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TECHNICAL PAPER:

CONTROL SYSTEM FOR COMPLETE BURNING IN FURNACE USING LAMBDA PROBE

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ABSTRACT

The objective of this work was to evaluate the biomass burning process in a furnace, using chip as a raw material and an oxygen sensor (lambda probe) to monitor the percentage of oxygen in the gases exhausted during combustion, aiming to maintain the percentage of the coefficient of excess air (α) in the operating range of 1.20 to 1.25%, considered ideal for the biomass (chip) used in the study. Once the excess air is identified at the upper furnace exit, the air entrance in the system will be closed by means of a butterfly valve using a servo motor driven by a Programmable Logic Controller (PLC). The valve was opened or closed according to the oxygen level; when it was lower than 1.20%, the door remained open, and it was closed when the level reached 1.25%, finishing the cycle of the process. The open and closed states of the valve occurred by means of two reed switch magnetic key sensors installed in the air intake system. For the control, monitoring and data acquisition, a supervisory system created using the Elipse SCADA software was used so it was possible to obtain a system database, which will provide important information to maximize the efficiency of the furnace.

Palavras:
ar aquecido
controle de processos
instrumentação
armazenamento de grãos

SISTEMA DE CONTROLE PARA QUEIMA COMPLETA EM FORNALHAS UTILIZANDO SONDA LAMBDA

RESUMO

Objetivou-se neste trabalho avaliar o processo de queima de biomassa em uma fornalha, utilizando o cavaco como matéria prima com um sensor de oxigênio (sonda lambda), para o monitoramento do percentual de oxigênio nos gases expelidos durante a combustão, visando manter o percentual do coeficiente de excesso de ar (α) na faixa de operação de 1,20 a 1,25%, considerados ideais para a biomassa utilizada (cavaco). Após a identificação do excesso de ar na saída da fornalha superior, a entrada de ar no sistema será fechada por meio de uma válvula borboleta, utilizando um servo motor acionado por um Controlador Lógico Programável (CLP). A abertura e o fechamento da porta ocorreram de acordo com o nível de oxigênio, quando o mesmo estava inferior a 1,20%, a porta se mantinha aberta, se fechando quando o nível alcançava o valor de 1,25%, encerrando o ciclo do processo. Os estados aberto e fechado da válvula ocorreram por meio de dois sensores de chave magnética *reed switch,* instalados no sistema de entrada de ar. Para o controle, monitoramento e aquisição de dados utilizou-se um sistema supervisório criado através do *software* Elipse SCADA, com este foi possível obter um banco de dados do sistema, que fornecerá informações importantes para maximizar a eficiência da fornalha.

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INTRODUCTION

In a warehousing unit, the grain drying stage is of fundamental importance for maintaining product quality for a longer period during storage, industrialization and final consumption. The drying process is applied to reduce the moisture content of agricultural products up to levels that allows a safe storage (WANG; LI; LAI, 2018).

In most farms, drying is carried out furnaces. The knowledge of the principle of proper functioning and operation is an essential condition for the rational use of energy in drying agricultural products (RAMAVANDI; ASGARI, 2018).

Furnaces are devices designed to ensure the complete and efficient burning of the fuel under efficient conditions that allow the maximum use of the thermal energy released by combustion, with the highest possible thermal efficiency. The design of a furnace should be based on the three combustionT's: temperature, turbulence and time. For a complete fuel combustion, a homogeneous air-fuel mixture at the optimal dosage and at the correct time must be pursued as it makes it possible to heat the fuel to its self-sustaining ignition (PRECCI et al. 2001).

The current ecological concern led Brazil to set strict environmental standards to optimize the thermal efficiency of furnaces, such as CONAMA Resolution No. 382/06 and its complementation described in CONAMA Resolution No. 436/11. So, it is necessary to minimize the excess air, while ensuring compliance with such standards (NETO, 2008).

Pollution control through particulate matter and the furnace thermal yield control are carried out independently by the respective operators. Thus, the interrelationship between excess air, thermal efficiency and pollutant emission is poorly understood, therefore, not optimized. Excess air influences both the thermal efficiency and the level of pollutant emission (COx, SOx, NOx) from furnaces (CAPOSCIUTTI; ANTONELLI, 2018).

