DEVELOPMENT OF A SUPERVISORY SYSTEM TO MEASURE THE TEMPERATURE INSIDE CHARCOAL KILNS

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Abstract. *This study proposes the thermal analysis of rectangular kilns which have an individual capacity to produce 20 tons of charcoal per coaling cycle. The objective is to measure the temperature with thermocouples located at various points inside of the kilns and to establish a relationship between temperature and charcoal quality. The thermal instrumentation previews the installation of 22 PT100 thermocouples in each kiln. These sensors will be connected to a motherboard wich transmits the signals to a computer by an electronic circuit and a wireless net. The temperatures will be stored in a supervisory system which presents the measured data in form of graphs and tables. This information will guide and assist the kiln operator during all stages of the charcoal production. This measurement procedure with a statistical analysis represents an important tool to reduce the drying, pyrolysis and cooling time. It also minimize the losses and increases the efficiency of the production process. Another important contribution is the reduction of emission of greenhouse effect gas.*

Keywords*: temperature, thermal instrumentation, charcoal kiln.*

1. INTRODUCTION

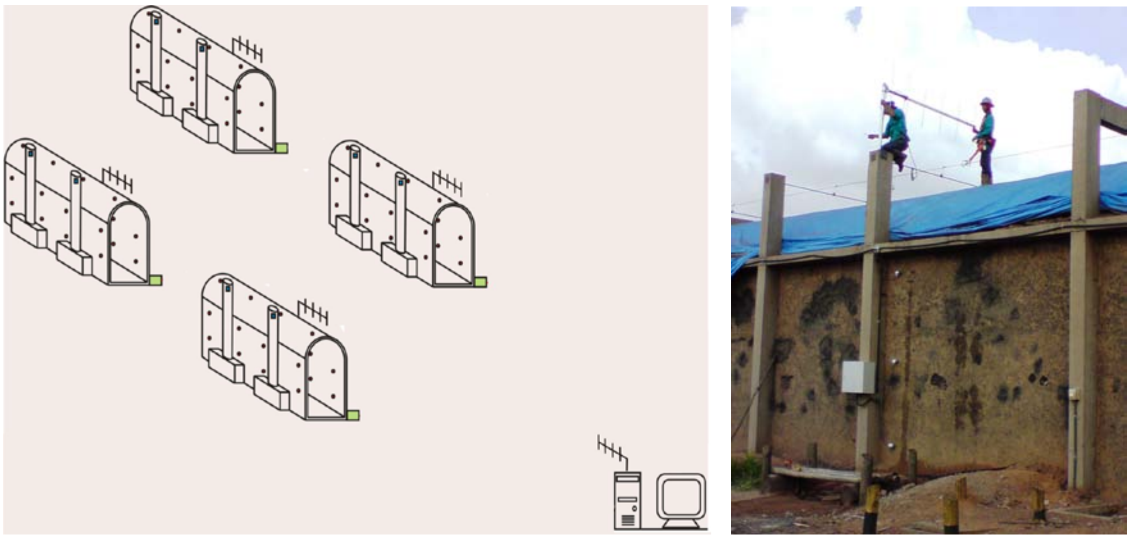
The development of thermal models and experimental procedures to control any type of equipment is fundamental to obtain profit, productivity and quality of the products. Specifically, in charcoal kiln where some problems such as the production time forecast, the time of drying of the green wood and the procedures to control the homogeneity of the burn are fundamental and are of difficult execution. Usually, some important variables that control the process such as the opening and closing of the chimney, humidity of the wood and time of cooling of the charcoal are strongly dependent on the practical experience of the kiln operator. This project proposes the development of an electronic supervisory system to analyze, control and optimize the production. This equipment also minimizes the losses and increases the efficiency taking in account the experience of the kiln operator and the production history. The objective is to reduce, significantly, the dependence on subjective aspects which are related to the charcoal production minimizing the drying, pyrolysis and cooling time. This system also intends to improve the burn of the charcoal with a consequent increase in the quality and productivity, besides contribuing to minimize the emission of greenhouse effect gases. This study initially proposes the thermal instrumentation and analysis of rectangular kilns with an individual capacity to produce 20 tons of charcoal per coaling cycle. The objective is to measure the temperature with thermocouples located at various points inside of the kilns and to establish a relationship between temperature and quality charcoal. The thermal instrumentation previews the installation of 22 PT100 thermocouples in each kiln. These sensors will be connected to a motherboard which transmits the signals to a computer by an electronic circuit and a wireless net. The temperatures will be stored in a supervisory system which presents the measured data in form of graphs and tables. By internet registered users can also evaluate the temperature inside the kilns during the coaling as well as analyze previous cycles. Such information will guide and assist the kiln operator during all stages of the charcoal production. Statistical tools will also be applied to analyze the data obtained during the production of charcoal. Some researchers have used a similar methodology to evaluate the coaling cycle. Raad and Winter (2007) presents some experimental procedures to optimize the production of charcoal. The coaling process is controlled by measuring the temperatures inside de kiln and controlling the flux of gases. They also proposed to use the tar to accelerate the drying process of the green wood. Guimarães Neto (2005) evaluates a container type charcoal kiln from technical and economical points of view. The evaluation of the carbonization involves the mean heating rate, mean final temperature and mean time of carbonization. The author also presents a chemical analysis of the charcoal produced and an economical and financial indicator of the improvements in the production. Assis (2002) presents a study to test, evaluate and adjust an alternative system for wood carbonization in pilot scale including the construction and test of a prototype. Six thermocouples were installed to verify the thermal profile inside the kiln. A statistical method, based on regression, was used to study the relationship among average internal temperature of the system and the average temperature of the gases eliminated by the chimney. Based on the temperature, three models were adjusted: linear, cubic and logarithmic. From the results, the author identified that the cooling time of the charcoal could be reduced. According to Gomes e Oliveira (1980), the green wood when submitted to heat, in high temperatures, suffers a series of transformation in which all the components are exhaustively modified. Trugilho and Silva (1998) affirm that the carbonization of the wood involves, therefore, complex phenomenons that make possible the generation of a high number of compositions. It can be divided in four stages according to the temperature (Medeiros e Resende, 1983), (Oliveira et. al., 1982): a) below 200°C – drying of the green wood; b) 200°C to 280°C – endothermical reactions: releasing acetic acid, methanol, wather, CO_2 among others ; c) 280°C to 500°C – exothermical reactions: releasing combustible gases CO and CH_4, besides tar; d) above 500°C – release of small amounts of volatile gases in special H_2. In all of the stages presented previously, it is verified that the thermal analysis of the charcoal production process is essential because the final quality of the charcoal is linked to the temperatures developed during the production. Such facts justify the development of the thermal supervisory system proposed in this study.

