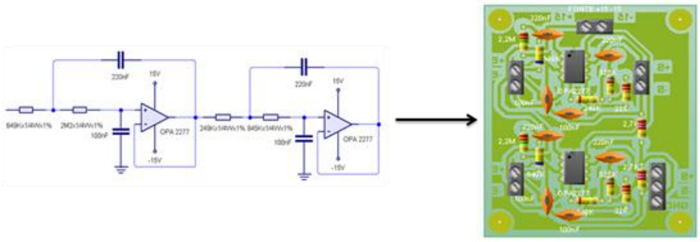

**Fig. 4. Low-pass filter circuit**

**Fig. 5. Data Acquisition Module**

Each thermocouple measures the temperature at a specific point of the power engine generator: *room temperature*, air *intake*, air *admission* and *exhaust* gases as shown on Fig. 6 to 9.

**Fig. 6. Thermocouple (*room* temperature)**

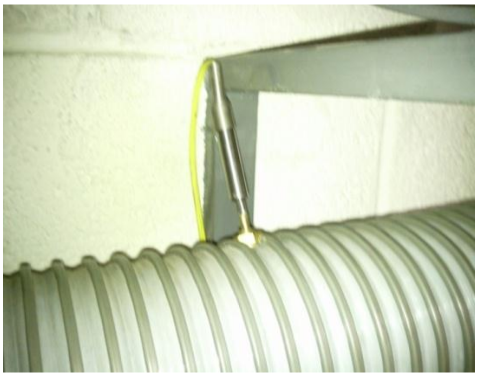

**Fig. 7. Thermocouple (air *inlet* temperature)**

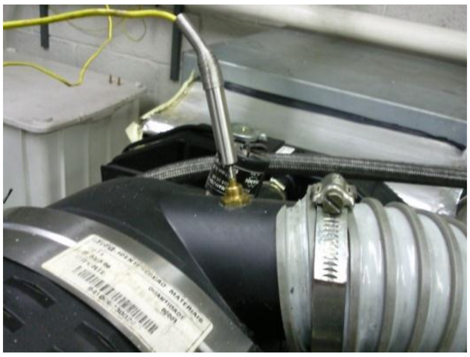

**Fig. 8. Thermocouple (air *admission* temperature)**

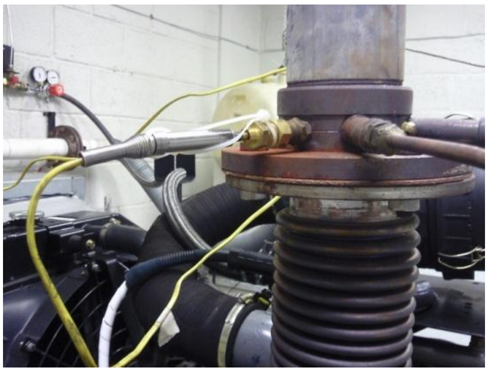

**Fig. 9. Thermocouple (*exhaust* gas' temperature)**

From the four thermocouples that constitute the *temperature measurement system*, three, *room*, air *intake* and air *admission* are analyzed in the temperature range between 0 °C and 40 °C and a thermocouple, *exhaust* gases, is analyzed in the range from 50 °C to 250 °C.

### 3.3. Metrological Specifications of Measurement System Components

In each component of the measurement system, the manufacturer informs, through its data sheet, the output errors provided in the input signals processing.

Table 3 shows the reported errors in the *I.C. AD595* data sheet.

**Table 3. *I.C. AD595* information**

| PARAMETER | VALUE |
|---|---|
| Calibration error at +25°C | ±3°C |
| Stability vs. Temperature | ±0,05 °C/°C |

Table 4 shows the reported errors from data sheet of the *operational amplifier OPA2277*. This amplifier was used in the production of active filters.

