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THERMAL INSTRUMENTATION AND ITS ECONOMIC ADVANTAGES IN CHARCOAL PRODUCTION

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Abstract. *The charcoal production represents an important economic activity for the steel-casting industry and boosts a development of Brazilian industry. In this process, temperature is a parameter that can influence both the quality and the yield of charcoal production. However, few thermal models have been proposed for kilns of the wood carbonization, especially for masonry ones, and, moreover, process control is often determined by visual checks and practical experience of the carbonizing agent. It means that the quality control of charcoal and productivity are directly dependent on human factor. Thus, in this work, it is presented an economic feasibility of implementing a supervisory system of temperature monitoring in masonry kilns type RAC 220 applied to charcoal prodution. For this, several cycles of carbonization were performed and thus negative and positive points of production and operation of the kilns were identified. It was verified that the thermal instrumentation provides good results and minimize losses, besides it also contributes to increase the thermal efficiency of the kiln and to obtain significant gains in gross incomes.*

Keywords: *charcoal production, Temperature Supervisory System, thermal instrumentation, RAC 220.*

1. INTRODUCTION

Charcoal is produced from the wood via pyrolysis or carbonization process. Contrary to what happened in industrialized countries, Brazil still widely practices the industrial use of charcoal. Brazil is the world's largest producer of this energetic input (INFOENER, 2009).

In 2007, approximately 90.4% of all charcoal produced in the country was consumed by industrial sector, mainly constituted by companies in the area of steel-casting, metallurgy, cement production. Figure 1 illustrates the charcoal consumption per sector.

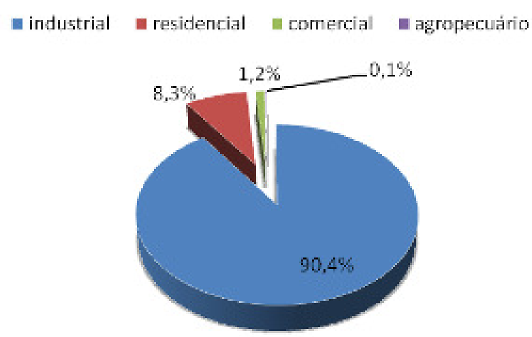

Figure 1. Charcoal consumption by sector (MME, 2008)

Predominantly, the charcoal plantsands are located amidst the woods. Slave's labor is often used or poor working conditions are provided for its employees that generally are not even registered officially. Pimenta et al. (2006) showed that many workers in this segment spend more energy than their abilities to produce. In another study, Minette et al. (2007) say that the activity of carbonization in kilns requires the physical efforts of the worker above the recommended limits of cardiovascular capacity, so this activity was classified as moderately heavy.

Also charcoal production causes a great environmental impact. Firstly, because of deforestation and uncontrolled burning of the wood. Secondly, high levels of carbon monoxide and carbon dioxide are emitted during carbonization, besides the huge emissions of methane and tar. These substances cause air pollution and contribute to the pollution of soil and its sub layers, and groundwater.

The process of charcoal production in majority of plantsands is the same as three thousand years ago: the part of the wood is consumed as fuel to provide energy for carbonization of the rest of the wood. More modern processes use other fuels, often from the very same carbonization process. Also, to minimize the pollution effects tar injection techniques within the carbonization kilns are being developed and used.

Despite of the importance of charcoal for the mankind development, its manufacturing process has not evolved as much as other industrial processes, and still is being executed the same way as at times of its creation. Currently the most modern kilns are the metal kilns that represent a high income, allow the process mechanization and a significant improvement of the work conditions (Guimarães Neto, 2005), (CPD, 2008) and (FAO, 2009), however this technology is not widely used yet (Oliveira, 2009).

Charcoal can be obtained in a very simple way. In Brazil, many farmers produce charcoal in the middle of the tillage, where the rest of the firewood is covered with ground or even by twigs, grass and tree branches, hence the fire can be opened easily by a little spark (Carneiro, 2007) and (Cavalcanti, 2009). This practice results in very low incomes turning production performed this way uneconomical.

Some types of kilns related to the process of wood carbonization have being developed over the years. Therefore different types of existent kilns are capable to alter the product characteristics (both physical and chemical) and, of course, the income (Moreira, 1964). Thus, some plantsands have been testing which kiln fits their profile.

