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Development of low cost tubular furnaces for Research & Development Laboratories

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Abstract. In order to contribute with the most diverse research and development laboratories in its experiments, this paper presents the development methods for the construction of electric furnaces able to operate at temperatures up to 1200°C, with high thermal inertia and low cost. Research and development laboratories in Latin America face many difficulties in maintaining their experiments, especially those related to the synthesis of materials. However, many labs do not have the philosophical tradition of building their own research equipment, depending on whether importing or buying expensive equipment. In this article, we demonstrate the possibility of developing furnaces with good thermal homogeneity using low cost materials found throughout Latin America. Finally, we describe the construction methods and the materials used in the construction of two different furnaces operating at temperatures up to 400°C and 1200°C, presenting very good thermal inertia and homogeneity. With an operational temperature up to 1200 °C, both furnaces have thermal inertia and homogeneity.

Key Words. *Furnace; Sand Thermostatic Bath; Thermal Inertia; Low cost laboratory equipment.*

Introduction. In traditional research and development laboratories it is cultural the development of their own experimental instruments and equipment. This implies being able to control the measurement parameters and finally creating a market. (1,2) On the other hand, in the Latin American reality, the research and development laboratories lack this philosophy. (3) Currently, in industrial material production, there are temperature stages that consume high amounts of energy that imply in higher costs. Therefore, there is a common interest in industrial sectors to reduce the total energy consumption.

Throughout this article, it will be presented two chapters about the construction and general characterization of two different furnace prototypes. In chapter one, the furnace named STB (Sand Thermostatic Bath) whose main purpose is high thermal inertia and homogeneity; and in chapter 2, a furnace with operational temperature up to 1200°C besides high thermal inertia and homogeneity.

Objective. The objective is to develop simple and direct construction methods of high operational temperature and thermal inertia and homogeneity, enabling the continuous research. Besides this, it is sought easier maintainability, allowing repairs and project modifications according to different needs. This implies building the furnace in modules.

CHAPTER 1

1.1. Materials and methods.

1.1.1 - Materials used and technical description.

1.1.1.1 Structural Case

It used a wood box with dimensions: (56,5 x 53,5 x 48,5) cm.

1.1.1.2 Ceramic Fiber Blanket *Thermofelt®* 6 x 2"

It was used mainly as thermal insulator. It can be used in temperatures up to 815ºC without degrading.

1.1.1.3 Nickel-Chromium resistance wire

Composition of 80% Nickel and 20% Chromium, being the one used in the construction of the thermostatic bath, total resistance of approximately 11 Ω. Its maximum operational temperature according to manufacturer is close to 1050ºC.

1.1.1.4 Refractory mass *Gabriela*

Its main function was to avoid direct contact between the resistance wire and the steel tube, also adding mechanical resistance and fixing the wires to the steel tube.

1.1.1.5 Steel tube

Total height of 0,3m and internal diameter of 0,1 m, used as the heating chamber due to its mechanical properties and melting point.

1.1.1.6 Sand

Used as enclosure to the heating chamber, with the main objective of stabilizing the temperature in the system. This is achieved due to the large mass of sand used and high thermal capacity and specific heat.

1.1.1.7 Voltage regulator

To control the temperature in the heating chamber, it was used a voltage regulator - Variac, due to low cost and good controlling characteristics.

1.1.1.8 Type K Thermocouple

Used for temperature measurements along the Sand Thermostatic Bath.

1.1.1.9 - Thermocouple meters for Type K Thermocouples *Minipa* MT401A

Used to measure the data sent from thermocouple wires.

1.1.2 - Construction Methods

Firstly, it was designed a possible prototype for the STB. the result of this first design is presented in Figure (1). Important note to the fact that the heating chamber is enclosed and surrounded by sand, allowing thermal stability and temperature measurements along the furnace in any point.

