ANALYSIS OF THE THERMAL PROFILES AND THE CHARCOAL GRAVIMETRIC YIELD IN THREE VARIATIONS OF RETANGULAR BRICK KILNS

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Abstract: *Charcoal assumes a major role in Brazilian economic scenario. The procedure for obtaining charcoal consists in carbonization of wood at certain specific temperatures in kilns. This ancient process has a few joined technologies and the kilns for such practice do not have any control instruments, in their great majority, becoming dependent on the ability of its operators. However, in recent decades several studies have been developed to improve the practice as well as the equipments that involve and control the stages of charcoal production. In this sense, this work proposes the analysis of the thermal profiles and the gravimetric yield in three variations of a rectangular brick kiln called RAC220: traditional (without any type of instrumentation), instrumented with thermal sensors (RTD PT100) and adapted with gasifier. The goal is to correlate temperature, gravimetric yield and quality of the produced charcoal. Immediate analyses were performed to determine the amount of fixed carbon, volatile gases and ashes contents in charcoal. Through such measurement procedures, together with statistical analysis, the aim is to identify an important tool to reduce the time of charcoal production and also contributes to minimize losses and to increase the thermal efficiency of the production process.*

Keywords: *thermal profile, temperature supervisory system, gravimetric yield, charcoal production.*

1. INTRODUCTION

The process of charcoal production in most companies is the same as three thousand years ago, which consumes part of the wood as fuel to provide energy for the rest of charring wood. Most modern processes utilize other fuels, often from the very process of carbonization, "Mulina et al (2009).

Small producers of charcoal kilns typically use built masonry coated with mud. These kilns are usually made in banks or land and do not have standardized formats. Their shapes and sizes differ from one to another, causing the process to be very irregular, which is dependent either directly to their operators. Usually these stoves do not have any kind of mechanization and either measuring instruments of the important variables of the process, harming both yield the final product quality, "Oliveira et al (2009)".

But most of the large scale industries of charcoal production use masonry kilns of various sizes, according to the production needs. Currently most of the masonry kilns have rectangular form, where the process can be mechanized. But the process is still being done in primitive form, so early that in most of cases the kilns usually do not have any kind of instrumentation.

The difference between large and small charcoal producers is that the process of wood carbonization in the case of the large producers is standardized (practices and wood to be proceeded). However, the utilized kilns have higher capacity, making a process difficult to control.

Currently, in these industries, the calculated yield is obtained by estimating the volume of the wood to be proceeded with the volume of the charcoal removed from the kiln. This calculation of production becomes a measure not reliable because the amount of the wood to be proceeded is directly related to subjective factors, such as experience of operators and positioning of the wood in the kiln, "Oliveira (2009)". For the more accurate calculation of production it is necessary to use the calculation of the gravimetric yield, which dependents on the wood mass and charcoal mass.

Ameloti (2010) and Mulina et al (2010) shown the development of thermal models and experimental procedures for controlling any type of equipment are fundamental for having a profit, productivity and product quality. Specifically in charcoal kilns, where some problems, such as forecasts of production time, time of the green wood drying and procedures to control the homogeneity of carbonization are fundamental and difficult to execute.

Usually, some important variables that control the process, such as opening and closing of the chimney, wood moisture content and cooling time of charcoal is highly dependent on practical experience of the workers. Thus a system of equipment was developed to instrument and optimize the charcoal production in rectangular masonry kilns. In his view, the thermal instrumentation must act in at least three aspects: increase thermal efficiency of the kiln, allowing an increase in productivity and quality of charcoal; reducing in the cycle time of carbonization of the charcoal; and, moreover, it is intended to reduce significantly the dependence from the subjective aspects that are related to the charcoal production, such as the process experience of operators.

Initially, this study proposes the instrumentation and analysis of thermal cycles of charcoal production in rectangular masonry kilns. The goal is to measure the temperature with pt100 temperature sensors located at various points within the kilns and establish a relationship between temperature and the charcoal quality. The instrumentation provides thermal installation of 22 pt100 sensors in each kiln. These sensors will be connected to a motherboard that transmits signals to a computer via an electronic circuit and a wireless network. Temperatures will be stored in a database and a supervisory system will present the data in graphs and thermal profiles. Such information will guide and help the operators during all phases of charcoal production.

Some researchers used a similar methodology to estimate the cooling cycle. “Raad and Winter (2007)” presented some experimental procedures to improve charcoal production. The cooling process is controlled by measuring the temperature within the kiln and by observing the flow of gases from chimneys. They also proposed using fuel to hasten the drying of green wood. “Guimarães Neto (2005)” evaluates economic points of a container type charcoal kiln. The assessment involves carbonization of the average rate of heating, mean final temperature and the mean time of carbonization. The author also gives a chemical analysis of charcoal and economic and financial indicators of improvements in production.