Thinking about these factors and knowing the importance of efficiency of the charcoal production for economical development of the country, some improvements have been developed for the sector in recent years, such as new technologies and carbonization practices. Thus, this study aims to assess the costs and financial return with the deployment of a temperature monitoring system developed for the charcoal production due to a partnership between the university and the plantsand.

2. CHARCOAL PRODUCTOIN

2.1. Influence of the temperature in industrial processes

Several studies have demonstrated the relationship between the temperature control and industrial production. In the petrochemical sector, for example, Silva (2009) presents a study that aims to monitor the temperature of tube wall in order to increase their useful life. In the case of steel-casting, in a blast furnace for example, the thermal control of the process helps to avoid the descent of molten minerals ensuring the uniformity of produced pig iron (Amorim et al., 2010). In recent years important works related to modeling and control of thermal processes can be mentioned, such as Muske et al. (2000), Nieckele et al. (2006), Jinsheng et al. (2007) and Vitorino (2009).

Ceramic industries also use thermal control and monitoring. In the manufacture of bricks and tiles a previous controlled drying is of great importance. If drying is not uniform, distortions appear in work pieces, but if it is too slow, the production will become uneconomical. To obtain an uniform drying (temperature gradients and minimized moisture) it is important to moderate properly the intensity of drying (Cadè et al., 2005). Other studies also show the importance of thermal control in the manufacturing process of ceramics, such as Guilherme (1998) and Vieira et al. (2003).

The temperature control is also very important in the manufacturing process of concrete. Inoue (1986) showed that the net heat storage inside a concrete block generates a temperature gradient that, if the concrete cannot move freely, causes the drop in the temperature, tensile stresses that can result in cracking compromising the durability of the structure. So the temperature control in the production of concrete should be monitored. The same can be seen in the study raised by Rawhouser (1945). Other production processes, such as manufacture of cement and glass, are directly dependent on temperature, as shown in studies conducted by Manfredini et al. (1997) and Quintero et al. (2002).

As regards the charcoal production in Brazil, one of the most widely used kilns is called surface kiln, popularly known as the kiln *rabo-quente*. This kiln type has some advantages: it is suitable for small farmers since construction cost is low, therefore it does not allow mechanization of the process. For this, large plantsands have been using the RAC 220 as a preference, that is made of masonry with metal doors that allows mechanization (Oliveira, 2009).

The masonry kilns have lower construction costs and provide significant income even though most of these kilns do not present any type of control. According to Moreira (1964), Mendes et al. (1982), Coutinho and Ferraz (1988), Vella et al. (1989), Trugilho and Silva (2001), Pinheiro and Sèye (2005) and Oliveira et al. (2010) thermal control of the carbonization process is of great importance since it directly influences the physical and chemical properties of charcoal.

Another parameter of great importance for plansands in the charcoal sector is the profitability that is directly related to the gravimetric yield (ratio between the amount of produced charcoal and amount of the wood put into the kiln). Silva et al. (1986) showed that the yield of a kiln is dependent on the carbonization temperature. The same was identified in studies of Trugilho and Silva (2001), Pinheiro and Sèye (2005), Costa et al. (2008) and Oliveira et al. (2010), what means that all these authors conclude that the gravimetric yield is strongly dependent on temperature levels achieved during production.

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Previous reports developed by the author of this study represent the temperatures developed in the kiln RAC 220 throughout the stages of charcoal production: drying, pyrolysis and cooling. In this case the temperatures were obtained by PT100 sensors scattered within the kiln (Oliveira, 2009). In Oliveira et al. (2010) was carried out a study of the thermal profiles of kilns RAC 220 with and without any thermal instrumentation and was concluded that instrumented kilns may present significant productivity gains. In another study, Oliveira et al. (2010) indicates the thermal behavior of the kiln RAC 220 adapted with gasificators and recirculating air aerator and compares temperature profiles of the instrumented kiln RAC 220, showing the main advantages of each technology. Raad et al. (2008), in its turn, present a control flow of gases during the carbonization of the wood. The results show how the improvements associated with the production process provide better quality of final product and consequently production gains.

This work aims to evaluate the financial return from the deployment of a system for monitoring temperature in the kiln called RAC 220 for the charcoal production. The studied kiln has the internal volume of approximately 440 m³ as shown in Fig. 2.