**Table 4. *Operational amplifier OPA2277* information**

| PARAMETER | VALUE |
|---|---|
| Input Offset voltage | ±10µV (MAX. ±35µV) |
| Input Voltage Noise, f = 0.1 to 10Hz | 0,22 µVp-p<br>0,035 µVrms |

Table 5 shows the reported errors from data sheet of the data acquisition module *DAQ USB-6229.*

**Table 5. *DAQ USB-6229* information**

| PARAMETER | VALUE |
|---|---|
| Conversion bits | 16 |
| Converted Voltage Range | 10 V |
| Resolution | 152,588 µV |
| Random error | ±76,294 µV |

## 4. METHODOLOGY

To the calibration of the measurement system for temperature and definition of the methodology used on the analysis, Brazilian Standardization ABNT NBR 13770 (Thermocouple - Calibration by comparison with a reference resistance thermometer) was taken as reference.

### 4.1. Experimental Apparatus

The calibration apparatus is constituted by a cold/heat source, to temperature equalization. This cold/heat source is a portable calibrator with temperature sensors developed by *Thermacal*, as showed on Fig. 10. To inform the reached temperature in its cold and hot chamber, the portable calibrator has an internal resistance thermometer – Pt-100 –. This resistance thermometer is the reference to compare the readings of temperatures measured by the measurement system.


**Fig. 10. Portable Calibrator of temperature sensors**

Table 6 gives information about the calibration of the internal resistance thermometer of portable calibrator.

**Table 6. Portable calibrator information**

| Standard resistance thermometer | | |
|---|---|---|
| Precision | | |
| Cold Source | ± 1°C | |
| Hot Source | ± 1°C | |
| Set point (°C) | Final temp. (°C) | Uncertainty (°C) |
| 0 | -0.03 | 0.015 |
| -20 | -20.02 | 0.031 |
| 50 | 49.97 | 0.031 |
| 100 | 100.02 | 0.038 |
| 200 | 199.97 | 0.048 |
| 500 | 500.05 | 0.078 |

### 4.2. Experimental Procedure

The points 0ºC, 10ºC, 20ºC, 30ºC and 40ºC or the nearest to them were used to analyze the thermocouples on the temperature range between 0ºC e 40ºC. The points 50ºC, 100ºC, 150ºC, 200ºC and 250ºC were used to analyze the thermocouple on the temperature range between 50ºC e 250ºC.

Each thermocouple is inserted in the portable calibrator separately and this stabilizes the temperature on each determined point. To each point, it takes 10 minutes to the temperature stabilization. The developed algorithm on *LabVIEW* software records the measured temperature acquired by the thermocouple in each point on 32 ms intervals until a total of 7800 acquisitions. The temperature of the standard resistance thermometer is inserted in the program. The software makes comparison between the temperatures with and without treatment. Due to the treatment, it was chosen a short sampling time of the signal, which gives the possibility of treating the signal without losing information. The temperature treatment by software is made by an average of the 50 last acquired temperatures

## 5. RESULTS

After the readings in each defined temperature for each thermocouple which composes the measurement system, the study of random and systematic errors at each point is done to the signal with and without software treatment.

Tables 7-10 show the results of measurements for each thermocouple and Fig. 11-14 shows graphs comparing the values of the modules of systematic and random errors of each measured point for each thermocouple.

**Table 7. Results of the thermocouple measuring *room* temperature**

| ROOM | | | |
|---|---|---|---|
| Point (°C) | Systematic error (°C) | Uncertainty | |
| | | Without Software Treatment (°C) | With Software Treatment (°C) |
| 0,00 | +2,68 | ±1,14 | ±0,33 |
| 10,00 | +2,05 | ±0,97 | ±0,17 |
| 20,00 | +1,72 | ±0,98 | ±0,21 |
| 30,00 | +4,67 | ±3,53 | ±2,48 |
| 40,00 | +4,47 | ±3,08 | ±2,21 |

**Table 8. Results of the thermocouple measuring the *input* air**

| INPUT | | | |
|---|---|---|---|
| Point (°C) | Systematic error (°C) | Uncertainty | |
| | | Without Software Treatment (°C) | With Software Treatment (°C) |
| 0,00 | +6,37 | ±1,22 | ±0,25 |
| 10,00 | +5,61 | ±1,23 | ±0,23 |
| 19,68 | +5,19 | ±1,35 | ±0,56 |
| 30,76 | +5,89 | ±1,22 | ±0,27 |
| 40,00 | +5,85 | ±1,22 | ±0,21 |