Already “Assis (2002) presents” a study for testing, evaluating and adjusting an alternative system of wood carbonization in pilot scale, including prototype building and testing. Six thermocouples were installed to check the thermal profile within the kiln. A statistical method based on regression was used to study the relationship between mean temperature inside the system and the mean temperature of the gases eliminated by chimney. Thus, based on temperatures, were adjusted three models: linear, cubic and logarithmic. With the results, the authors identified that the cooling time of charcoal can be reduced.

“According to Gomes and Oliveira (1980)”, the wood when subjected to high temperatures, suffers a range of transformations in which various components are modified. “Trugilho and Silva (1998) affirm that” the wood carbonization involves complex phenomena that make possible the generation of a high number of compositions. According to the temperature the process of wood carbonization can be divided in four phases “(Medeiros and Resende, 1983) and (Oliveira et al, 1982)”: below 200 ° C - drying of green wood, 200 ° C to 280 ° C - endothermic reactions: release of acetic acid, methanol, water, carbon dioxide among others, 280 ° C to 500 ° C - exothermic reactions: release of combustible gases like carbon monoxide and methane, and coal tar; above 500 ° C - release small amounts of volatile gases especially such as hydrogen. In all these presented phases, it is verified that the thermal analysis of the process is essential to the quality of charcoal. These facts justify the development of the supervisory system temperature proposed in this study.

2. METHOD

2.1. Kilns Description

In most industries that produce charcoal, masonry kilns are used for the carbonization practice. One of the kiln models analyzed in this work is constructed of brick masonry and has a rectangular geometry, related to the model RAC 220 (R = rectangular, AC = Acesita, 220 m³ capacity) with the following dimensions: 26 m x 4,0 m x 4,2 m. Its internal volume is approximately 440 m³. The kiln RAC 220 has, at its ends, steel doors coated with refractory materials, that aim to reduce heat losses. “Figure 1” represents the kiln in the study.

Figure 1. Rectangular masonry kiln: model RAC 220

The kilns have four combustion chambers with dimensions 25 cm x 25 cm, which are essential to initiate the carbonization process and also for the control of oxygen. The cameras are connected to four air inlets with diameters of 25 cm. Also, the RAC 220 has two fume channels, and each is connected to a chimney with dimensions of 50 cm in diameter.

Also, another type of kiln is analyzed in this study. This in its turn, also masonry, has the same shape and dimensions like the kiln model described above, but does not use combustion chambers, instead, was adapted by recirculators. For the initiation of research, it is important to ensure that all kilns involved in this study are under the same conditions of use, i.e. have the same structural conditions. Thinking about this, a preliminary assessment was realized, identifying and correcting structural flaws in all the kilns studied, such as cracks in walls and gas pipelines.

The kiln adapted with recirculators and gas burners is made of metal pipes, terminally isolated, that forme a recirculation of the gases in preferred directions, homogenizing the temperature at all points of the kiln during the drying stage and pyrolysis. This procedure aims to reduce the amount of brands (which has not turned to charcoal) and ash, and increase the quality and productivity of charcoal. “Figure 2” presents a suitable kiln RAC 220 with recirculation systems and gas burners.

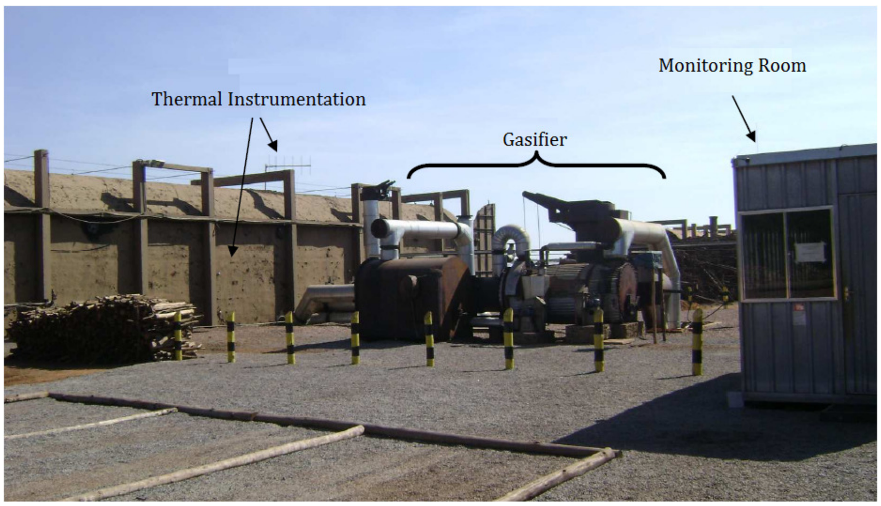

Figure 2. Arrangement of the gas inlet and outlet of the kiln RAC 220

On the pyrolysis phase, the resulting gases are burned, recycled and injected back into the process. For such adaptation to be functional, in another words, refill energy excess during the charcoal production, it is required for minimum two interconnected kilns.