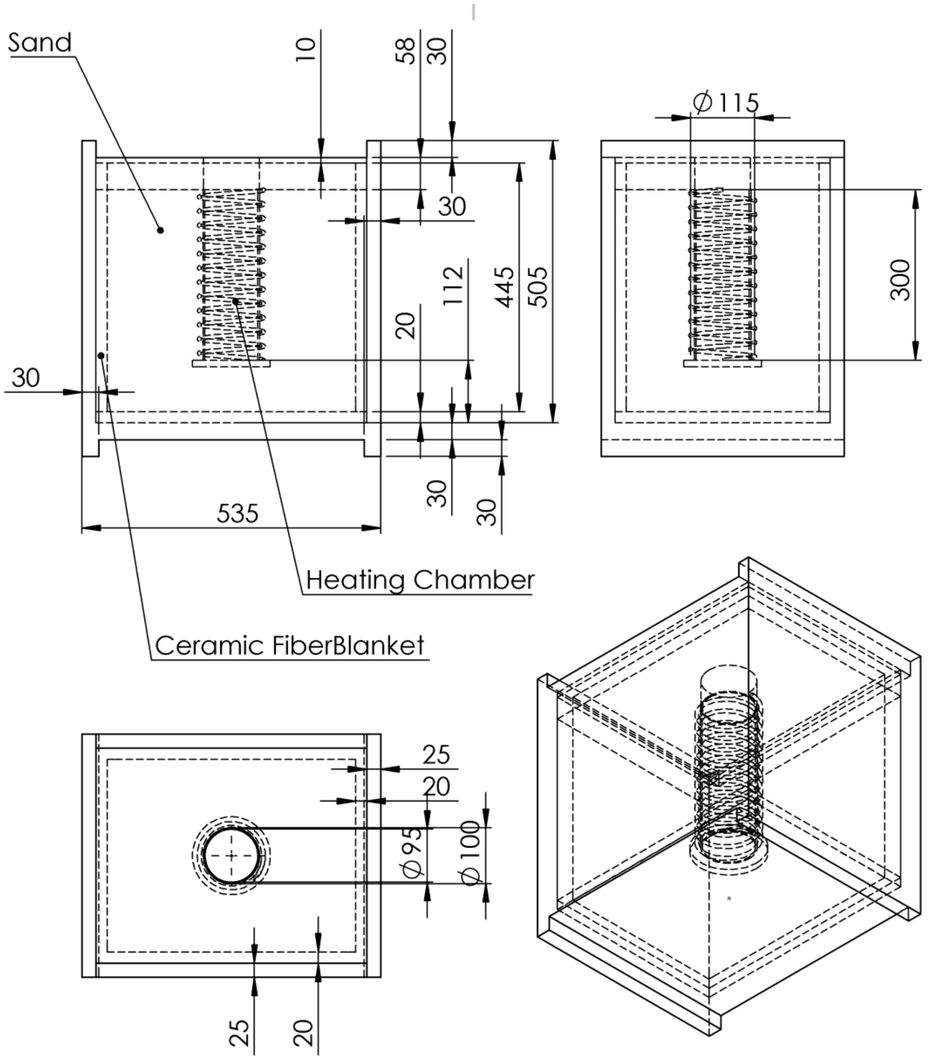

Figure 1 - Isometric views of the Sand Thermostatic Bath.

After the design phase, the construction phase was marked firstly by the conformation of the resistance wires. This was possible by attaching one end of the resistance wire to a threaded screw to wind the resistance wire and the other end to a screwdriver.

Then it was added the refractory mass around the steel tube to fix the resistance wire and make sure it was not in direct contact to the steel tube, otherwise it would cause a short circuit. The preparation method of the refractory mass was according to the manufacturer's instructions. In order to help fixing the wires to the steel tube, it was used twine. After all this process was done a thin second coat of refractory mass was added to the heating chamber and resistance wires.