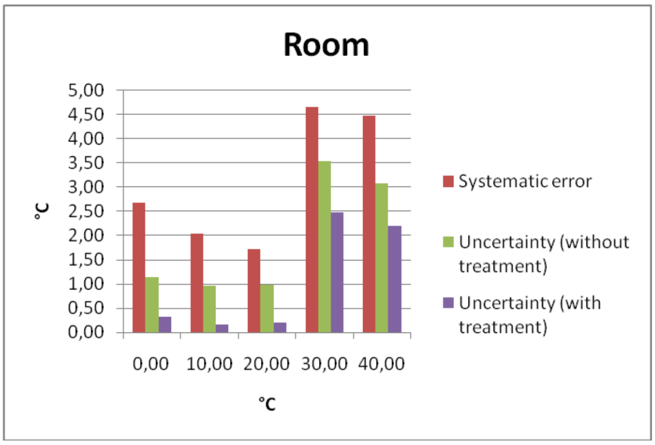


**Fig. 11. Graph of errors in the measured points for thermocouple *room temperature***

**Table 9. Results of the thermocouple measuring the *admission* air**

| ADMISSION | | | |
|---|---|---|---|
| Point (°C) | Systematic error (°C) | Uncertainty | |
| | | Without Software Treatment (°C) | With Software Treatment (°C) |
| 0,00 | +8,72 | ±7,25 | ±1,10 |
| 10,00 | +5,12 | ±6,87 | ±1,01 |
| 19,82 | +2,68 | ±6,89 | ±1,31 |
| 30,13 | +2,70 | ±6,49 | ±0,99 |
| 40,00 | +2,65 | ±6,88 | ±0,98 |

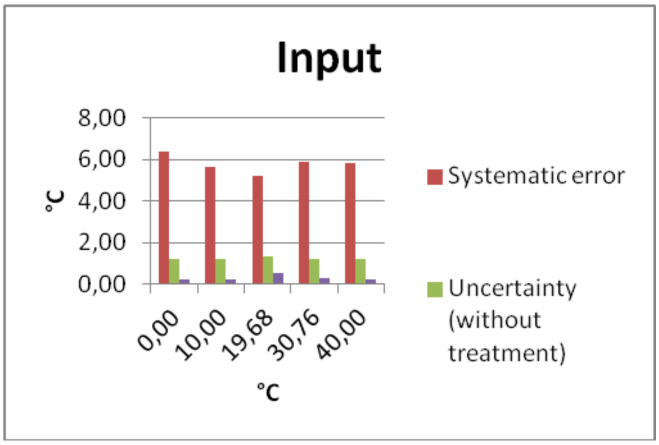


**Fig. 12. Graph of errors in the measured points for thermocouple *Input***

**Table 10. Results of the thermocouple measuring the *exhaust* gases**

| EXHAUST | | | |
|---|---|---|---|
| Point (°C) | Systematic error (°C) | Uncertainty | |
| | | Without Software Treatment (°C) | With Software Treatment (°C) |
| 50,00 | +2,41 | ±1,21 | ±0,32 |
| 100,00 | +3,34 | ±1,21 | ±0,25 |
| 150,00 | +3,82 | ±1,22 | ±0,26 |
| 200,00 | +3,31 | ±1,24 | ±0,25 |
| 250,00 | +2,51 | ±1,16 | ±0,18 |