Excess air is defined as a percentage above the stoichiometric amount. For gaseous fuels, usually 1 to 2% excess air is provided for liquid fuels, the excess commonly used is within the range of 5 to 10% and for solid fuels such as pulverized coal, excess air can be reached at 25% (GIL et al., 1987). The values for the excess air coefficient (α),

Table 1. Usual values for excess air coefficient (α) (CERON, 2010).

Fuel	Furnace or burner type	α
Pulverized coal	Complete Aqua tubular	1.15-1.20
	dried-bottom complete Aqua tubular	1.15-1.40
Crushed coal	Cyclone furnace	1.10-1.15
Coal	Fixed grate	1.30-1.60
	Vibrating grate	1.30-1.60
	Rotating grate	1.15-1.50
	Fixed grate, bottom feeding	1.20-1.50
Fuel oil	Register oil burner	1.05-1.15
	Multi-flue burner	1.05-1.20
Acid residue	flat-flame vapor burner vapor	1.10-1.15
Natural gas	Register-type burner	1.05-1.10
Coke oven gas	Multi-fuel burner	1.07-1.12
Blast furnace gas	inter-tube nozzle burner	1.15-1.18
Wood	Grate	1.20-1.25
Bagasse	All furnaces	1.25-1.35
Black Liquor	Kraft and Soda recovery furnace	1.05-1.07

according to fuel and furnace are shown in Table 1.

Combustion, which is given by the ratio between air and fuel, cannot be controlled by fuel flow, as the energy generated by the furnace depends on the amount of fuel introduced. Thus, the only variable that can be changed is the combustion air flow (ŞAHIN, 2015)

The air flow is regulated by an open loop control system as a function of the fuel flow, directly activating the air flow control. Open-loop control consists in a system that has no feedback, setting the air/fuel ratio, but unsatisfactory in many cases. Demands on variable loading and burning of alternate fuels, common in industrial processes, modify the optimal air/fuel ratio. Burning fuel mixtures of fuels with composition, temperature, viscosity and lower heat of combustion value (HC) and variable air temperature require frequent readjustments, making this control impractical. Thus, to ensure complete combustion, even under the worst operating conditions, a large excess air (20-30%) is required (BLASEUBAUER, 2010).

Optimizing excess air requires a more precise combustion control, which can be achieved through a closed-loop control system. A closed-loop control system consists of using an output measurement and feedback of this signal for comparison with the desired reference, whereas open loop control differs in that as it controls the process without using a feedback, as shown in Figure 1. That is, it is performed based on the analysis of CO_2, O_2 and CO in the combustion products at the furnace exit (ŞAHIN, 2015)

The O_2 analyzers are used to control combustion because they are available at low cost, have short response time, require little maintenance and directly measure excess air in the chimney. However, its main disadvantage lies in the fact that the control value needs to be adjusted for each fuel and combustion rate, as the measured value does not depend solely on the reaction stoichiometry. The O_2 found in the products may be due to inactive burners, open hatches, infiltrations, among others. Thus, air infiltration into the furnace may make O_2-based control unfeasible (LOPES et al., 2003).

Therefore, the objective of this work was to develop a closed loop control and supervision system for complete furnace burning, using a lambda probe O_2 sensor.