While the refractory mass was being cured and dried, it was build a structural case made of wood and elaborated a ceramic base for the heating chamber. After all this was finished they were assembled according to the project's design, and sand was added inside STB.

In order to obtain the experimental data and temperature measurements, Type K thermocouples were used. They were positioned according to the type of measurement and position along the STB. Temperature was controlled using the voltage regulator.

1.2. Results and Discussion.

Figure (2) refers to the time needed to reach stabilization temperature when 40 Volts were applied to the heating chamber. It took 56 hours to reach a stationary temperature, which demonstrates the high thermal inertia of the STB furnace. Even with the voltage variation in the electrical network in Brazil, the STB furnace maintained a stable temperature with a variation of ±1^{0}C.

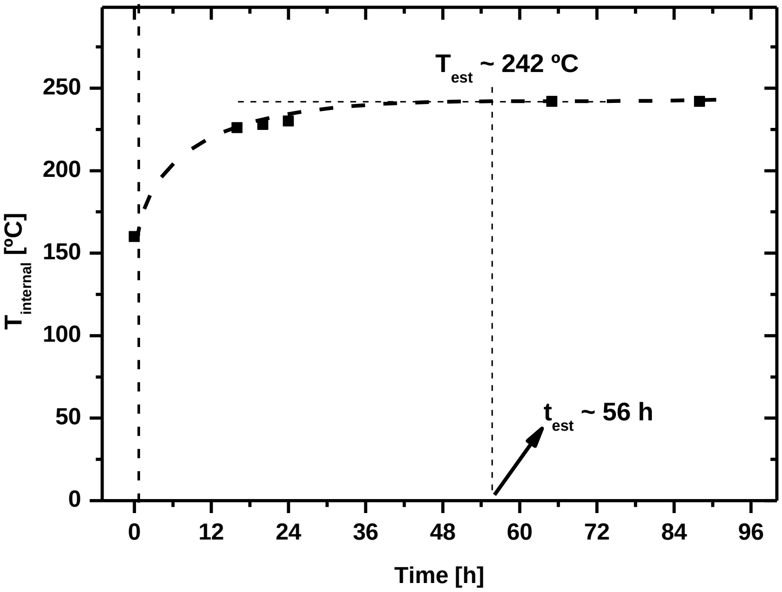

Figure 2. Heating curve of the STB furnace for a voltage of 40 volts.

In Figure (3), it was shown the cooling curve of the STB furnace after removing its polarization. The time that it takes the STB furnace to cool to room temperature demonstrates its high thermal inertia.

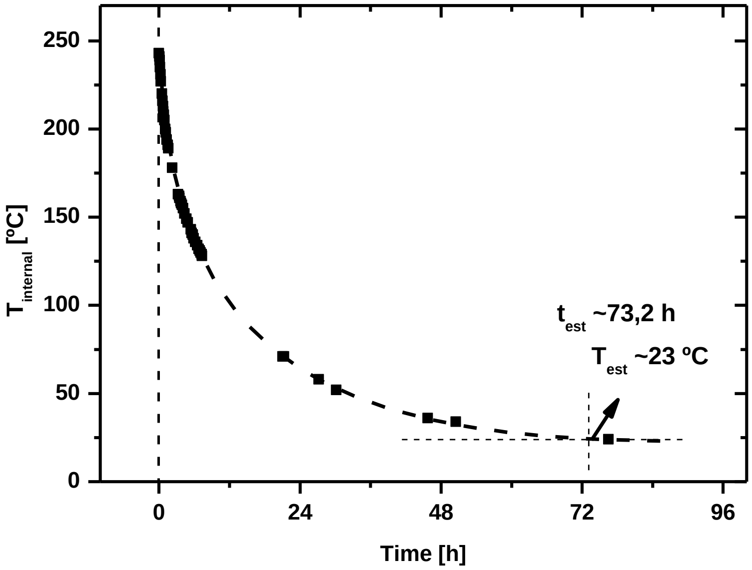

Figure 3. Cooling curve of the STB.

