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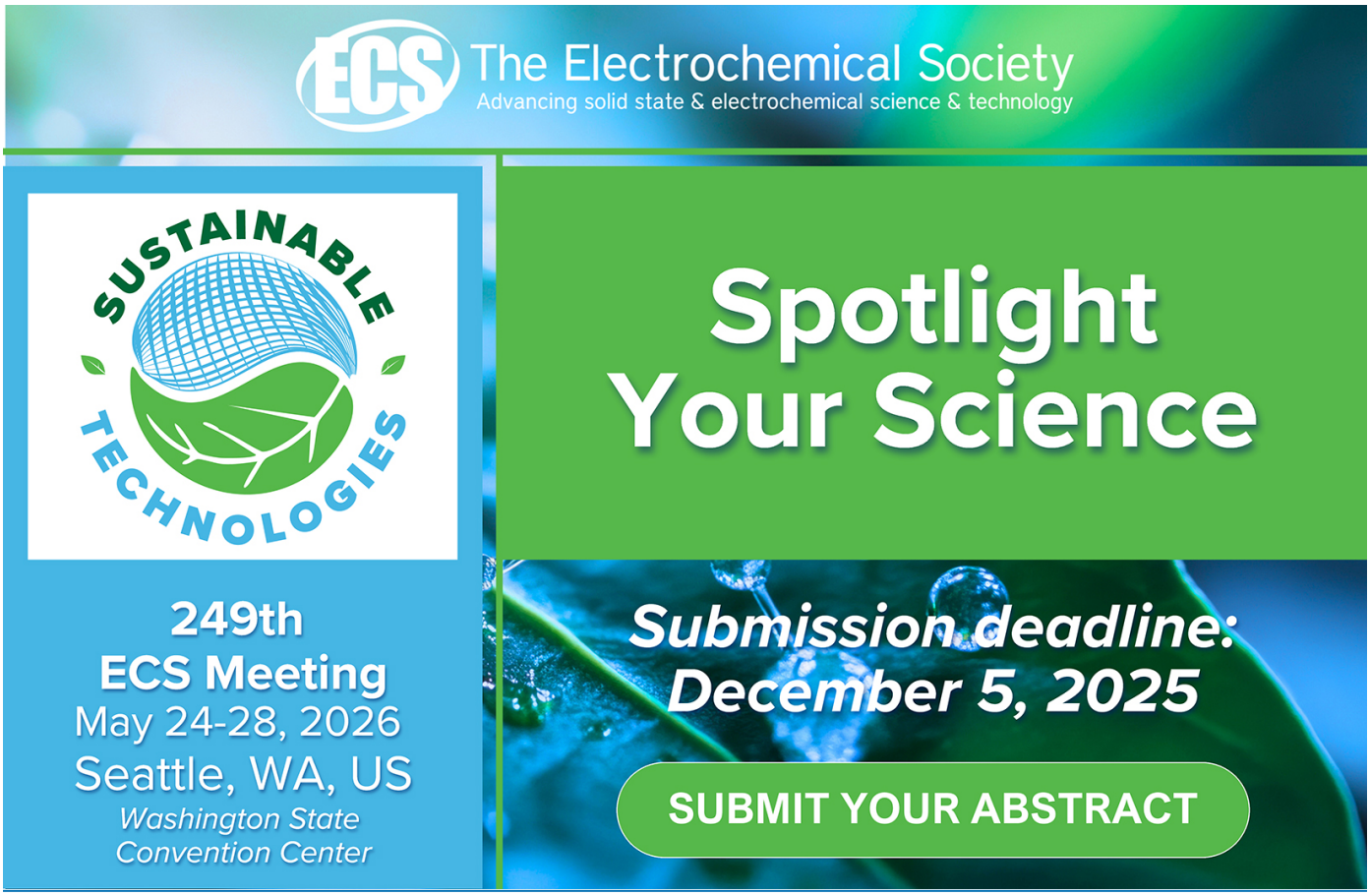
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Energy evaluation of clay firing process and combustion gases in an intermittent kiln

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Abstract. The recording of temperatures in different positions in the firing process in an intermittent kiln to produce ceramic materials is presented, which led to the energy evaluation, determining the heat used for the clay firing process and the heat losses. In addition, a study of the emissions of pollutant gases released into the environment was carried out, as stipulated in the protocol of control, and monitoring of stationary source. In the energy balance, large energy losses were detected in heat accumulation in the masonry of 7.20×10^6 KJ of the energy supplied, representing 16.99%, and in the kiln walls of 5.20×10 KJ, representing 12.17%. As a result, it is necessary to make constructive and operative changes in the operation of the kilns, which will lead to the recovery of residual heat in the use of drying of parts, drying, and preheating of combustion air, reducing energy consumption and emissions of pollutants into the atmosphere. The average concentration of particulate matter released into the environment was 1056.60 mg/m^3, 422% higher than the standard, affecting people's health.