2. THE INDUSTRIAL PROBLEM: PROPOSAL OF THERMAL INSTRUMENTATION

The objective of this study is to measure the temperature inside a typical charcoal kiln as shown in Fig. 1.

Figure 1. Typical masonry kiln

The thermal instrumentation previews the installation of 22 PT100 thermocouples in each kiln. These sensors will be connected to a motherboard which transmits the signals to a computer by an electronic circuit and a wireless net. The temperatures will be stored in a supervisory system which presents the measured data in form of graphs and tables. Fig. 2 shows the proposal of thermal instrumentation and the installation of the equipments.



a) b)

Figure 2. Thermal instrumentation: a) Proposal of the thermal instrumentation; b) Installation of the equipments.

The conception and assembly of the electronic system, in relationship to others already existent, were based on the following requirements:

- reduced costs in relationship to the other industrial systems;
- ease of installation;
- development of proper technology for future partnerships;
- updating possibility and incorporation of new functions and components in industry.

After a search about industrial systems already existents and others developed by companies and universities it was verified that the purchase of all components and accessories would increase very much the cost of the project. Hence, some components of the system were bought such as the thermal sensors (PT100), cables and electronic components, while others were developed such as the software, hardware, wireless data acquisition and backup system of energy.

3. COMPONENTS OF THE SYSTEM

3.1. Thermocouples

The characteristics required of the thermocouples installed in the kilns are: rugged design for use in industrial/open air environments. It must have heavy duty features such as metal jacketed wire and metal heads that provide resistance to mechanical shocks. Such conditions are indispensable for industrial equipment subjected to the weather and an eventual mechanical adjustment. Based on these experimental characteristics the thermocouple RTD (PT100 ohms) was chosen. This type of sensor has an aluminum head and a 304 stainless steel sheath. Fig. 3 shows a typical thermocouple and one fixed to the kiln subjected to the heavy duty conditions.

a) b) c)

Figure 3. Thermocouple RTD PT100. a) A typical PT100; b) Thermocouple fixed to kiln with mud; c) Rain water inside the thermocouple

Figure 3 shows that the thermocouples have to endure the industrial conditions and the environment. Fig. 3b presents a sensor fixed to the kiln. In this case, the PT100 is positioned in the oven through a hole in the wall. Mud is packed in the space between the sensor and the hole to avoid the entrance of air in the kiln. During the coaling cycle it is common to appear tar upon the thermocouples, especially those close to the chimney. Fig. 3c shows that the head of the PT100 should be sealed to avoid entrance of dust and rain water. In this figure it is also possible to see the electronic circuit inside the head of the thermocouple. In this study the sensors and the electronic system were previously calibrated for a range of temperature between 50°C to 500°C using a hot point cell.