In Figure (4) it is shown the characteristic curve of the STB furnace, voltage x stationary temperature. The linearity demonstrates that there is low interference of temperature variations in the surroundings, allowing the non-use of digital controllers, and at the same time granting its thermal inertia.

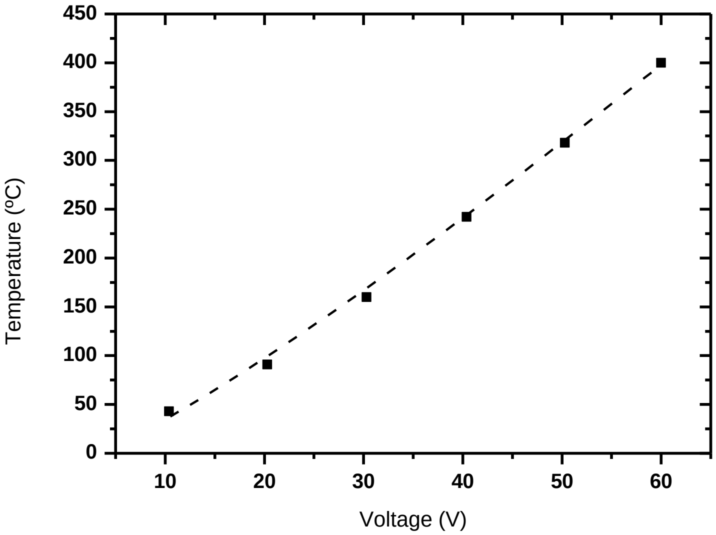

Figure 4 – Characteristic curve of the STB furnace.

Finally, for the characterization of the heat fluxes, isothermal layers were made for the STB furnace.

In Figure (5) it is shown the thermal characterization of the STB furnace for a specific height (326 mm). It is observed in the dark brown area of Figure 4, corresponding to 15cm in diameter, where in this region, even with exothermic or endothermic reactions the temperature tends to be stationary, indicating a high thermal inertia. Furthermore, the STB furnace allows the placement of reactors along the STB furnace.

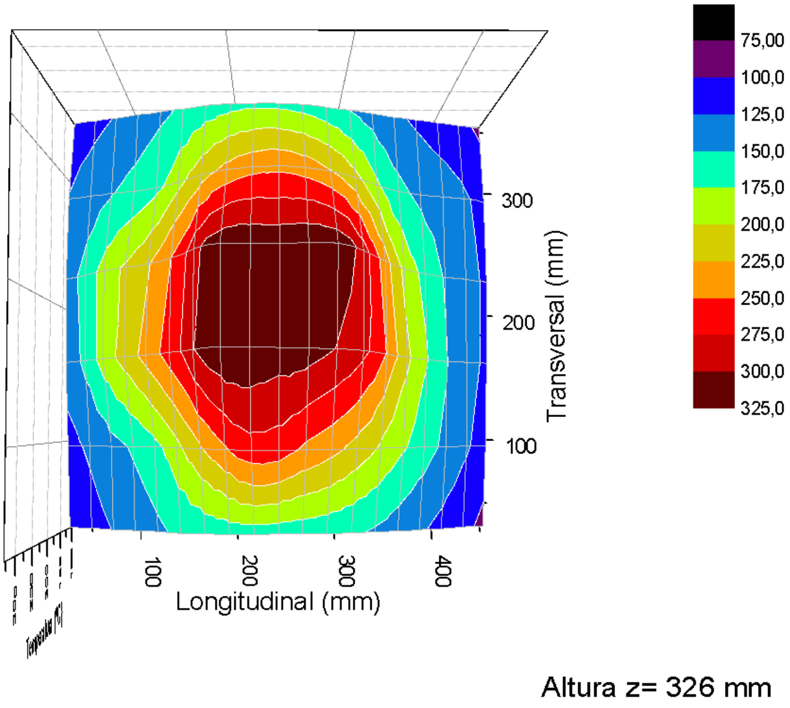

Figure 5 - Isothermal layers of the STB furnace for 326 mm.