1. Introduction

The production of ceramic materials in Ocaña, Colombia, is done in empirical way [1], and traditional way [2], using kilns with incomplete combustion processes [3], increasing fuel consumption [4], and leading to low quality and non-compliance with the quality standards of their products [5], which generate health problems due to their emissions into the environment [6]. The use of intermittent kilns in the production of ceramic materials in the municipality of Ocaña, Colombia, guarantee the mass production, a reduction in fuel consumption and gas emissions into the environment, and compliance with product quality standards.

The objective of the research is to record temperatures in different positions of the intermittent kiln leading to energy evaluation in the firing process of ceramic materials, in addition to measurements of pollutants emitted into the environment in this process. With the energy evaluation carried out, large energy losses in heat accumulation in the masonry and furnace walls were detected. For this reason, constructive and operative changes should be made in the operation of the kilns, leading to great possibilities of residual heat recovery in the use of parts drying, drying, and preheating of combustion air, improving the combustion of coal, reducing energy consumption, reducing emissions of pollutants into the atmosphere and improving the quality of the products.

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2. Methodology

The study was carried out in the intermittent kiln of "Granito de Oro" brickworks and contains the energy evaluation of the clay firing process and the environment emissions of different pollutant gases as established in "Resolución 909 de 2008" [7]. The circular cross-section kiln has an inside diameter of 2.12 meters and a height of 4.52 meters with a wall thickness of 0.24 meters. The number of bricks in the firing process was 4300 and coal consumption was 1500 Kg [8].

2.1. Design and installation of the temperature acquisition system

A data acquisition system was designed to record the firing process temperatures, for this purpose, two acquisition cards equipped with 8 type K thermocouples each were used [9]. In the first card, the inner kiln chamber temperatures were recorded from position 1i to position 8i. Additionally, the external temperatures from position 1e to position 8e were recorded through the second card, in total 16 temperature sampling positions were applied. Thermocouple locations were as follows: T_1 inside center temperature, T_2 inside floor temperature, T_3 inside wall temperature, T_4 gas temperature, T_5 outside center temperature, T_6 outside floor temperature, T_7 outside wall temperature, and T_8 ambient temperature.

2.2. Procedure for the measurement of polluting emissions

Before conducting the measurements of polluting emissions, a preliminary sampling was carried out to know the emission characteristics in the fixed source. Sampling was performed according to the methodology and procedures established for the Environmental Protection Agency (EPA). For atmosphere emissions [10]. A Bacharach combustion gas analyzer approved by the EPA was used to determine the gases emitted during the firing process in the kiln.

The evaluation of polluting emissions consisted of the following stages: (i) determine sampling site and sampling points in the chimney; (ii) estimate the velocity and emissions volumetric flow; (iii) determine the oxygen (O_2) and carbon dioxide (CO_2) concentrations that make up the gases; (iv) calculate the humidity content in the gas; (v) determine the emission of particulate matter; (vi) evaluate the sulfur dioxide (SO_2) concentration; and (vii) determine the nitrogen oxides (NO_x) concentration according to regulations established by the "Ministerio de Ambiente, Vivienda y Desarrollo Territorial", Colombia, in the protocol for the control and monitoring of atmospheric pollution generated by fixed sources [11]. Also, the gas analyzer allowed to determine the combustion efficiency, the excess air and the gases temperature emitted to the environment; for the gases measurement in the Hoffman kiln chimney, a total of 3 runs were made every 15 minutes in three ducts or nipples designed for that purpose [12].

2.3. Correction at reference conditions

The measurements result of the different pollutants had to be corrected for two reference conditions; the first reference condition correction of 25 °C, and 760 mmHg was carried out with Equation (1) [13].

$$C_{CR} = C_{CL}\left(\frac{T_{CL}\cdot P_{CR}}{T_{CR}\cdot P_{CL}}\right), \quad (1)$$

where C_{CR} is the concentration of the pollutant at reference conditions in (mg/m^3), C_{CL} is the concentration of the pollutant at local conditions in (mg/m^3), T_{CL} is the temperature of the gases at the outlet of the duct in (K), T_{CR} is the temperature at reference conditions in (K), P_{CL} is the pressure of the gases at the outlet of the duct in (mm Hg), and P_{CR} is the pressure at reference conditions in (mm Hg).

Once performed the correction at reference conditions, the second correction at reference oxygen conditions of 18% was carried out through Equation (2) [13].

$$C_{CR(O_2 ref)} = C_{CR(X\,\%)}\left(\frac{21-\%O_{2ref}}{21-\%X}\right), \quad (2)$$

where $C_{CR(X\,\%)}$ is the pollutant concentration at reference conditions, $C_{CR(O_2 ref)}$ is the correction to reference oxygen conditions of 18%, $\%O_{2ref}$ is the oxygen concentration of 18%, and %X is the oxygen measured at the exit of gases (%).