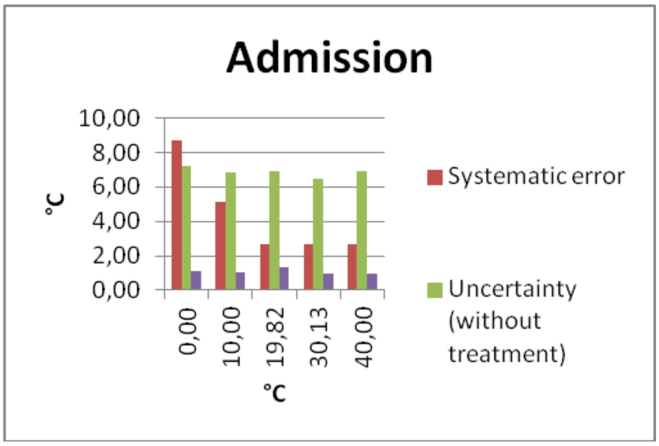


**Fig. 13. Graph of errors in the measured points for thermocouple *Admission***

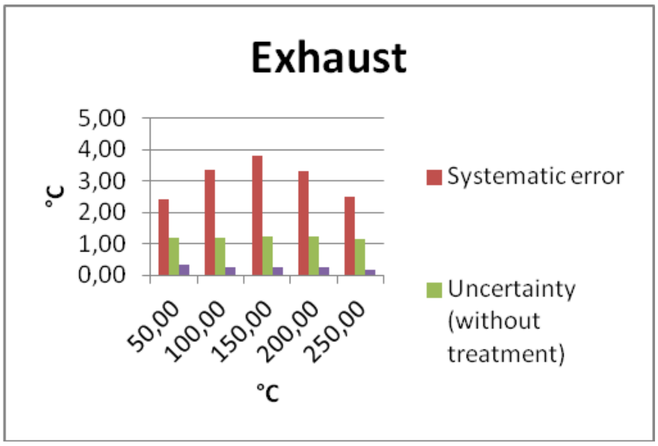


**Fig. 14. Graph of errors in the measured points for thermocouple *Exhaust***

## 5.1. Uncertainty Determination Sheet

Based on the measurements results, uncertainty determinations in each measured point for each thermocouple were made. These determinations consist in calculating the systematic and random errors taking into account the errors of each component used in either systems of measurement or the equipment used for calibration.

A total number of 20 uncertainty determinations were calculated - 5 points in each one of the 4 thermocouples - will be shown in Table 11. It shows the model used to calculate the uncertainty determination at the point 50 ° C from one of the thermocouple which measures the temperature of the *exhaust gas*. For other points, the same model table was used.

**Table 11. Uncertainty Determination table for the point 50°C from a thermocouple measuring the temperature of *exhaust* gases**

| Exhaust (with software treatment) - Point 50°C | | | | | | |
|---|---|---|---|---|---|---|
| Sources of uncertainty | Systematics Effects | Random Effects | | | | |
| Description | correction [°C] | gross [°C] | distribution type | divider | μ [°C] | ν |
| Repeatability | -2,41 | | normal | 1 | 0,3200000 | 7799 |
| Heat source | 0,00 | 1,0000000 | uniform | 1 | 0,5773503 | ∞ |
| Operational Amp. | 0,00 | 0,0500000 | uniforme | $\sqrt{3}$ | 0,0288675 | ∞ |
| low-pass filter | 0,00 | 0,0000220 | uniforme | $\sqrt{3}$ | 0,0000220 | ∞ |
| Data aquisition module | 0,00 | 0,0076294 | uniforme | $\sqrt{3}$ | 0,0044048 | ∞ |
| Combined correction | -2,41 | | | | | |
| Combined Standard Uncertainty | | | normal | | 0,6607466 | ∞ |
| Expanded Uncertainty (95%) | | | normal | | 1,3214932 | |

With the information from the tables of the balance sheets of uncertainty, are plotted graphs of the calibration of thermocouples, as Fig. 15-18.