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CHAPTER 2

2. 1 Materials and Methods.

2.1.1 - Materials used and technical description.

2.1.1.1 - Red construction bricks.

This material was used due to its structural characteristics and low thermal conductivity, having in mind that red bricks have air ducts in their interiors and being a ceramic, it is characterized as thermal insulator.

However, such ceramic possesses high expansion coefficient that causes rupture when submitted to high temperature gradients. This material use was restricted to external parts of the furnace where the temperature gradient is lower. For internal parts other material was used.

2.1.1.2 - Paver.

Used in regions where structural properties were needed, and a high temperature resistance was important (near the heating chamber) and due to its low expansion coefficient and low thermal conductivity (Thermal conductivity close to 0,9 W/m.K).

2.1.1.3 - Ceramic Fiber Blanket *Durablanket*® 1400.

Used as the main thermal insulator in the system due to its low thermal conductivity (approximately 0,3 W/m.K, according to manufacturer). With its composition, mainly of Zirconia Oxide, it withstands operating temperatures close to 1400º C without degrading.

2.1.1.4 - Resistance Wire *Kanthal* A1.

Made of Iron, Aluminum and Chromium. Total resistance of the heating element used in the furnace was close to 26 Ω. Such composition allows operating temperatures close to 1400º C.

2.1.1.5 - Steel Plate SAE 1020.

Used as structural component in the base of the furnace due to its mechanical properties and low cost.

2.1.1.6 - Aluminum heat sinks.

Due to the long time to cool the furnace, they were designed to speed up the cooling time.

2.1.1.7 - Alumina tube.

Used as the heating chamber due to its chemical inertia, melting point and structural properties.

2.1.1.8 - Refractory Mass *Laitogni*® 95.

Its main purpose is fixing the heating element to the Alumina tube, besides operating as a thermal insulator. Its composition is mainly Aluminum Oxide with small amounts of Calcium Oxide and Iron Oxide.

2.1.1.9 Voltage regulator.

To control the temperature in the heating chamber, it was used a voltage regulator - Variac, due to low cost and good controlling characteristics.

2.1.1.10 Type K Thermocouple.

Used for temperature measurements along the Sand Thermostatic Bath.

2.1.1.11 -Thermocouple meters for Type K Thermocouples *Minipa* MT401A.

Used to measure the data sent from thermocouple wires.

2.1.2 - Construction Methods.

The first phase of the design for the furnace was deciding where the heating chamber was going to be placed in, and the position of the heating elements. Below in figures (6) and (7), we expose the results of the first phase of design.