2.2. Thermal Instrumentation

In this study four kilns model RAC 220 was analyzed from thermal point of view, two of them are conventional (use combustion chambers) and the other two are adapted with gas burners and recirculators. Thus, for a preview of the thermal profile 22 temperature sensors model pt100 were installed inside the each kiln to be studied during cycles of carbonization, distributed over them, as illustrated in “Fig. 3”.

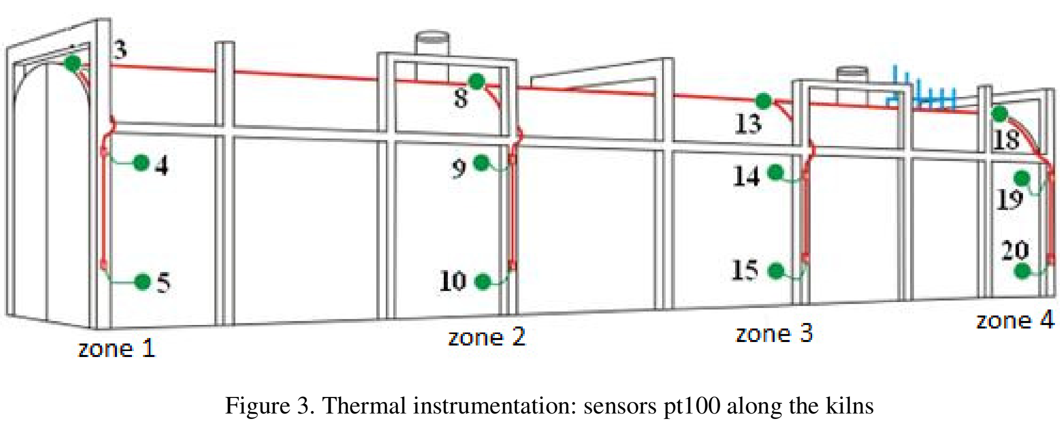

Figure 3. Thermal instrumentation: sensors pt100 along the kilns

These sensors are connected to a motherboard that sends signals to a computer through an electronic circuit and a wireless network. The temperature data is stored in a supervisory system that returns the data measured in the form of graphs, tables and by graphical views. All equipment, hardware and software used for obtaining and processing the data in this study were developed at the Faculty of Mechanical Engineering, Federal University of Uberlandia by the team of the Laboratory of Heat and Mass Transfer - LTCM.

The process of the wood carbonization, mostly is devoid from great technologies. Often the temperature control of the carbonization process is carried out only by instruments of precision and little empirical observations of the operators in the outer regions of the kiln "(Oliveira, 2009)". The carbonization temperature is another important parameter in the production process. "According to Briane and Doat (1985)" the higher is the carbonization temperature the greater is the amount of fixed carbon in charcoal and lower is the gravimetric yield of the process.

Thus the supervisory system developed and installed in the kilns will lead to a higher accuracy of the temperature in process. From information about the temperatures, the development of a database on production, the experience of operators, it is expected that in future, can perform a statistical analysis of data in order to define optimized production procedures. Such information will be put into the software so that it can improve production and guide the operator during the entire cycle of charcoal production.

2.3. Description of Wood and Operational Procedures

This study aims to assess parameters that are directly dependent on wood inserted in the kilns. Therefore, as the previous structural assessment of the kilns, also the wood used in the carbonization process should be standardized. "Petroff and Doat (1978) showed that" the chemical composition of wood influences the yield of the charcoal production. "Subsequently, Brito and Barrichello (1981) did a study" with different types of wood from the Amazon region and also concluded that wood density directly influences the yield of charcoal.

Some companies producing charcoal try to mix up the mean diameter of logs to be proceeded in order to reduce brands and grimes (ash), in addition, to standardize the final product quality "(Oliveira, 2009)". Thus, all studied cycles of carbonization used processed wood in logs with 3 meters in length and 10 cm to 20 cm in diameter. The woods are made from cloned seedlings of Eucalyptus urophylla. Logs with diameters larger than 20 cm generally are not recommended because it produces charcoal with low grain size. Already logs with diameters smaller than 10 cm, disrupt logistics and increase the filling time of the kilns and consequently increase production costs "(Carneiro, 2007)". In this work, for all cases, the logs used were classified as coarse wood (above 10 cm).

Inside the oven, due to operational conditions, the logs were positioned horizontally and for allowing the hot gases flow, these are supported on "pillows wood." The average volume of timber placed inside the kiln is approximately 125 m³; however, this value can vary depending on the ability to manipulate the agented operators. In determining the gravimetric yield of production before the wood is processed, it is necessary to harvest the wood discs for making a moisture analysis. So discs were collected "as described by Oliveira (2009)" and sent to the LTCM where all moisture tests were performed. According to the data obtained by the laboratory, it was seeing that the wood has been preceded at the mean moisture percentage equal 30%.