Figure 2. Typical rectangular kiln – RAC 220

2.2. The carbonization procedure

In Oliveira (2009) it was found that the process of the wood carbonization is divided into three stages, namely: drying, pyrolysis and cooling. During drying the wood put into the kiln starts to throw off large amounts of water kept inside. At this stage, the temperature varies a little bit more than 100°C. In the subsequent stage, called pyrolysis, the wood begins to be carbonized and is processing in charcoal. At this stage the temperature control is extremely important as it can vary greatly over the kiln due to involved dimensions. The thermal control during the pyrolysis process directly influences the quality of the product and its chemical properties, such as in the fixed carbon, which is inversely proportional to the temperature of carbonization. According to Oliveira et al. (2009), Brazilian steel-casting industries require charcoal with fixed carbon above 75%, and for this reason, the carbonization temperature should be around 340°C (Briane and Doat, 1985).

Finally, the cooling step begins when the wood has already practically turned into the charcoal. During cooling, the charcoal must remain in the kiln which, in its turn, is completely sealed, so there is no air inlet. The carbonization cycle is completed when the kiln temperature is around ambient temperature. Usually this last stage lasts eight days and one full cycle in the kiln RAC 220 lasts approximately 12 days. Figure 3 shows the relationship between temperature and production time of the kiln RAC 220.

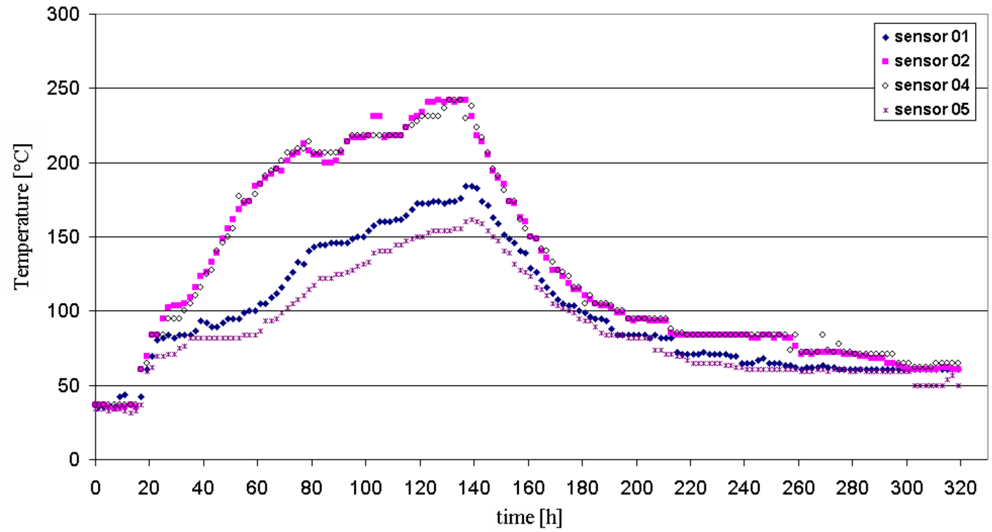

Figure 3. Normal curve of carbonization of the particular region in the kiln RAC 220 (Oliveira, 2009)

The cooling step can be clearly identified through the Fig. 4 that shows the temperatures in the smoke channels (kiln chimney). In this case, it can be noted that starting from 130th hour the temperature in this region drops to the levels close to ambient temperature, indicating that the kiln is sealed and that the cooling step has started.