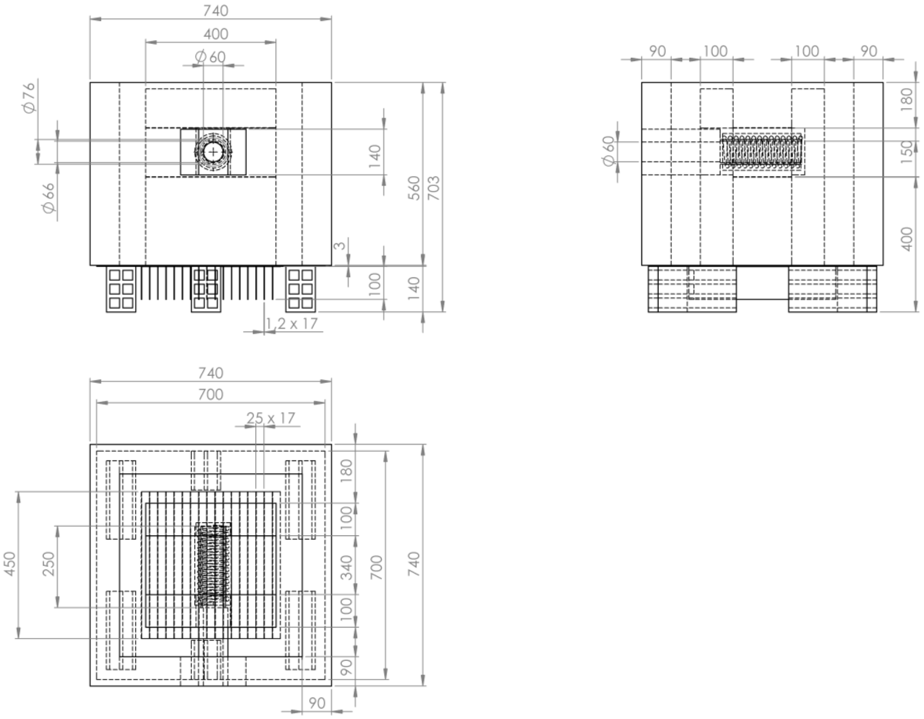

Figure 6 - Dimensions of the furnace.

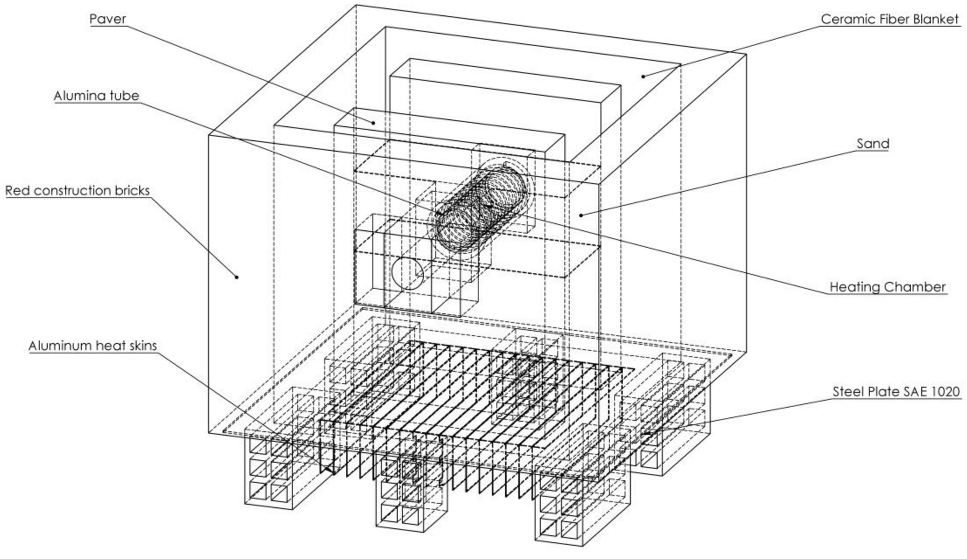

Figure 7 - Dimetric projection and constituents localization.

With the materials easily available, we built the heating elements using Resistance Wire *Kanthal* A1, using the same process used to build the heating elements of the STB. Total resistance of the heating element was approximately 26 Ω.

The next step was assembling the heating chamber and installing the heating elements to the Alumina Tube and adding refractory mass *Laitogni*® 95 around the heating elements. The process of sintering and curing was followed according to manufacturer's instructions.

While the ceramic was being prepared, the base of the furnace was assembled installing the aluminum heat sinks to the steel plate SAE 1020 and placing them on top of the the base red construction bricks. The walls of the furnace were built using the red construction bricks, the ceramic fiber blanket *Durablanket*® 1400 was added inside while the walls were being constructed. When the building of the heating chamber was finished it was added to the furnace, and sand was inserted around the heating chamber. After this process was done, the voltage regulator was used to start heating the resistance wires to obtain data on the heating ramps and stabilization temperatures. For the temperature measurements, Type K thermocouples were placed inside the heating chamber and fixed during the whole process of temperature measurement.