After collecting the wood discs, the wood is processed as described above. Furthermore, after completion of the cycles of carbonization, the quantity of brands and the charcoal produced in each cycle were weighed. These values allowed to establish the gravimetric yield of each cycle, which is defined as the ratio between the amount of charcoal produced and the amount of wood put into the kiln on a dry basis. And finally, after the opening of kilns, charcoal samples were collected according to NBR 6923 and also sent to LTCM, where tests were performed immediately according to NBR 8112.

3. RESULTS

For this work, the collection and organization of data was made in the three ways of charcoal producing in masonry kilns. The first considered method was the conventional method of charcoal production in kilns RAC 220 (using optical sensors and the experience of operators), the second was as same as the first, but now using the pt100 sensors and tools in supervisory system, and lastly the technology of kilns and burners adapted with gas recirculators was analyzed. Thus, nine cycles were studied, accounting for three cycles for each production methodology.

Initially the time of wood carbonization was monitored inside the kilns, in sequence their cooling time was identified and, eventually, the total production time of each cycle was defined. Together with the values of weight and moisture content defined in the laboratory, the percentage of gravimetric yield on dry basis was obtained (% RGS) by Eq (1):

$$\%RGS = \frac{mass\ of\ charcoal\ produced}{mass\ of\ wood\ put\ into\ the\ kiln} \times 100 \quad (1)$$

"Figure 4" presents an analysis of production time in according with each methodology.

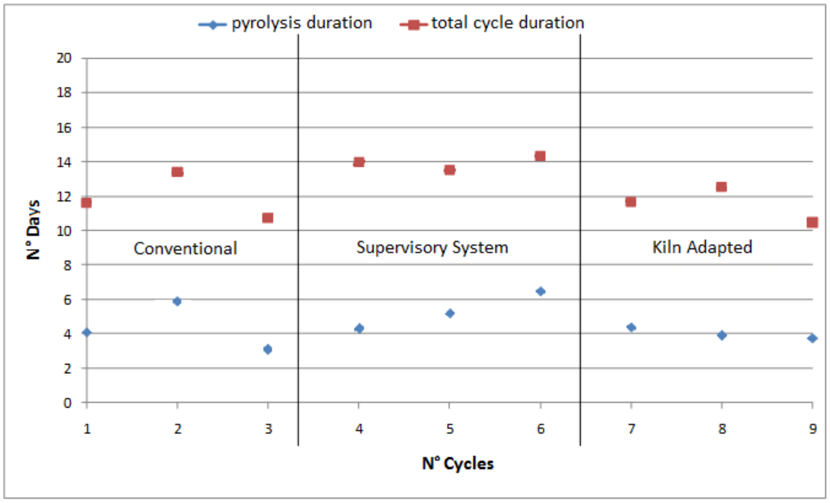

Figure 4. Analysis of time production due to each production methodology

"Figure 4" shows that the carbonization time in adapted kilns is more homogeneous due to the inside forced injection of hot gases. From such practice it is possible to standardize the time of carbonization as the amount of moisture, type and diameter of the logs. It is sufficiently for the operator to control the flow of generated gases in the chamber of gas burner. Already in the conventional methodology, and in methodology aided by the supervisory system, carbonization occurs from the brands burning in underground chambers. The hot gases slowly enter the kiln due to the natural recirculations. In this case, the control of gas flow is realized by the operator through the opening or closing the combustion chambers.

Another important feature of the adapted kilns is to the absence of air (oxygen-free atmosphere) during the phase of wood pyrolysis. In this case the transition from the wood to the charcoal occurs without burning its own wood to supply the energy to the process. All the energy required in this process is coming from a gasificator, located outside the kiln. Since there is no flame in the kiln because of the induced gas that form a positive pressure inside, preventing the entry of oxygen, the cooling time is sharply reduced. Already in the other kilns, pyrolysis occurs in the air presence (oxygen atmosphere) which provides fires in some regions inside the kiln.

To start the cooling process, the kilns are sealed to prevent any entry of air. However, due to the fires, charcoal takes longer to cool, what provides a significant increase in production time and consequently the reduction of corporate earnings and charcoal producing.

"Figure 5" presents an analysis of the percentage of ash and volatile materials due to the each production methodology. The results are compared to ideal values, as defined by national black metallurgy "(Oliveira, 2009)".