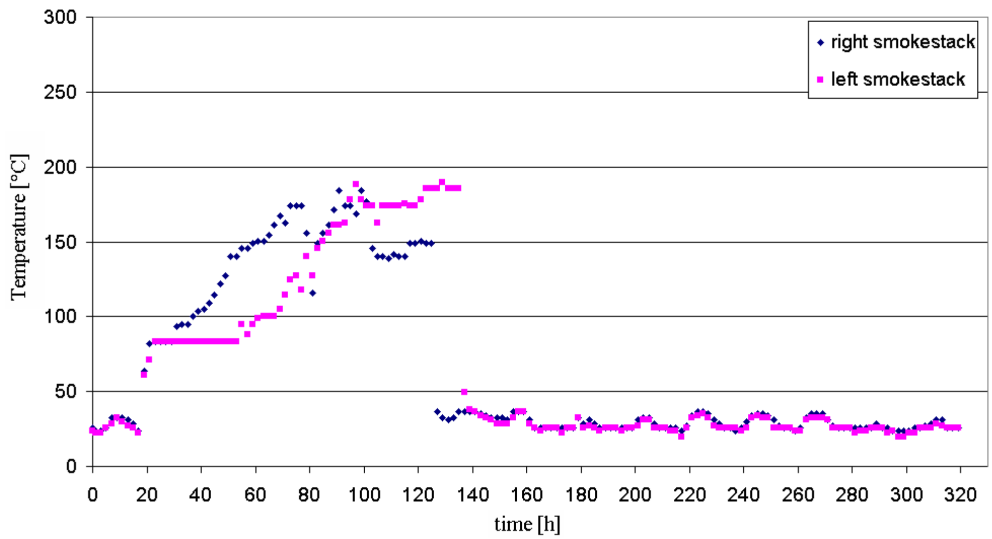

Figure 4. Temperatures measured in the chimney of a kiln RAC 220 (Oliveira, 2009)

For the implementation of this study, production cycles were analyzed where carbonization procedures had been previously established by the Company and are called “Standard Practice”. This practice, in a certain form, is directly linked to the experiences of carbonizing agents which are aided only by an optical pyrometer able to perform measurements of temperatures in some locations outside the kiln (Oliveira, 2009). To analyze the kiln heat and evaluate the ability of carbonizing agents in the leading of the carbonization process, temperatures inside the kiln were monitored by means of a Supervisory System Temperature (TSS) proposed by Mulina et al. (2009). Figure 5 presents the software developed for monitoring transient thermal and real time in different regions of the kiln. It is noteworthy that the TSS was used only to follow the standard practice of carbonizing agents and employees, i.e. there was no intervention by the researchers involved in this work.

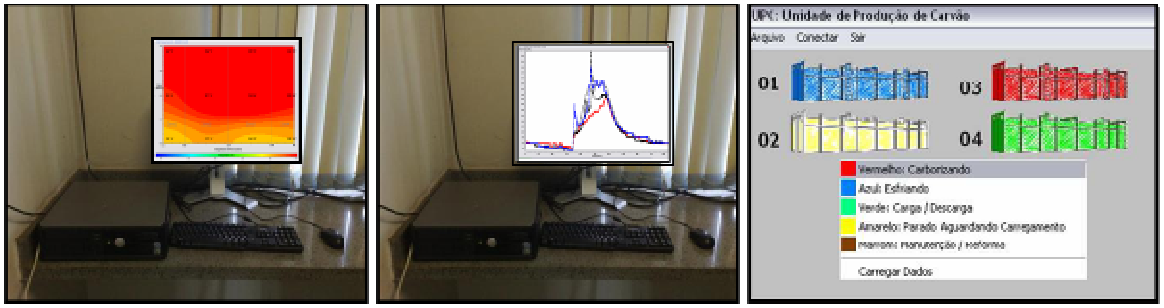

Figure 5. Temperature Supervisory System – TSS (Mulina et al., 2009)

3. RESULTS

3.1. Analysis of the gross gain considering the standard practice of carbonizing agents and temperature profiles measured by TSS

According to the studies presented above, it becomes possible to analyze production cycles and identify practices adopted by carbonizing agents by monitoring heat of the kiln. Figures 6 and 7 show the temperatures measured in real time inside the kiln and inside the chimneys, respectively, during one cycle of carbonization where failures in production were identified.