2.2 Results and Discussion.

In Figure (8) we have the temperature curve at 70 volts of the 1200^{o}C furnace. It was possible to reach a temperature of 430^{o}C after 15 hours with a small variation of ± 2^{o}C.

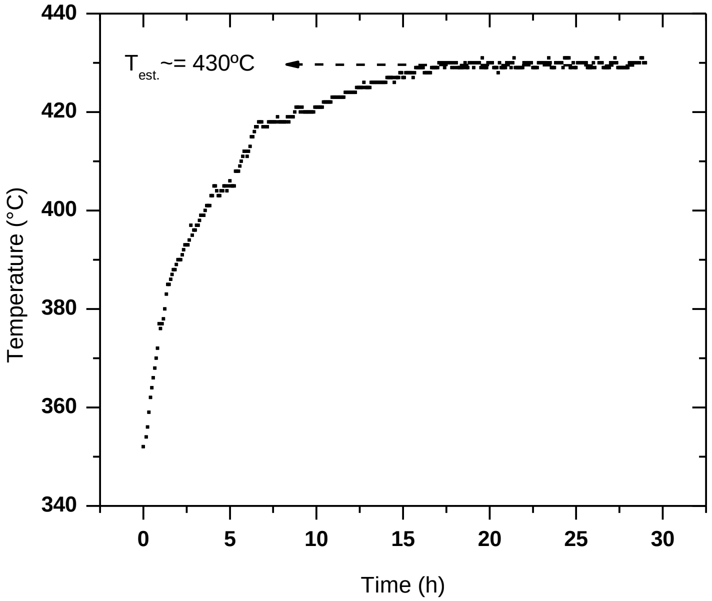

Figure 8 -Temperature curve for the 1200 ^{o}C furnace at 70 volts.

In Figure (9) it is possible to observe the existence of oscillations in the temperature curve during both the heating ramp and the temperature stabilization zone.

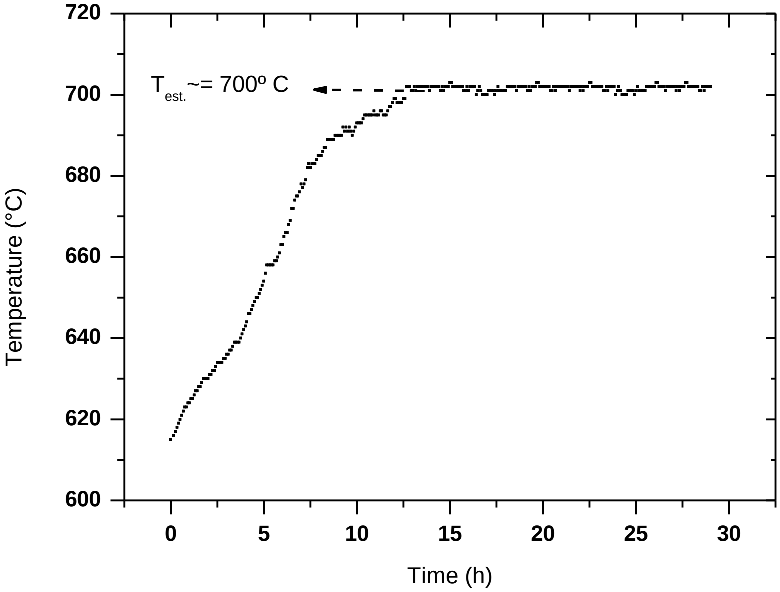

Figure 9 - Temperature curve for the 1200°C furnace at 100 volts.

In Figure (10), around the furnace's maximum operational temperature, when 140V were applied and it is measured a current of approximately 5.4 amperes. The power used to reach 1150°C with a variation of ± 10°C was approximately 950 W.