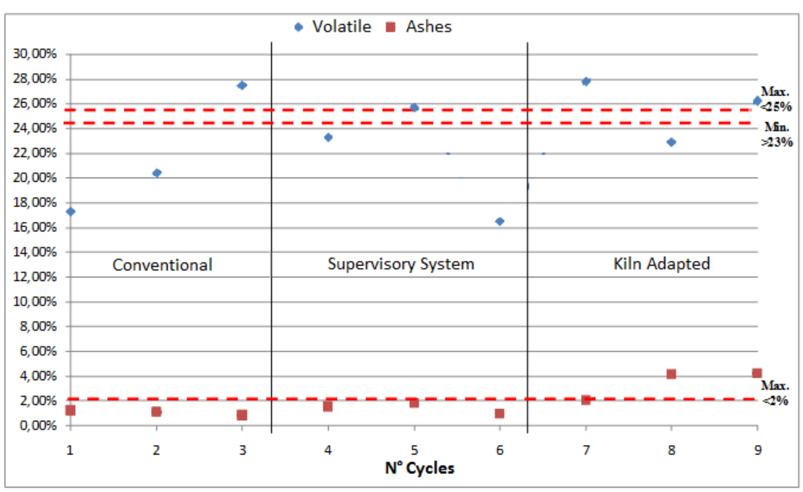

Figure 5. Analysis of the percentage of ash and volatile materials due to each production methodology

In this figure, it is verified that in the Conventional Kiln and Kiln with the Supervisory System, the percentage of ash is consistent with the pattern set by the national black metallurgy, in another words, the presented values are less than 2%. Already in Adapted Kilns the ash content increases considerably. It is believed, in this case, that the increase of ash content is related to the high temperatures of gases from the chamber gas burner, since there was no monitoring and controlling the temperature inside the kiln. So no one knows for sure how much the temperature can influence the percentage of ash of charcoal. However, it is believed that the ash content may be related to other factors such as the structure and species of wood, the type of fertilizer used in the planting of trees and others.

With regard to the percentage of volatile materials, no methodology could provide values within the range defined by the national metallurgy. However, among the methodologies presented, the kilns had a lower adjusted oscillation in relation to the full standard set.

Another analysis performed here, and certainly the most important for companies producing charcoal and the steel industry, refers to the percentage of fixed carbon and gravimetric yield of the kilns. The amount of fixed carbon in charcoal has a strong influence on the production of steel, so that some steel mills define what this value should be above 70% "(Oliveira, 2009)". The gravimetric income relates the amount of the produced charcoal and the quantity of wood to be proceeded (for wet or dry basis). Obviously, the higher is the income, higher is the output and higher is the Company profit. "Figure 6" presents a comparison of the values of fixed carbon and gravimetric yield between the methods studied.

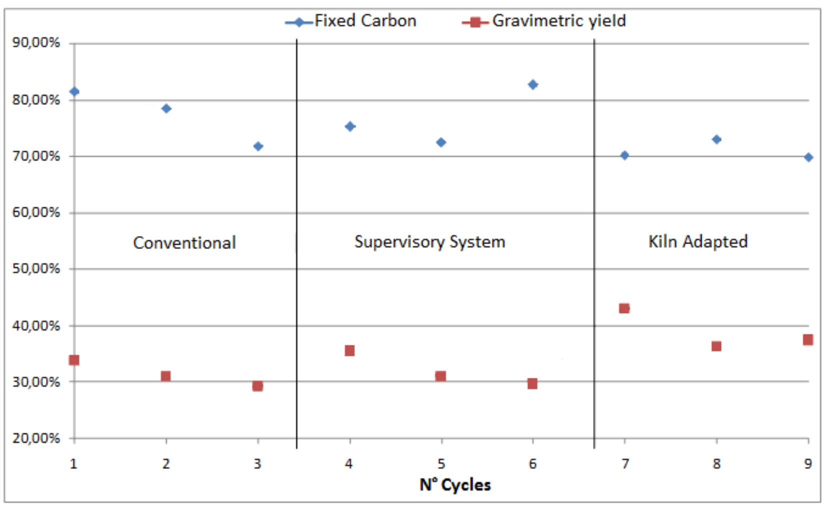

Figure 6. Fixed carbon x Gravimetric yield

In "Figure 6" it is noticed that, in terms of gravimetric yield, results in kilns are the best. Therefore, for fixed carbon, it appears that the higher content of fixed carbon was identified in the kiln aided by supervisory system.

Importantly, as "shown by Briane and Doat (1985) and Mezerette and Vergnet (1994)", the fixed carbon content is inversely proportional to the gravimetric yield. Such behavior can be identified in almost all cycles shown in "Fig. 6" However, the literature analysis is based on the carbonization temperature. Thus, this work was chosen to relate the final temperature of carbonization with the average percentage of fixed carbon and gravimetric yield, taking as an example the cycles of the kilns with the Supervisory System. "Figure 7" presents the results for each cycle and "Fig. 8" shows the relationship "identified by Briane and Doat (1985)".