3.2. Acquisition system

Basically, the acquisition system is composed by a motherboard that sends a digital signal to the electronic circuit in the head of the PT100 (Fig. 3c) for the value of the resistance. The value is recorded in a flash memory card and sent to a PC by a wireless net. A software is used to convert the data to temperature based on the calibration process. The conception and development of the system is based on the following principles: recording of the temperature and real-time data recorder in digital format. In this case the user can download data from the flash memory card by the wireless net. The system uses a standard power supply and a rechargeable battery that can function up to 12 days, preserving data and settings in the event of a power loss. In this case the data is stored in the flash memory for subsequent viewing or transferring. Fig. 4 shows the installation and the components of the acquisition system.


a)


b)

Figure 4. Acquisition system. a) Installation and configuration; b) Motherboard and components of the system

The complete acquisition system has a tree type structure as shown in Fig. 5.

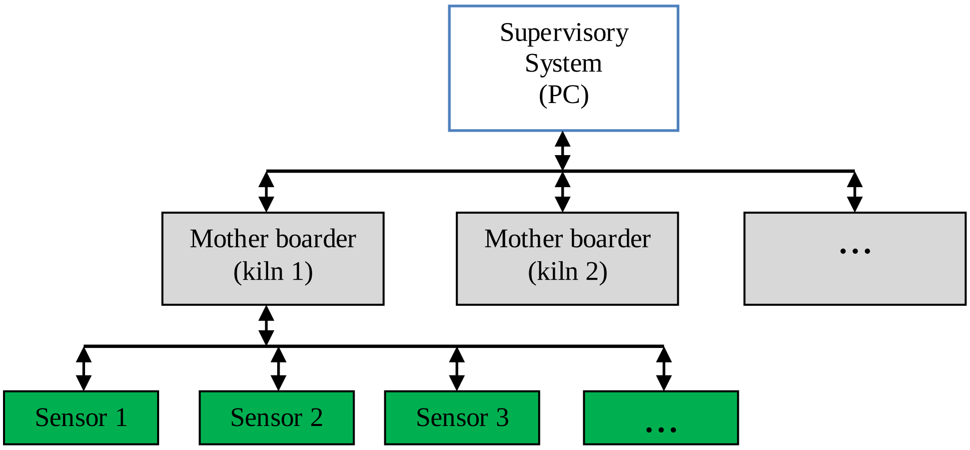


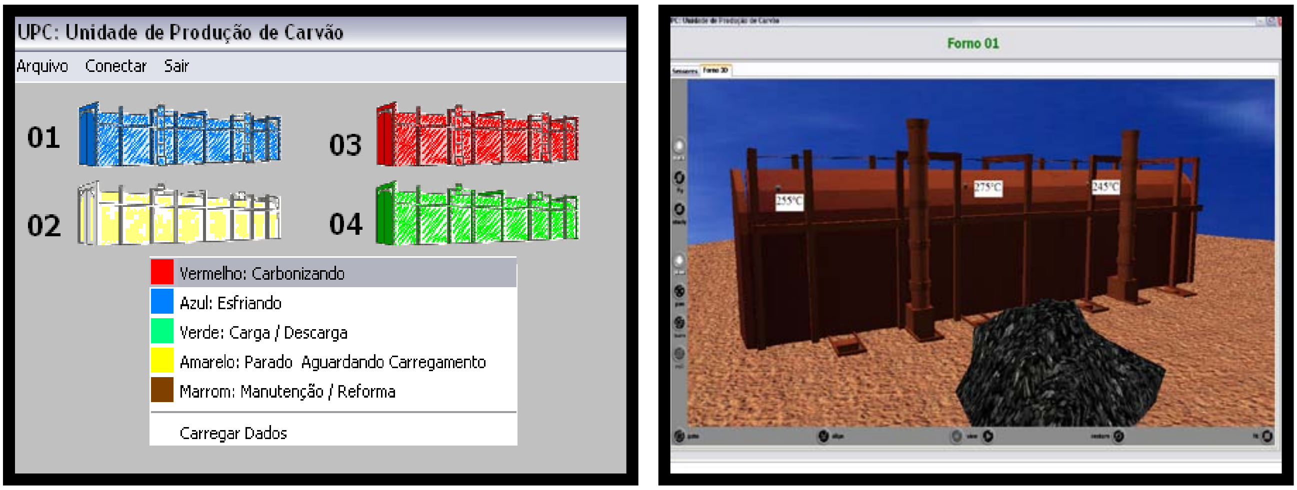
Figure 5. Tree type structure of the acquisition system

The supervisory system sends a request for temperature acquisition to the motherboard of a kiln: this procedure is based on the number of the kiln and the code of the operation to be executed. Recognizing this information, the kiln begins the acquisition of the temperatures. In this case the data bus is turned on, after a period of time, the motherboard begins to address each of the sensors and the values of temperature are obtained individually. Each thermocouple has an interval to reply, otherwise an error value is sent to the motherboard. After receiving all the values of the sensors, the motherboard records the data in the flash memory and sends a reply to the supervisory system with all the acquired values, including those that presented errors. Once received, the temperature signals are treated and the values are recorded in the database.