2.4. Excess air and combustion efficiency

The calculation of excess air was evaluated according to method 3 established by the EPA using Equation (3) [13].

$$\%EA = \frac{\%O_2 - 0.5 \cdot \%CO}{0.264 \cdot \%N_2 - (\%O_2 - 0.5 \cdot \%CO)}, \quad (3)$$

where %EA is the excess air, $\%O_2$ is the percentage of oxygen, %CO the percentage of carbon monoxide, and $\%N_2$ is the percentage of nitrogen in the combustion gases. On the other hand, the evaluation of the combustion efficiency was carried out as [13], see Equation (4).

$$\eta_c = \frac{\%(CO_2)_{Real}}{\%(CO_2)_{Theoretical}}, \quad (4)$$

where η_c is the combustion efficiency, $\%(CO_2)_{Real}$ is the actual reaction between the fuel and the oxidizer, and $\%(CO_2)_{Theoretical}$ is the complete fuel reaction.

3. Results

The firing process previously carried out in the selected kiln had lasted two days; as a result, the testing and execution of the program was carried out so that the software would record temperatures in the time interval every 3 minutes. Finally, the monitoring in this kiln lasted forty hours and 2400 temperature data were recorded in each thermocouple. The Figure 1 shows the temperature profiles at the selected positions in the kiln, from position 1 to position 8. The abscissa represents the time interval every three minutes, and the ordinate represents the temperature recorded in °C.

The temperature difference between the base and the top of the load in the firing chamber of "Granito de Oro" brickworks' kiln is 300 °C. Therefore, it is a very large difference that makes the firing deficient, and the bricks that are closer to the flames of the kiln may melt or the bricks located in the highest part of the kiln may remain raw. The recorded temperature increases of more than 20 °C per hour in the firing process of the products affects the commercial quality standards of the bricks [14], and production of the bricks [15].

To carry out the energy evaluation in the intermittent kiln, the temperature profiles, and the guidelines for the calculation of thermal balance in brick kilns were considered [16]. Firstly, it was necessary to determine the coal composition used for the firing process, in this sense, several samples were taken, pulverized, and analyzed in the coal laboratory of Universidad Francisco de Paula Santander, Colombia, and metallurgical laboratory of Universidad Industrial de Santander, Colombia, respectively. Clay properties [17], kiln and loading products dimensions as well as the emission factors for Colombian fuels [18], necessary for the energy evaluation were also evaluated.

The thermodynamic balance of intermittent kiln revealed that the heat that is used for the clay firing process and 68.71% corresponds to the heat that is lost to the outside during the process. The heat loss through the kiln masonry is equivalent to 7.26×10^6 KJ of the energy supplied (16.99%), followed by losses through the wall kiln that were 5.20×10^6 KJ (12.17%), finally, 0.91×10^6 KJ (2.13%) were lost due to the gases discharged in the chimney.

Based on the energy evaluation, it was determined that the heat loss in the heat accumulation in the masonry of the kiln was 7.26×10^6 KJ. Additionally, approximately 221 Kg of coal are being consumed per firing process in each kiln due to heat accumulation in the masonry. Therefore, the change in technology from an intermittent kiln to a continuous process kiln would save 2652 Kg of coal per kiln per month, provided that three firings are carried out per week, as is currently the case.

Figure 2 shows the results obtained for the pollutant emissions as well as the permissible values according to standards of "Ministerio de Ambiente, Vivienda y Desarrollo Territorial", Colombia, for manufacturing industries of refractory, non-refractory, and clay ceramic products. The abscissa represents the pollutants, and the ordinate represents the concentration of the pollutants recorded in mg/m^3. The Figure 2 shows the comparison of the value recorded for each pollutant and compares it with the value established in the standard. Note that all values of pollutant emissions were corrected at reference conditions and at reference oxygen conditions of 18%, also, each value reported corresponds to the average value of three measurements.