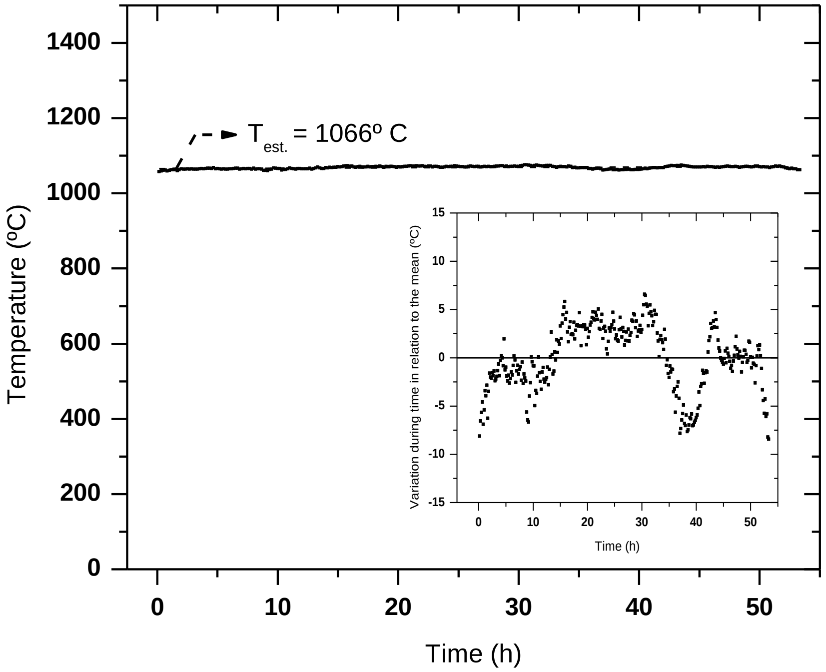

Figure 10 - Temperature curve for the 1200^{o}C furnace after thermal stabilization for 140 volts.

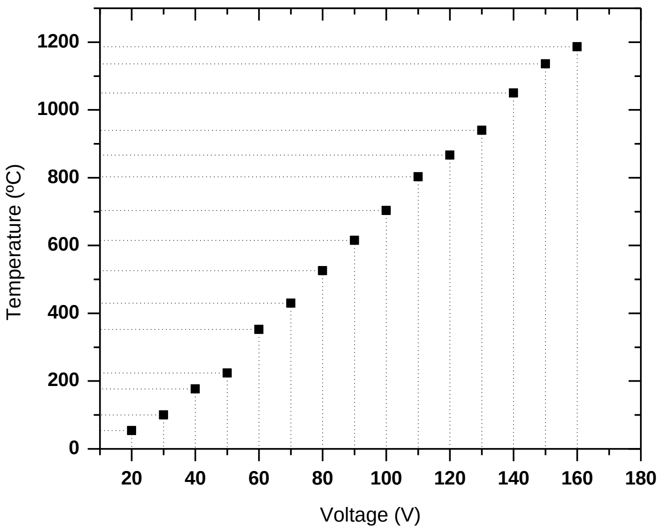

Figure 11 – Characteristic temperature curve of the 1200^{o}C furnace.

For the usage of the 1200°C furnace with processes that need heating ramps, instead of modifying the furnace's operational temperature, it is possible to move the sample along the heating chamber axis, therefore taking advantage of the temperature gradient in the heating chamber. In posterior articles to the published, it will be discussed and demonstrated how to experimentally study the heat fluxes and apply theories to these types of technologies.

2.3 Conclusion.

It is possible to develop and build thermal laboratory equipment at low cost with thermal inertia and homogeneity. The developed STB furnace permits temperatures up to 500°C and thermal stability around ± 1°C using low power. The 1200°C furnace built also permits operational temperatures around 1200°C with thermal inertia and homogeneity, also using low power. In projects like this, it is possible to form human resources better prepared for technological development.

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