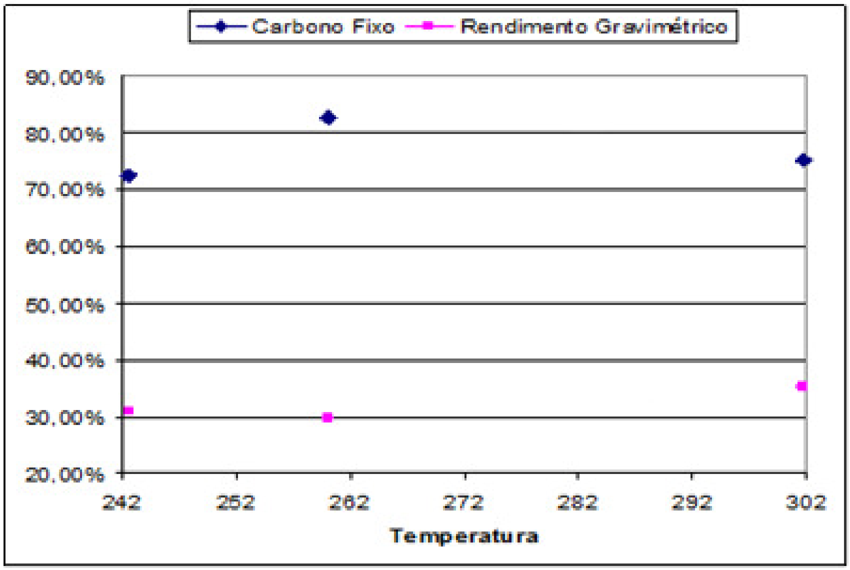

Figure 7. Relationship between temperature, percentage of fixed carbon and gravimetric yield in the conventional methodology and aided by the use of supervisory system

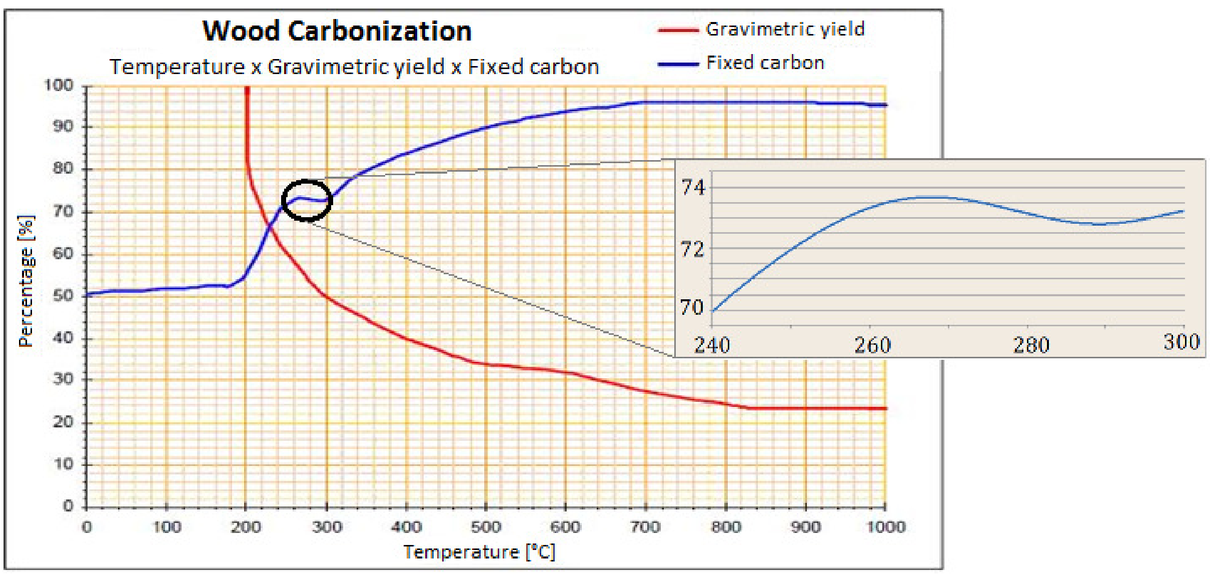

Figure 8. Relationship between temperature, percentage of fixed carbon and gravimetric yield

Transverse plane of the kiln - dashed line of the Fig (9) is defined according to the width and height of the kilns RAC220 - shows the thermal profiles for each production methodology. To obtain the temperature in the transverse plane, firstly, it was defined a grid along the plane and with a graphic rendering software the temperatures were established.