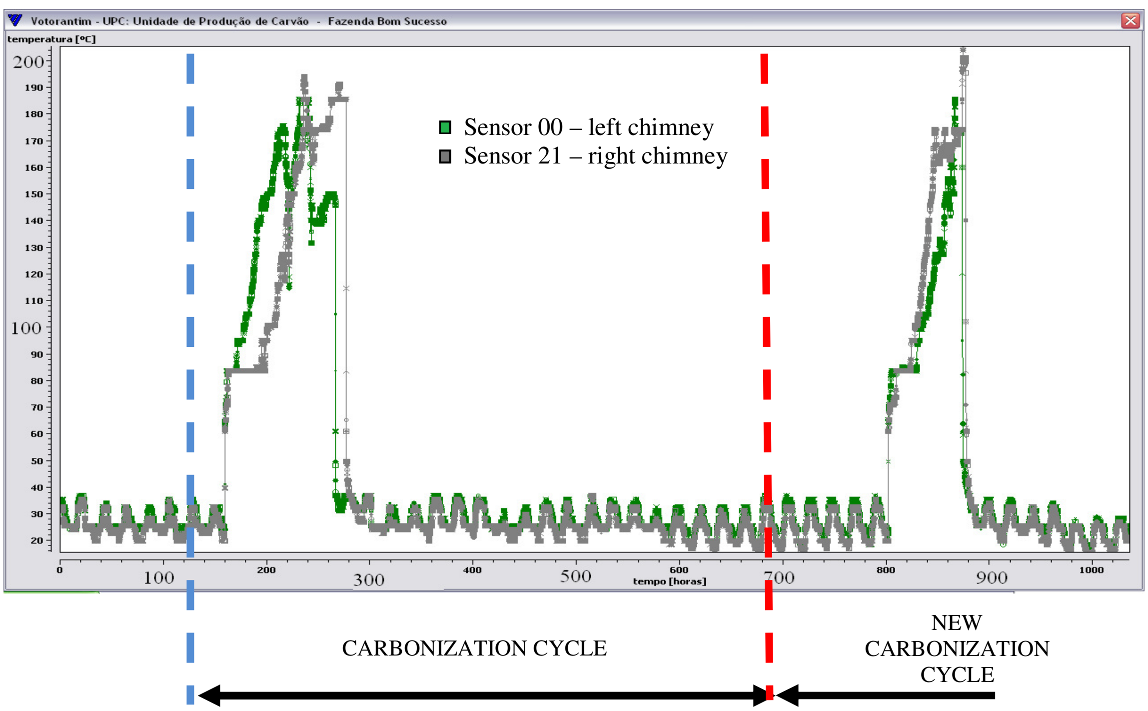

Figure 6. Analysis of the temperature inside the chimneys during one production cycle

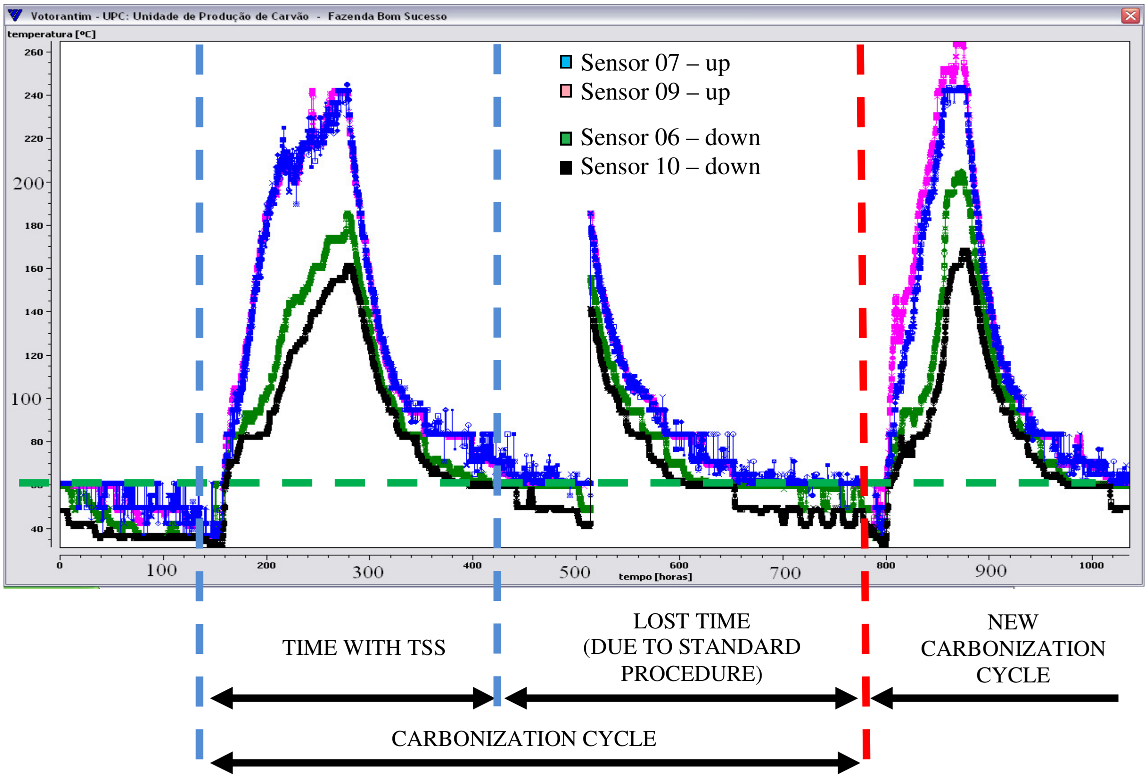

Figure 7. Analysis of the temperature inside the kiln during one production cycle