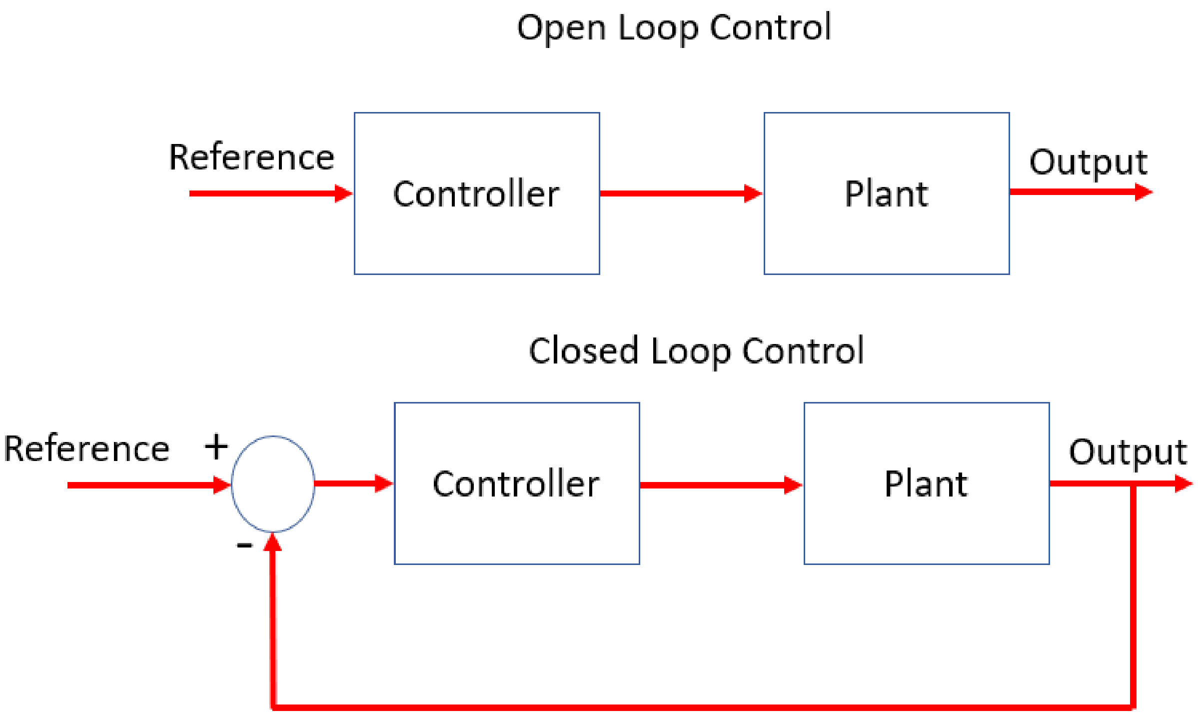

Figure 1. Open and closed loop control.

MATERIAL AND METHODS

The furnace used for the implementation of the complete burn control and supervision system is located at the Biofuels Laboratory in the Department of Agricultural Engineering of the Federal University of Viçosa. The furnace uses refractory bricks as its combustion chamber walls to minimize heat exchange with the outside environment. The combustion chamber is approximately 0.25 m wide and 0.80 m high with a grate for burning fuel store.

Chip was used as fuel for the burning, which resulted from the crushing of eucalyptus wood, whose sizes ranged from 5 to 10 cm. Figure 2 shows some furnace points and the fuel used in the study.

Some modifications were needed to control the complete burn in the furnace. First, it was necessary to set a butterfly valve at the main air entrance, to change its state between open and closed, thus controlling the amount of air in the system. For the control of the valve, two Reed Switch sensors were installed, as shown in Figure 3, where the two states of the air entrance valve can be seen.

For the opening and closing of the butterfly valve, a servo motor was installed directly coupled to the valve shaft as shown in Figure 4. A servo motor is a closed loop position control engine.

Figure 2. (a) Combustion chamber and furnace grate; (b) Chip; (c) Ash warehouse.

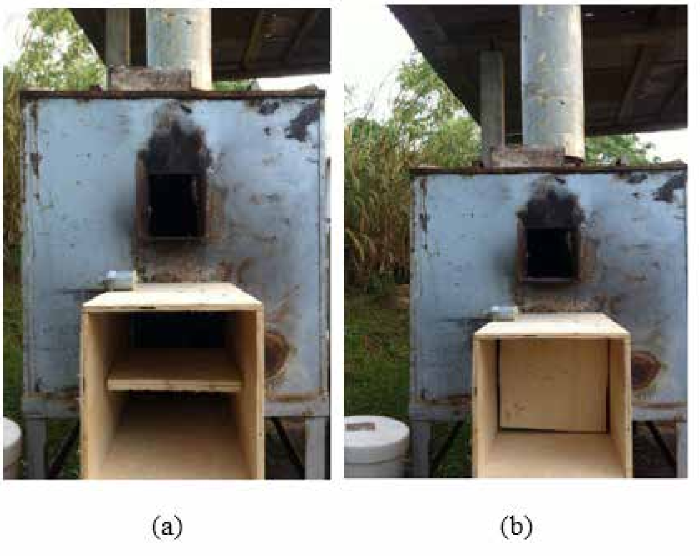

Figure 3. (a) Open air admittance valve. (b) Closed air admittance valve.

Once the system was set, a lambda probe was installed in the chimney to detect the percentage of oxygen in the combustion gases in order to control the air admittance in the furnace.