In this case, all of the sensors positioned in a kiln are connected by cable to the motherboard which sends the data to the supervisory system by a wireless connection. The database is recorded in the flash memory installed in each motherboard and in the supervisory system according to the following sequence: date, time and temperature of each sensor.

3.3. Software

The software has the following functions: communication, administration of the database, graphic visualization and thermal and statistical analysis of the production. As shown in Fig. 6a it has to work continually because it is responsible for the transmission of data between the server and the kilns. Backup copies of the data are created in intervals of time.



a) b)

Figure 6. Developed software: a) Continuous analysis of the kilns; b) Temperature at specific points of a kiln

The program also sends the data to a WEB server to be accessed at anytime and anywhere by the company. The user can visualize the temperatures inside the kilns during the production period in form of graphs (Figure 6b and 7b) or analyze the report of temperature in previous periods as shown in Fig. 7a.

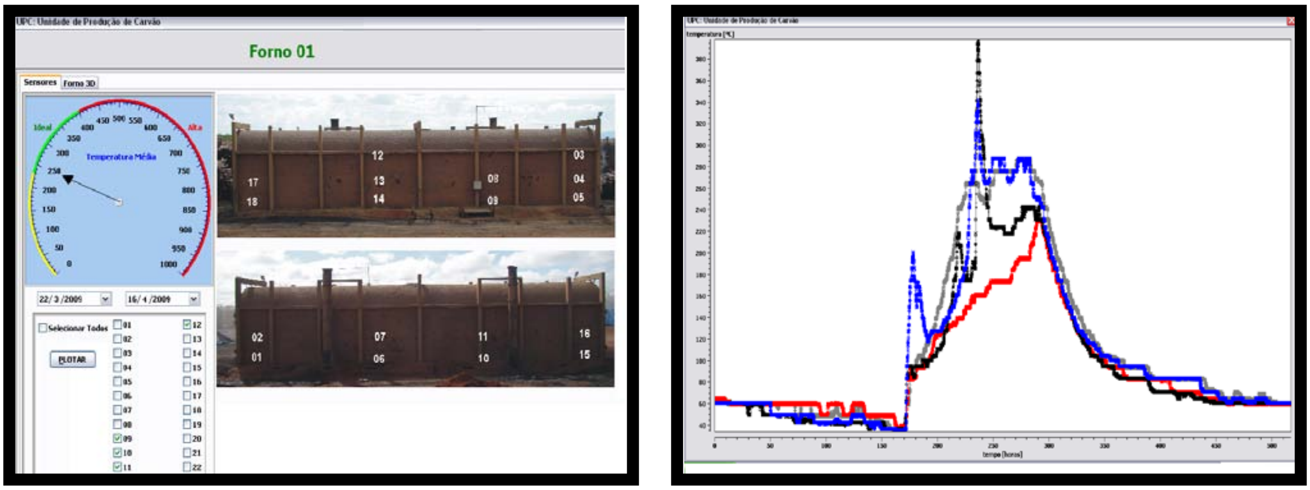


Figure 7. Thermal analysis: a) Choice of period of analysis and thermal sensors; b) Temperature versus time inside the kiln

Based on the temperatures, using the practical experience of the kiln operator and statistical analysis of the production process, the idea is to improve the software so that in the future it can assist, control and optimize the charcoal production. In this case, problems such as the carbonizing and cooling time forecast, the homogeneity of the burn, timing of opening and closing the chimney which are fundamental and difficult control will be solved by the use of the supervisory system, which will guide the kiln operator during all stages of the charcoal production.

4. ANALYSIS OF THE THERMAL FIELDS INSIDE A CHARCOAL KILN

After the presentation of the supervisory system, a coaling cycle will be analyzed and in this case, some interventions in the kiln were accomplished based on the evaluation of the thermal fields. In the production process logs of wood with 3 meters length and 10cm to 20cm diameter, dried naturally in an approximate period of six to eight months were used. The logs were from clone seedling of *Eucalyptus urophylla*. The logs are positioned inside of the kiln horizontally in form of "wood pillows" due to operational conditions and to allow the flux of hot gases between the logs. The average volume of logs inside a kiln is approximately 125m³. Fig. 8 shows the location of the thermocouples in the analyzed kiln. The sensors 03, 08, 13 and 18 located in the roof of kiln were turned off during this test.