In Figure 6 one can observe the temperatures measured about 2 m above the ground by sensors located inside the kiln chimneys. Measurement of the temperature in this region is extremely important for the charcoal production, since it identifies the transition from pyrolysis stage to cooling. During the pyrolysis gases leave the chimney and for cooling of the kiln to be continually lasted, the carbonizing agent should seal the base of chimneys, what interrupts the passage of hot gases by the thermal sensors and, thereafter, any rise in temperature in this region, during the cooling period may indicate failures in the process.

Figure 7, in its turn, represents the temperatures in the inner regions of the kiln obtained by sensors located at different points in its interior. Analyzing judiciously this figure, one can observe an unexpected rise in temperature inside the kiln during the cooling stage of presented carbonization cycle, i.e. after 500 hours when the chimneys were already sealed. This undesirable increase in temperature can be interpreted as a failure of production; it may likely be due to the cracks in the wall of the kiln that were not perceived by carbonizing agents. These cracks allow the air to enter inside the kiln, causing the combustion of charcoal what results in temperature increase.

Due to the "standard practice" of the Company, the kilns should be opened when the temperature outside the doors - made from sheet metal - reaches 30°C (temperature measured by a manual pyrometer) and the temperature inside the kiln is 60°C in average (temperature measured via TSS). Normally a carbonization cycle of the wood lasts from 12 to 14 days. Accordingly, if the carbonizing agents were aided by TSS, the cycle actually could have been finished even before the normal time and failures like shows Fig 7, which was a result of increased production time, could be avoided.

Table 1 presents an analysis of mean gross income per carbonization cycle considering the production time according to the "standard practice" of carbonizing agents (SPP) and the production assisted by thermal monitoring system (TSSP). For this, it was accepted US$ 72.25 per cubic meter of coal, based on dollar value on March 28, 2011 corresponding to R$1.6610 (Banco Central do Brasil, 2011) and an output of 110 m³ charcoal per batch. It is noteworthy that the production cycle, as the Figs. 6 and 7 show, began after 125 hours of measurement.

Table 1. Gross income per production cycle

	Production time		N° cycle/month	Gain (US$)
	hours	Days	1	7,946.95 (1)
Standard Procedure Production (SPP)	640	26,66	1.12	8.900,58 (2)
TSS Production (TSSP)	285	11,87	2.52	20,026.31 (3)
			Mensal gross income (US$)	11,125.73 (4)
			Annual gross income (US$)	133,508.76 (5)

(1): 110 [m³] x 72.25 [US$]; (2): 1,12 [n° cycle] x 7,946.95 [US$]; (3): 2,52 [n° cycle] x 7,946.95 [US$]; (4): (20,026.31 – 8,900.58) [US$]; (5): (12 × 11,125.73) [US$]

The value of mensal gross income represented in Table 1 was calculated by the difference between the gain obtained with the TSS and the gain obtained with production using "standard practice". The value of annual gross income was represented by the sum of the mensal incomes during a year.

In this case, one can clearly note a big difference between the mensal gross income when the cycle is carried out by an empirical way and forecast gross income when production is aided by the TSS. In this preliminary study the gain is 225%. Therefore this calculation does not show exact gross incomes, because operational failures of this type do not occur in all carbonization cycles, however these failures are quite commonplace. For more precise analysis, one must make a statistical analysis of the occurrence of such failures during the year.

Such operational failures are commonplace in the production of charcoal and are often caused by lack of communication between the carbonizing agents, turns of duty and experience exchange between different operators. Figures 8 and 9 show some operational failures that result in such cases.