With the furnace prepared to receive the control system, the system control software was implemented using ladder logic. In order to program this logic, we used WEG's CLIC02 Edit Software, which acted as the controller of the entire furnace burning process.

The probe sends the oxygen percentage readings in the fuel gas to the control center; the Programmable Logic Controller (PLC) compares this percentage with the ideal amount set for the chip in grate furnaces, which ranges from 20 to 25%. (Table 1), thus defining whether to open or close the oxygen entrance. The flowchart of the closed loop control process is shown in Figure 5.

Figure 4. Servo motor used to open /close the air admittance valve.

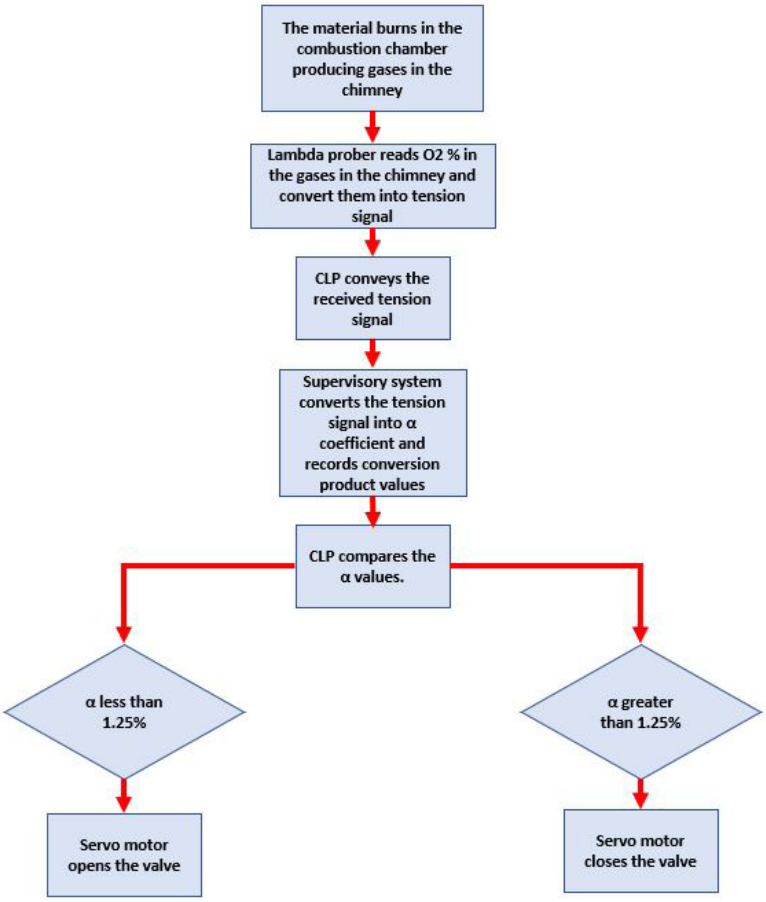

Figure 5. Flowchart of the closed loop control system process.

A supervisory system was created so the system operator could view and analyze all data obtained by the control system. The supervisory system was created using the Elipse Scada Software, which was connected to the PLC using the methodology proposed by Pedruzi (2014). In that system, the operator can monitor variables such as the state of the oxygen supply system, the oxygen content in the air at the furnace exit and the exit gas temperature in an operating room.

Figure 6 shows the main screen created for this system, where numbers from 1 to 8 indicate the principal components, explained in detail in Table 2. A rotary coffee drier was added in the supervisory, which was used only to demonstrate an application for the furnace.

Another screen in the supervisory system is the trend graph (Figure 7). Such screen allows observing the graph at real time, which gives to the operator the coefficient α. In addition, a button has been configured to generate a report in .xlsx format with all data obtained by the Lambda sensor, recorded every 5 seconds.