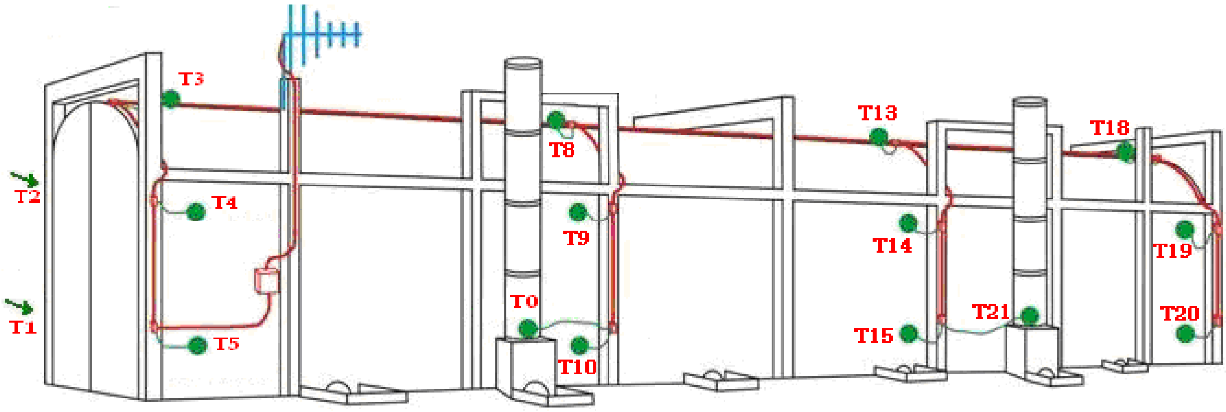


Figure 8. Location of the thermocouples in the kiln

Figure 9 shows the temperatures measured in region 1 close to the left door of the kiln according to Fig. 8. It can be seen that the difference between the temperature measured by sensors located at the top of the kiln (02 and 04) and those located at the bottom (01 and 05), during the pyrolysis process, is about 50°C. The sensors 02 and 01 are on the rear wall of the kiln. However in the cooling process (after 140 h) the temperatures tend quickly to be similar.

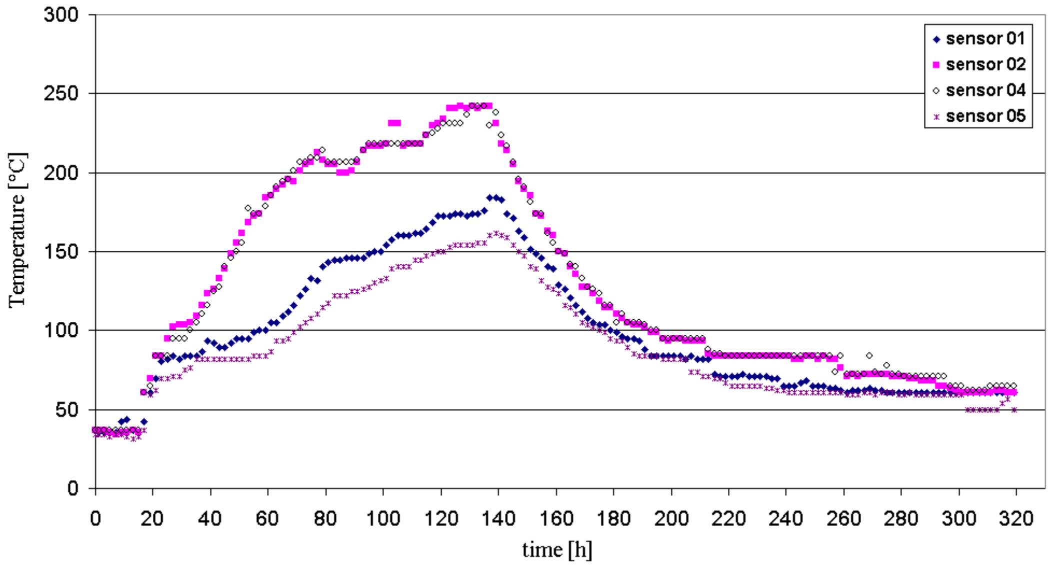


Figure 9. Temperatures in region 1 close to the left door of the kiln

Figure 10 shows the region 2, composed by the thermocouples 06, 07, 09 and 10. The sensors 06 and 07 are on the rear wall of the kiln. It can be observed that the temperatures are greater than those near the left door. The temperature at the top of the kiln reaches 280 °C and the difference between the top and the bottom is greater than 100 °C. According to Assis (2007) the correct temperature inside the kiln during carbonization is from 250°C to 350°C. In this range of temperature, it is possible to produce charcoal with fixed carbon about 65% to 75%, as required by the Brazilian industries (Jacomino et al., 2002). Regions of the kiln with temperature below to 250°C presents a great amount of brands (large pieces of partly charred wood, not usable as fuel) are observed close to the doors and at the bottom regions of the kiln as shown in Figs. 9 and 10.