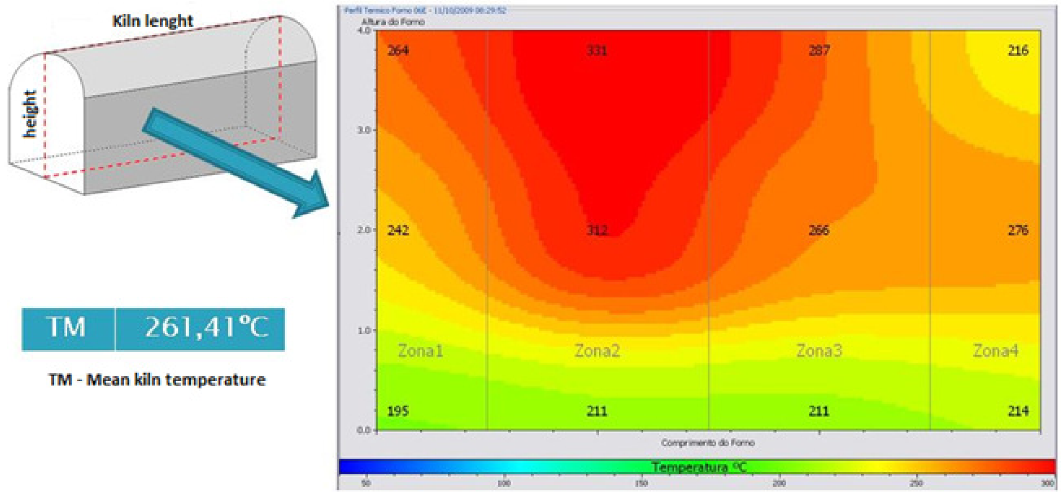

Figure 9. Thermal profile of the final stage of carbonization in the Conventional Kiln

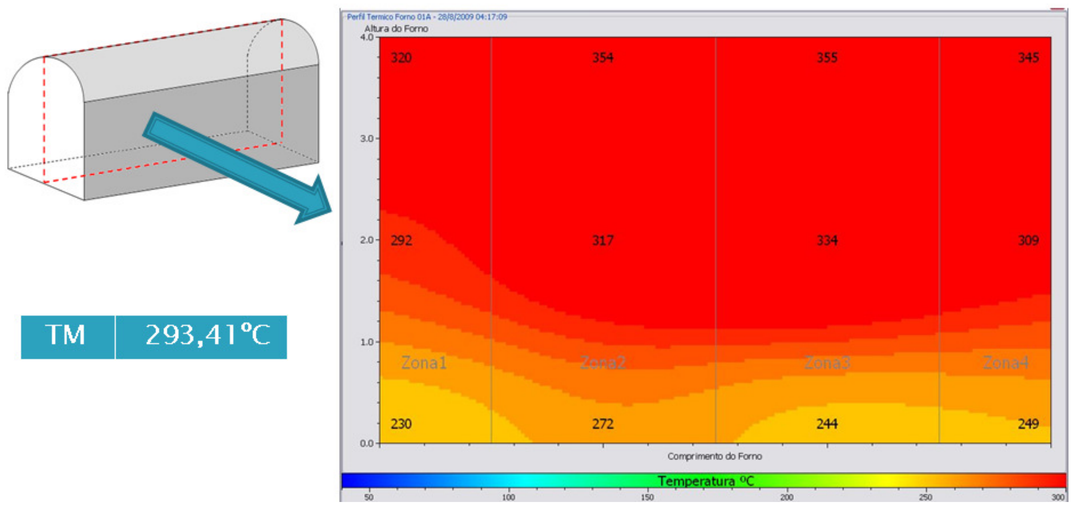

Figure 10. Thermal profile of the final stage of carbonization in the Kiln Aided by the Supervisory System - temperature controlled

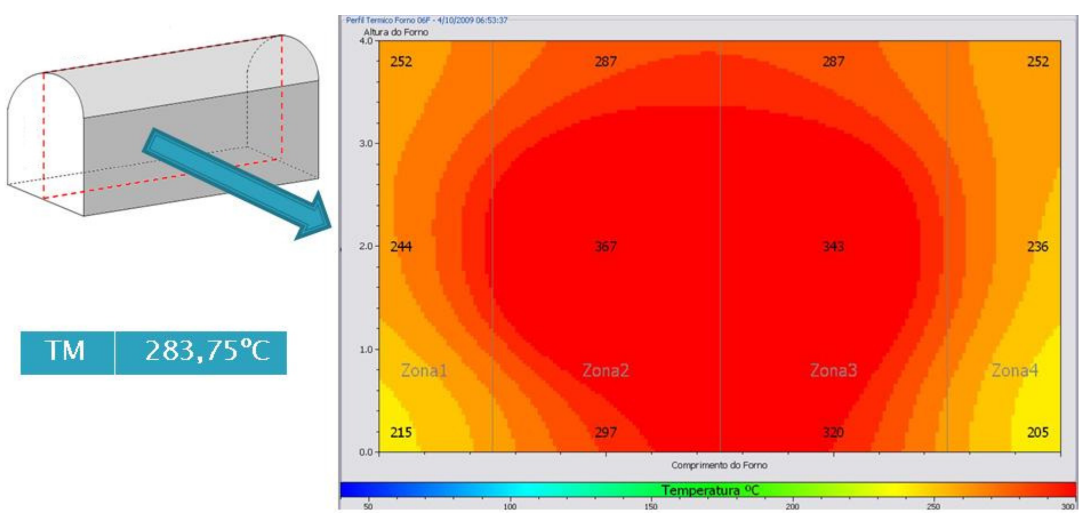

Figure 11. Thermal profile of the final stage of carbonization in the Adapted Kiln

Analyzing the "Fig. 9 – 11", it appears that in the Conventional Kiln there is a large temperature difference between zones of carbonization, which leads to the production of charcoal with different qualities in each zone of the kiln. Moreover, due to low temperatures close to the doors, there is the formation of brands in these regions. This cycle still has the lowest average final temperature of carbonization.