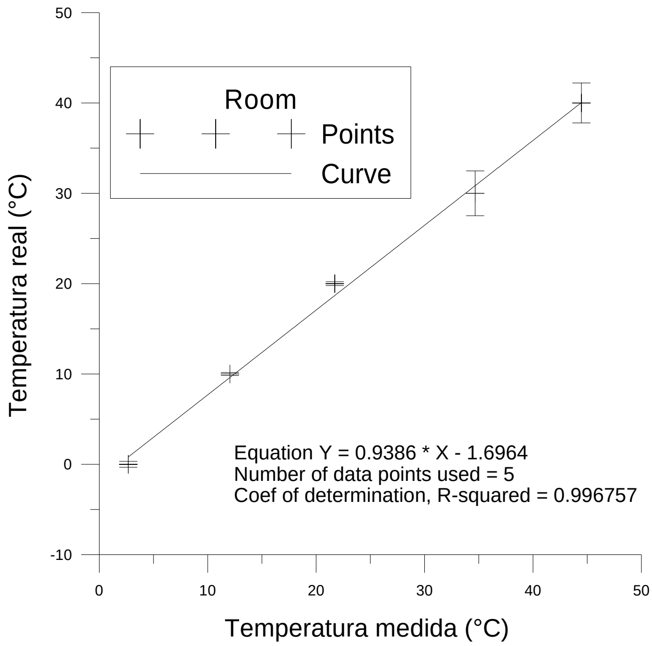


**Fig. 15. Calibration chart for the thermocouple measuring the *room* temperature**

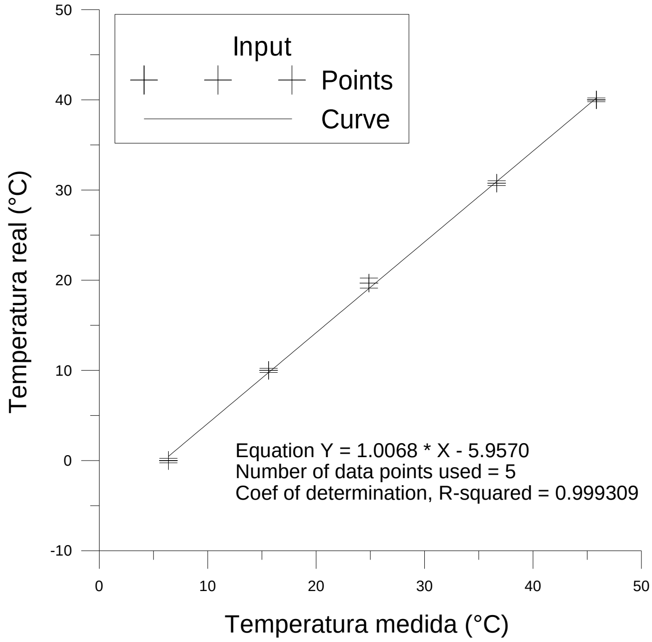


**Fig. 16. Calibration chart for the thermocouple measuring of the *Input air* temperature**

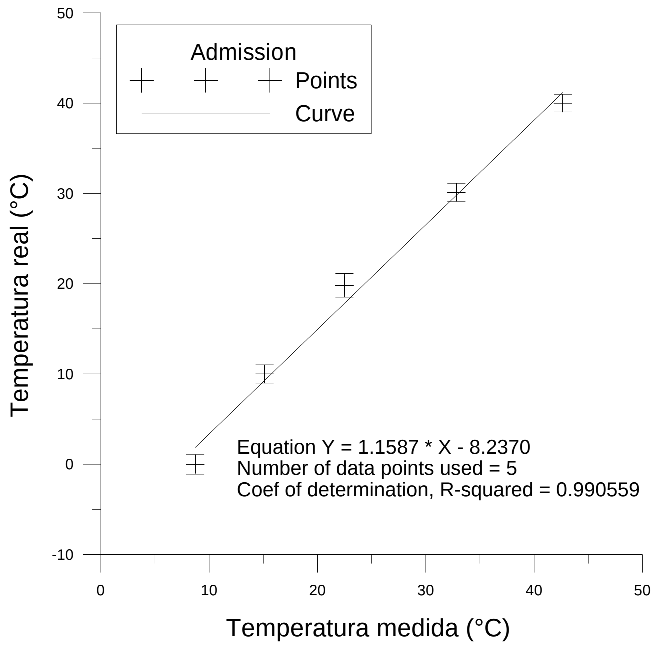


**Fig. 17. Calibration chart for the thermocouple measuring the *admission air* temperature**

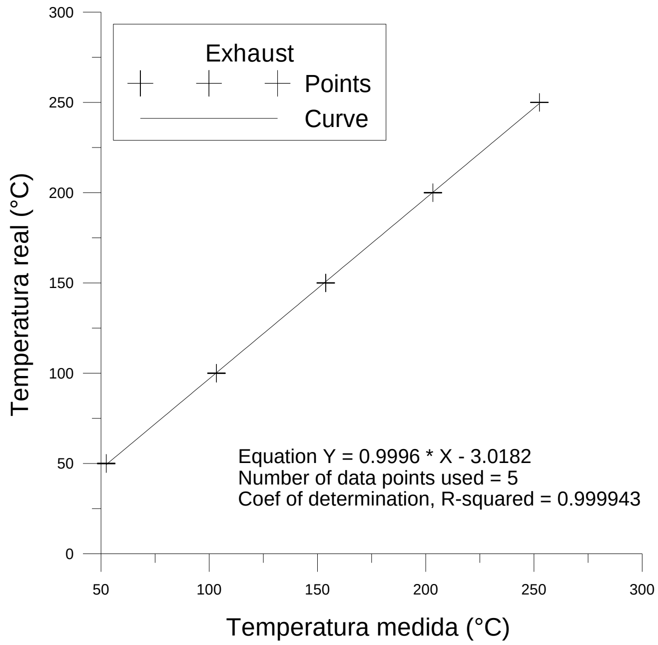


**Fig. 18. Calibration chart for the thermocouple measuring the temperature of *exhaust gases***

## 6. DISCUSSION E CONCLUSIONS

For the analysis of results, we must consider that the thermocouples were already in use by LabGE for at least five years. During this period, they were subjected to unknown conditions until this study. The measurement system currently used was developed to meet an inaccuracy of up to ± 2.00 ° C. This lack of clarity serves as the requirements for the study of the conditions of high electromagnetic noise undergoing experimental platform.

The signals from all thermocouples for all temperature points showed a significant improvement in measurement uncertainty when subjected to information processing by software. This treatment is suitable for random errors, systematic errors for it does not apply. The data in Tables 7-10 and the graphs of Fig. 11-14 show these results.

The *Room Temperature* thermocouple presented only a systematic error decreasing for the first three measured points and stability in this error for the last two. Analyzing the random errors, there is stability for the first three points around 1,00°C in the signal without treatment and 0,25°C in the signal treatment. As for the last two points is found just above uncertainties of 3,00°C for the signal without treatment and between 2,00°C and 2,50°C for the signal treatment. It is concluded that this thermocouple has low linearity and imprecision does not meet the established maximum for the temperature range between 30,00°C and 40,00°C should be replaced or improved its measurement system.