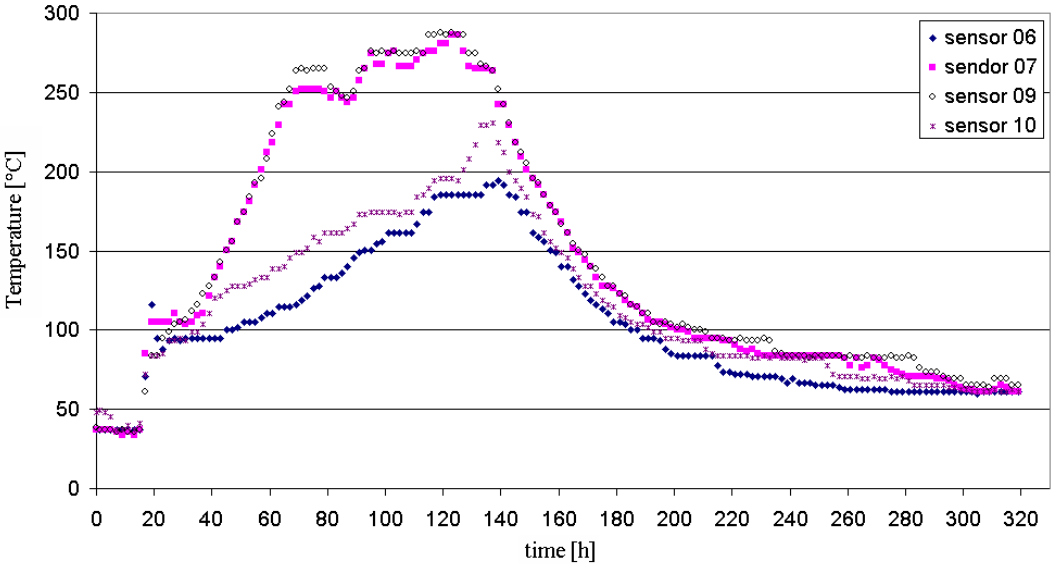


Figure 10. Temperatures in region 2 close to the center of the kiln

During the whole production period region 3 was the only one to present some irregularities in the temperature. Fig. 11 shows that the temperatures measured by the sensors 11 and 12, located at the rear wall of the kiln, reached high values after three day of carbonization. In this case, due to the analysis of the temperatures, the kiln operator went to the kiln to check the irregularities. Some holes in the wall were verified, besides the mud was not fixed appropriately. After correction of the problem, sensor 11 changed behavior, becoming similar to the values of sensor 15, located symmetrically in the bottom of the kiln. The same was verified in the temperatures measured by sensor 12 which became similar to sensor 14.

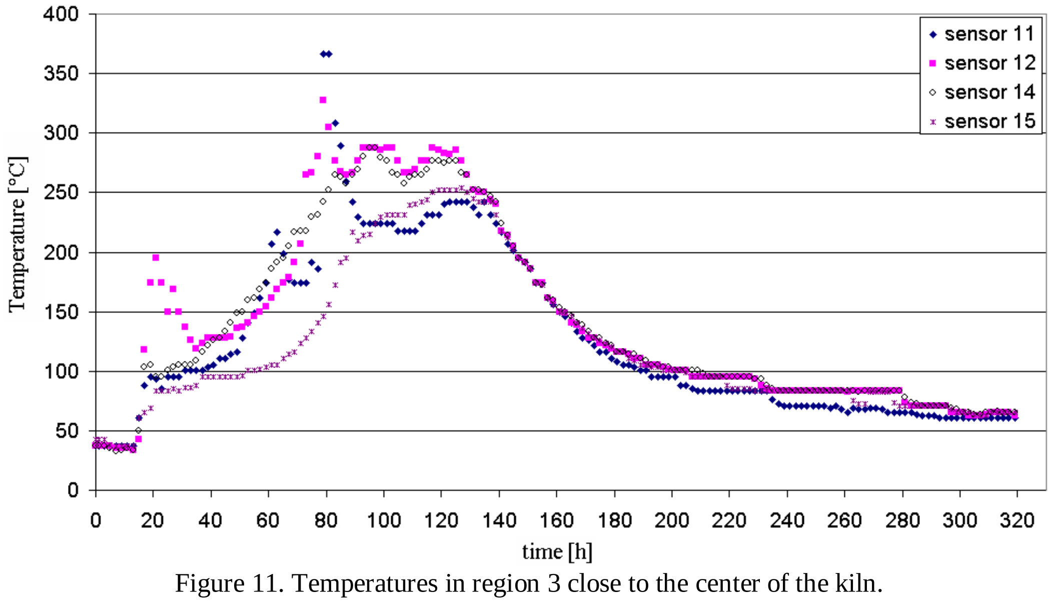


Figure 11. Temperatures in region 3 close to the center of the kiln.