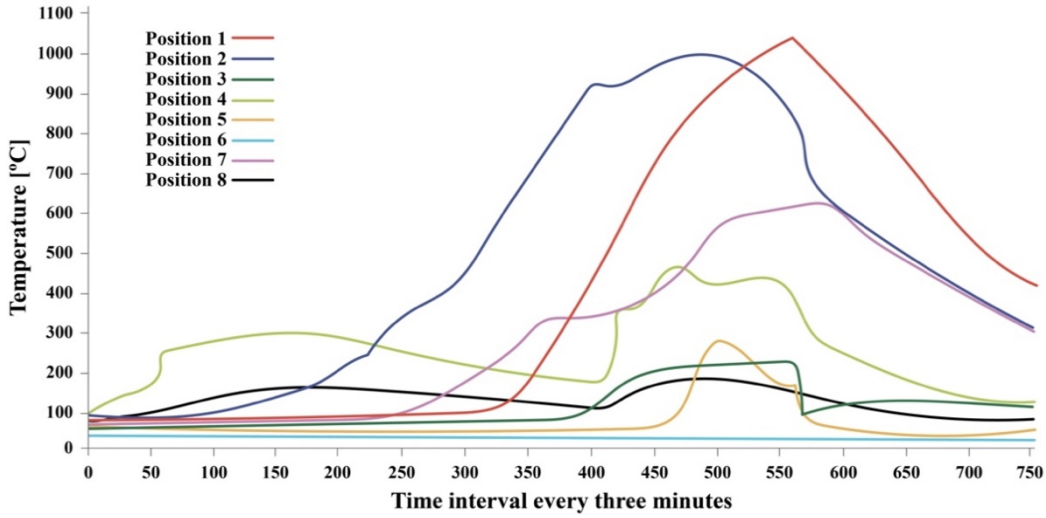


Figure 1. Temperature profiles at the selected positions of kiln.

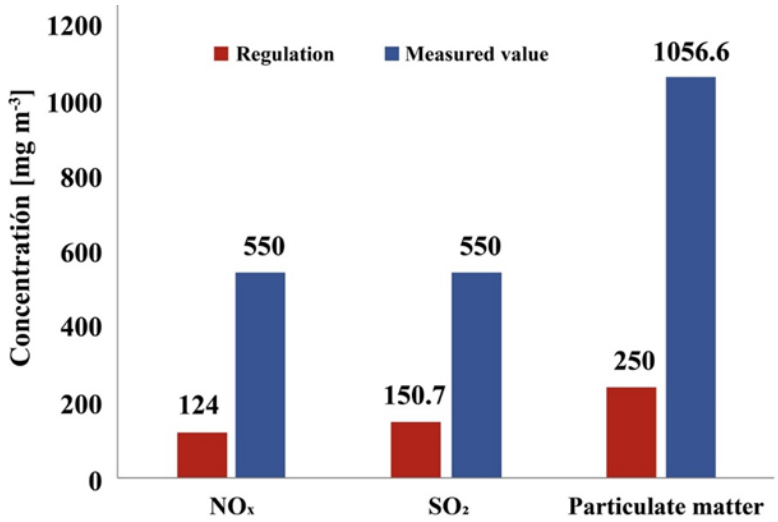


Figure 2. Comparison of results of pollutant measurements with the regulation.

4. Conclusions

The design and development of the graphic interface allowed the acquisition of temperature in the kilns for the production of ceramic materials, demonstrating the potential of the computational tool. This made it possible to quantify the energy losses in the firing process and, as a result, to propose constructive and operative changes in the operation of the kilns. One of them is to change the kiln design leading to the reuse of exhaust gases. To achieve this, the gases are directed to the interior of another kiln already prepared and loaded, causing the gases to pass through the interior of the other kiln before

going to the chimney, reducing the action of the buoyancy of the hot gases, the residence time of the gas inside the kiln. Thus, the hot gases will exchange heat with each other, providing a preheating of the next load of bricks. With this, the production in the kilns will be sequential and in cycles, raising its temperature, improving the combustion of coal, reducing energy consumption, reducing emissions of pollutants into the atmosphere, and improving the quality of the products.

In the acquisition of exhaust gas temperature data in the selected kiln, temperatures ranging around 100 °C were observed, implying great possibilities for waste heat recovery in the use of parts drying, as well as drying and preheating of combustion air. The thermodynamic balance of intermittent kiln revealed that the amount of heat supplied by the fuel was 49.2×10 KJ. Of this amount, 68.71% represents the portion of heat that is used for the clay firing process and 31.29% corresponds to the heat that is lost to the outside during the process. The average temperature of the exhaust gases at the chimney exit was 66.15 °C, which indicates compliance with Ministerio de Ambiente, Vivienda y Desarrollo Territorial regulations. In addition, the gases emitted to the environment still have the possibility of recovery of residual heat to be used for pre-drying parts as well as preheating of combustion air.

The average value of particulate matter concentration emitted to the environment through the kiln chimney was 1056.60 mg/Nm^3, which indicates that it is not complying with "Ministerio de Ambiente, Vivienda y Desarrollo Territorial" normative, in this sense, systems that allow filtering of particles such as cyclonic method should be implemented. Due to the fact that intermittent kiln of "Granito de Oro" brickworks does not have control and adjustment of the combustion process, it has an excess air of 28.56% and combustion efficiency of 88.22%. This air excess generates an increase in fuel consumption, thermal losses, and an increase of emissions to the environment.

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