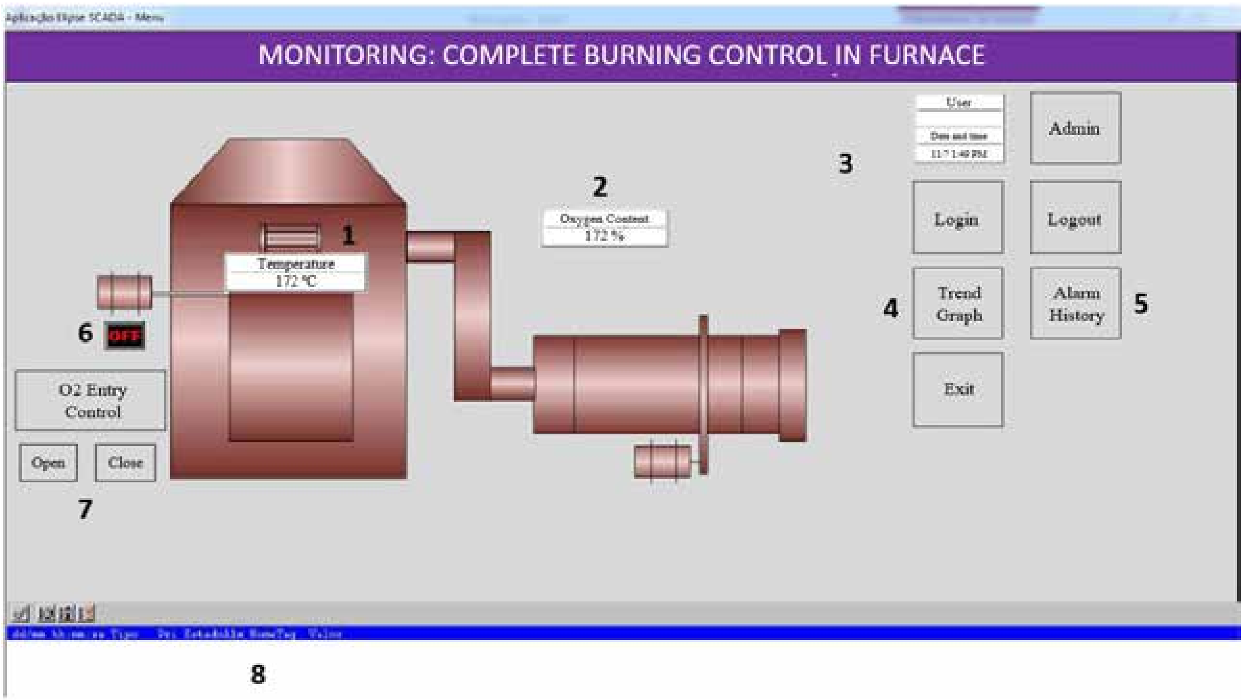

Figure 6. Principal screen of the supervisory system.

Table 2. Primary functions of the supervisory system.

Number	Function
1	Displays the temperature in the combustion chamber.
2	Displays the O_2 content.
3	Displays the user logged into the system and date and time.
4	Button to access the trend graph screen.
5	Alarm history screen access button.
6	Display illustrating the status of the air intake valve (open = ON; closed = OFF).
7	Buttons that allow manual control of the air intake valve if the system is not in automatic mode.
8	Display that will exhibit the alarms.