Figure 12 shows the temperatures in region 4 close to the right door of the kiln, where the sensors 16, 17, 19 and 20 are located. In this case, the temperatures are similar to those shown in Fig. 9 close to the left door. As foreseen, the sensors 17 and 19, located at the top of the kiln, presented temperatures higher than those measured by the sensors 16 and 20, located at the bottom. Besides the average temperature in this region is lower than those in region 2 and 3, which confirms that these regions as the coldest of the kiln. In spite of the doors being made with refractory materials, they also contain steel, which contribute to the dissipation of heat. Because of this it is very common to obtain brands in the region as shown in Fig. 13.

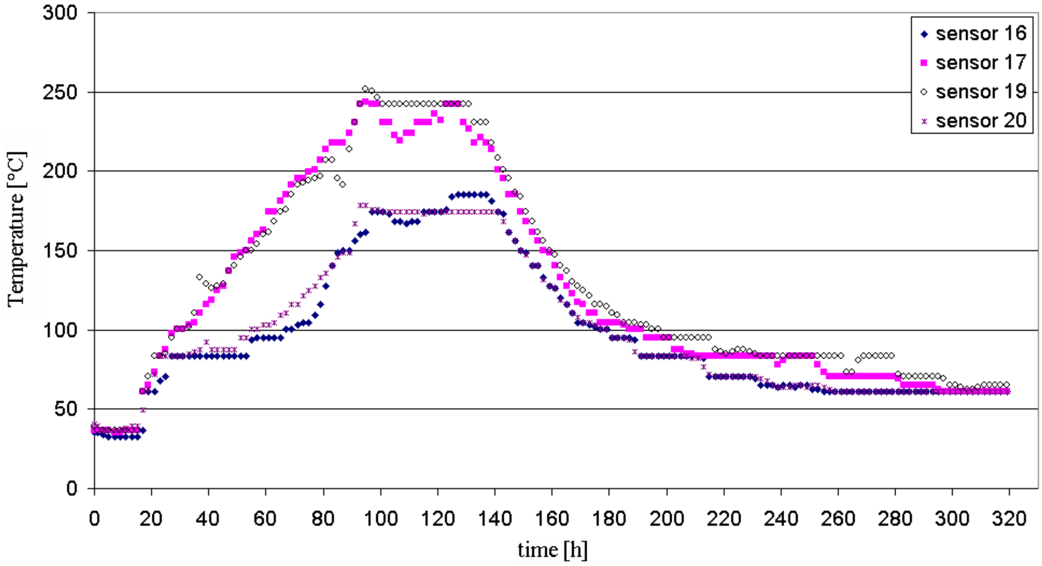


Figure 12. Temperatures in region 4 close to the right door of the kiln

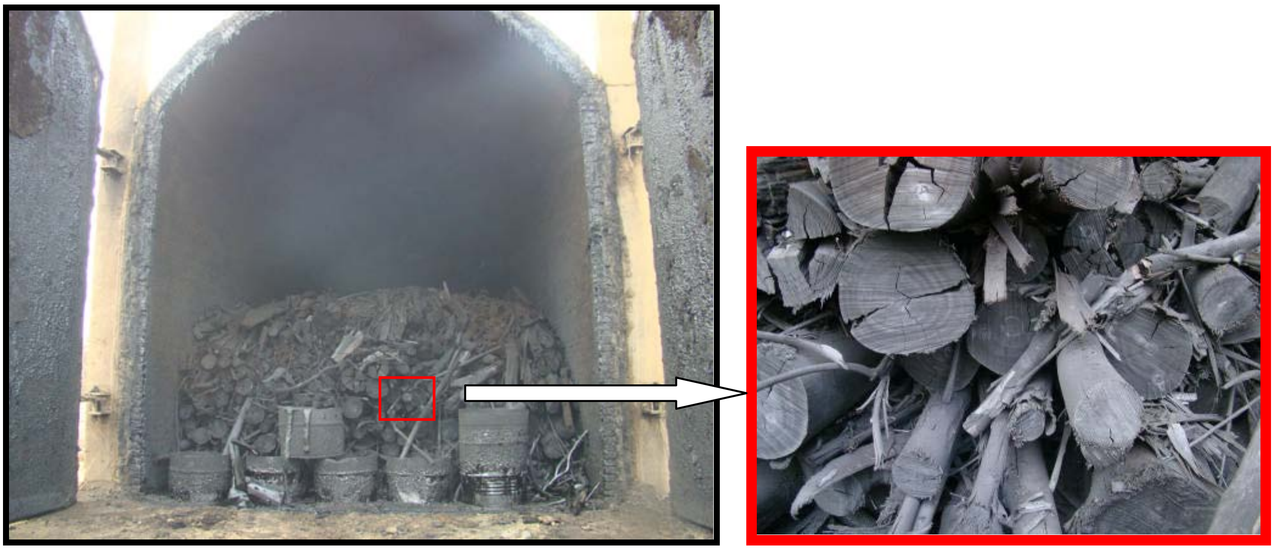


Figure 13. Brands in the region close to the door.