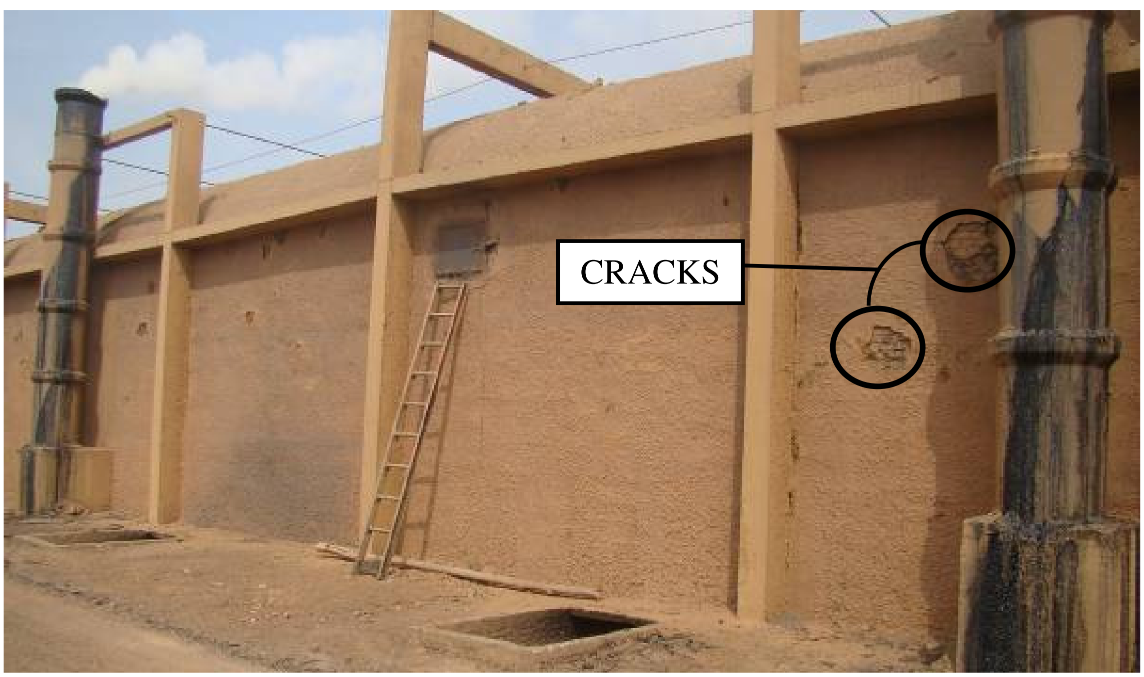

Figure 8. Cracks in the wall

Figure 9. Air inlet during the cooling step

Figure 8 shows cracks in the wall of a kiln RAC 220. The kiln RAC 220 is constructed of masonry and covered with mud. Rain, wind and oscillation of internal pressure often detach a bar from the wall of the kiln providing the formation of cracks that often remain unnoticed by less experienced carbonizing agents. Another very serious operational failure which is caused mainly by lack of communication of carbonizing agents is the air intakes (Fig. 9) or when the output of smoke remains opened during the cooling stage of the kiln, allowing entry of air inside the kiln.

Due to the results obtained in this exploratory study, one can see that relatively high incomes can be achieved in a carbonization process only with control of the temperature and time of production. However, further studies are needed to confirm the results. In addition, only the gain related to the production time were considered in this study, i.e., no specific studies of gravimetrical yield and physical and chemical properties of charcoal were produced.

3. CONCLUSIONS

This study analyzed a technology developed for the area of charcoal production, presenting its economic viability when deployed. It was found that using of a Supervisory System Temperature (TSS) one can and should improve and correct the carbonization cycles in order to increase productivity and reduce the costs. This fact shows that the temperatures measured by the TSS may eventually help the carbonizing agent to identify irregularities of the process and correct them in time.

Also a feasibility analysis of an instrumented kiln via the TSS proposed in this paper was presented. In this case, a production cycle was evaluated and it was found that the TSS allows an increase in gross income in addition to help the carbonizing agent to identify irregularities in the process and correct them during the production cycle. It is emphasized that future tests, based on statistical analysis, would be the basis to confirm effectively the results presented in this paper. Furthermore, more careful study of the production process should be performed taking into account the type and weight of the wood put into the kiln, drying time along with the weight and quality of the charcoal produced in each region of the kiln.

Thus, it was concluded that with TSS installed it is possible to obtain the temperature inside the kiln, correct thermal irregularities during the cycle and determine the correct time of its opening avoiding a restart of the charcoal process or even fires and sparks at the opening. Such characteristics and operational practices stemming from the installation of TSS can provide a further reduction in production time, increase of the gravimetric yield and improve final product quality.

4. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Government Agencies - CAPES, CNPq and FAPEMIG.

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