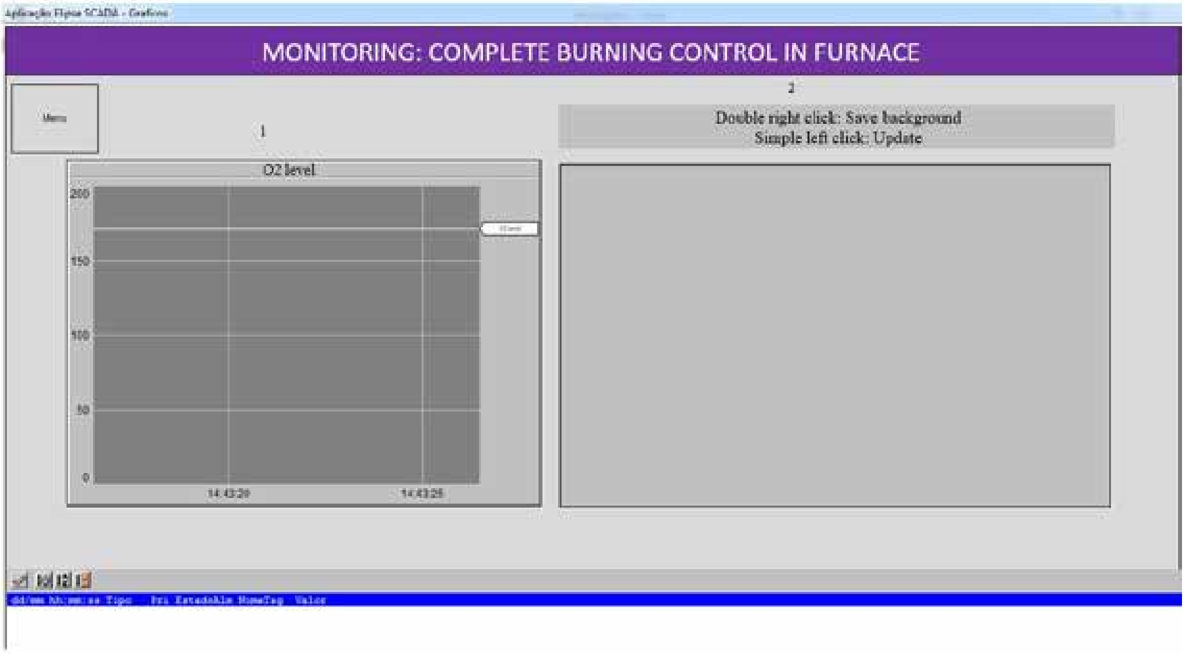

Figure 7. Trend graph screen in the supervisory system.

RESULTS AND DISCUSSION

By using the data acquired by the supervisory system, it was possible to plot into the MATLAB software the excess air coefficient results obtained during 3500 s of burning, during which time it was possible to observe the operation of the closed loop control system, as illustrated in Figure 8.

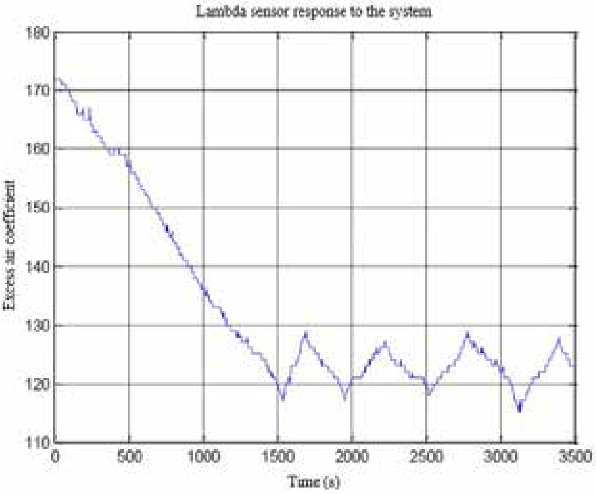

Figure 8. Graph of data collected by the supervisory system of the excess air coefficient during 3500 seconds of burning.

The analysis of the Figure 8 allowed observing the following:

a) At the beginning of the measurements it can be seen an excess air which occurs because the process is at its start, so the air admittance valve remains closed and the air coefficient decreases until reaching the minimum desired value of 20%. At this moment, the valve will open and start bringing air into the burning system.
b) The system takes approximately 1500 s (25 min) to reach the 1.2% point when the command to open the air admittance occurs for the first time.
c) Peak ranges are approximately 480 s (8 min).
d) The system obtained responses outside the desired range (20 to 25%) during the process. This is common in systems working at high temperatures because the response of the involved variables is slow and as the materials dilate, the false air intake is inherent in the system, which can cause variations both below and above the determined set points.
e) The lowest value recorded was 1.15% and the highest value was 1.29%.

As it can be seen in Table 1, the optimal value of the α coefficient for wood burning in grate furnaces is between 1.20 and 1.25%. The range of values found in this study was between 1.15 and

1.29% with a percentage error of 4.16% and 3.2%, for the lower and upper limits, respectively. The factors that are likely to have contributed to these errors were the slow system response and the false air entrance that is inherent to high temperature systems due to the dilation of the materials used in the study. However, it can be observed that as the system went into operation, the coefficient remained within the optimal range most of the time.

CONCLUSIONS

- The closed-loop control system developed in the study was efficient in the complete burning, since it was able to maintain the excess air coefficient within the desired operating range, most of the time. Small gaps in the air intake port and openings for biomass insertion may have influenced the results, which were off the desired operating range.
- The supervisory system developed in this work facilitated the monitoring of the process, without the physical presence of the operators near the furnace, making their work easy and improving its quality, both in relation to their health and safety. In addition, it was possible to obtain a system database, which will provide important information to maximize furnace efficiency.

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