Finally it is important to present the temperatures measured in the chimneys of the kiln as shown in Fig. 14.

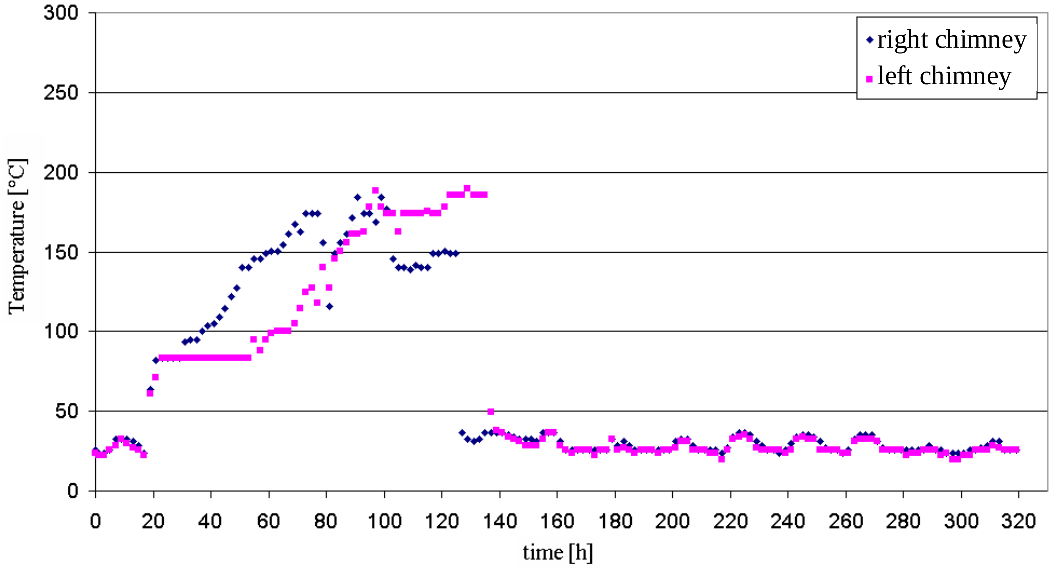


Figure 14. Temperatures measured in the chimneys

Analyzing the temperatures in the chimneys it is possible to identify clearly the transition from pyrolysis (20h to ~130h) to the cooling process (after 130h). Fig. 14 also shows that the chimneys were not closed simultaneously. It is possible to observe a difference of 10 hours between closing of the chimneys. In fact, it happened because the production was not yet controlled by the supervisory system. It is based on the practical experience of the kiln operator. In this case, the chimneys are closed only when the temperatures at the left and the right door of the kiln, measured one meter from the ground with an infrared sensor, reach 180°C. However, it can be observed that the first chimney to be closed was the one positioned on the right side of the kiln, close to region 3, where the higher temperatures were observed (Fig. 11) during the production process. In this case, the use of a supervisory system could help the kiln operator to take the correct decisions to optimize the production process. In fact the next objective of this study is to improve the supervisory system, to guide and assist the carbonizing agent during the whole stages of the charcoal production.

5. CONCLUSIONS

This study presents the thermal instrumentation of rectangular kilns with an individual capacity to produce 20 tons of charcoal per coaling cycle. The objective is to measure the temperature with thermocouples located in various points inside the kilns and establish a relationship between temperature and charcoal quality. An electronic supervisory system was developed to analyze, control and optimize the charcoal production. The objective is to minimize the drying, pyrolysis and cooling time and hence increase the efficiency of the charcoal kilns. This system also intends to improve the burn of the charcoal with a consequent increase in the quality and productivity, besides contributing to minimize the emission of greenhouse effect gases. A practical coaling cycle was also analyzed. Although the assembly and installation of the supervisory system is not totally concluded, the temperature measurements during the cycle helped the kiln operator to identify some irregularities during the production and to correct them in time. The next objective of this work is conclude the assembly of the supervisory system, to guide and assist the carbonizing agent during the whole stages of the charcoal production.

6. ACKNOWLEDGEMENTS

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