In the methodology which was interposed using the supervisory system, "Fig. 10", there is a higher final average temperature of carbonization. Also striking in the uniformity of temperature in this cycle compared to the others. In the case of the Kiln Aided by Supervisory System, from hardware and specific software, monitors the temperature in real-time production and the flaws were corrected during the carbonization cycle itself.

It is noteworthy that for the Adapted Conventional Oven, there were only monitoring of the temperatures, i.e. that no interventions were made in cycles based on the measured temperatures. The objective was to map the heat inside the kilns and compare the obtained results from each method of production.

In the Adapted Kiln it is clear that there is the difference in temperature between the zones of the kiln. Again, it is possible to identify low temperatures in the regions of the doors. An interesting fact is that in the Adapted Kiln even with recirculated air, it was impossible to homogenize the temperature throughout the kiln, with low temperatures in the region of the doors, showing a failure of isolation in this region. This may explain the high concentration of brands in this region as shown in "Fig. 12".

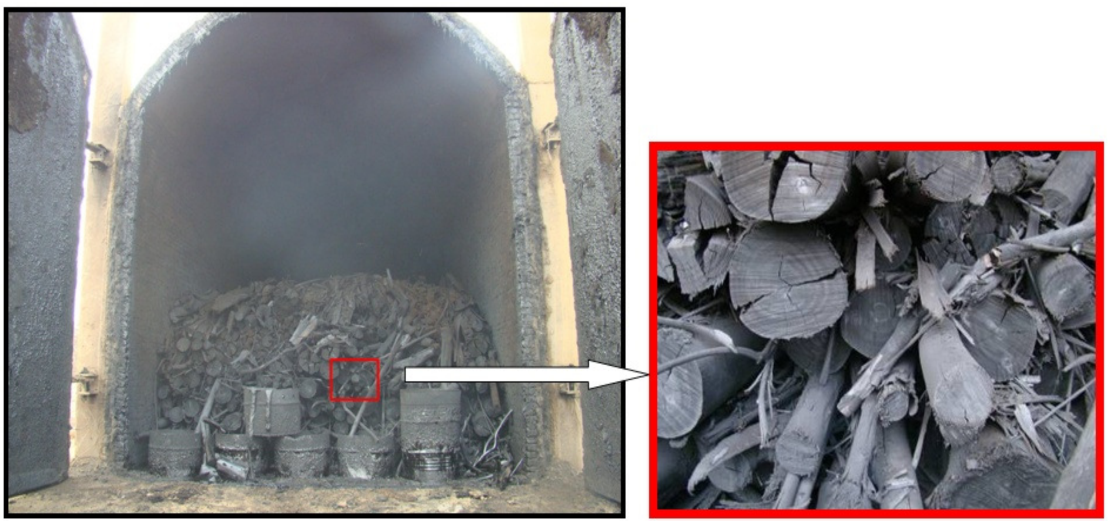

Figure 12. Formation of large quantities of brands in the region of the gates

The study covered by this work, was held amid the global economic crisis of 2008 and prevented from having segment, so it was not possible to obtain more data needed for a statistical validation as well as The test plan (design of experiments) as well as uncertainties.

4. CONCLUSION

This study presents the thermal instrumentation of three 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. Thus, with obtained results it is obvious that the adjustments made in kilns and RAC 220 with recirculated gas burners can provide significant gains in production. However, the map shows that thermal cycle to produce charcoal quality is needed to heat the kiln instrumentation, i.e. one must have the temperature control in all areas of carbonization. Only in this way the insurance of companies that charcoal is produced in accordance with the standard set by the national metallurgy can significantly increased.

Then, according to the literature and with data obtained in this study, it appears that the carbonization temperature has strong influence on the percentage of fixed carbon and gravimetric yield. In this sense it is proposed to provide the thermal instrumentation of the other kilns.

From the cycles analyzed, it is noticed that, in isolation, each methodology and technology deployed generate some improvement in the charcoal production. However, the ideal would be to join them to achieve the optimum condition for production.

Also can be studied improvements in the doors insulation. Thus, it is expected to obtain gains in yield with decreasing gravimetric training brands in these regions of the kilns.

5. ACKNOWLEDGEMENTS

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