The *Input* thermocouple showed good linearity, and the systematic errors in each measured point varied in the range between 5,50°C and 6,50°C. This also presented for all measured points uncertainties smaller than 1,50°C without signal treatment - which already meets the established maximum uncertainty - and less than 0,30°C with the treated signal. It is concluded that this thermocouple meets the required questions since the systematic errors are corrected.

The *Admission* thermocouple presented decreasing systematic errors introduced by the third point, leveling off from this. The uncertainties in the whole measurement range, changed between 6,50°C and 7,50°C for the signal variation between untreated and 0,90°C and 1,50°C to the treated signal. It is concluded that this thermocouple meets the required requisites, since the provided signal is handled via software for the improvement of their uncertainty and systematic errors are corrected.

The *Exhaust* thermocouple presented a variation in the form of negative parable in the variation of the systematic error over the measurement range, with the apex point of 150,00°C. This also presented stability in the measurement uncertainty. Ranged from 1,16°C and 1,22°C without signal processing and between 0,18°C and 0,32°C with the treated signal. It is concluded that this thermocouple also meets the required requisites, without the need for signal processing via software to improve the uncertainty and since their systematic errors are corrected.

Based on the developed work the uncertainty values and also the systematic error for all temperature sensors were indentified. This means that the authors know exactly the error value in the work range, so they can correct the reading and also the random error in the measurements. All procedures and data analysis was implemented based in reference standardization – NBR13770. With this temperature instrumentation analysis the authors are able to go forward in a detailed analysis of the diesel cycle engine performance.

## 7. FUTURE WORKS

Based on the same methodology used in this work, is intended to develop a *pressure measurement system*. This system will register the internal pressure from combustion chamber of the power engine generator.

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