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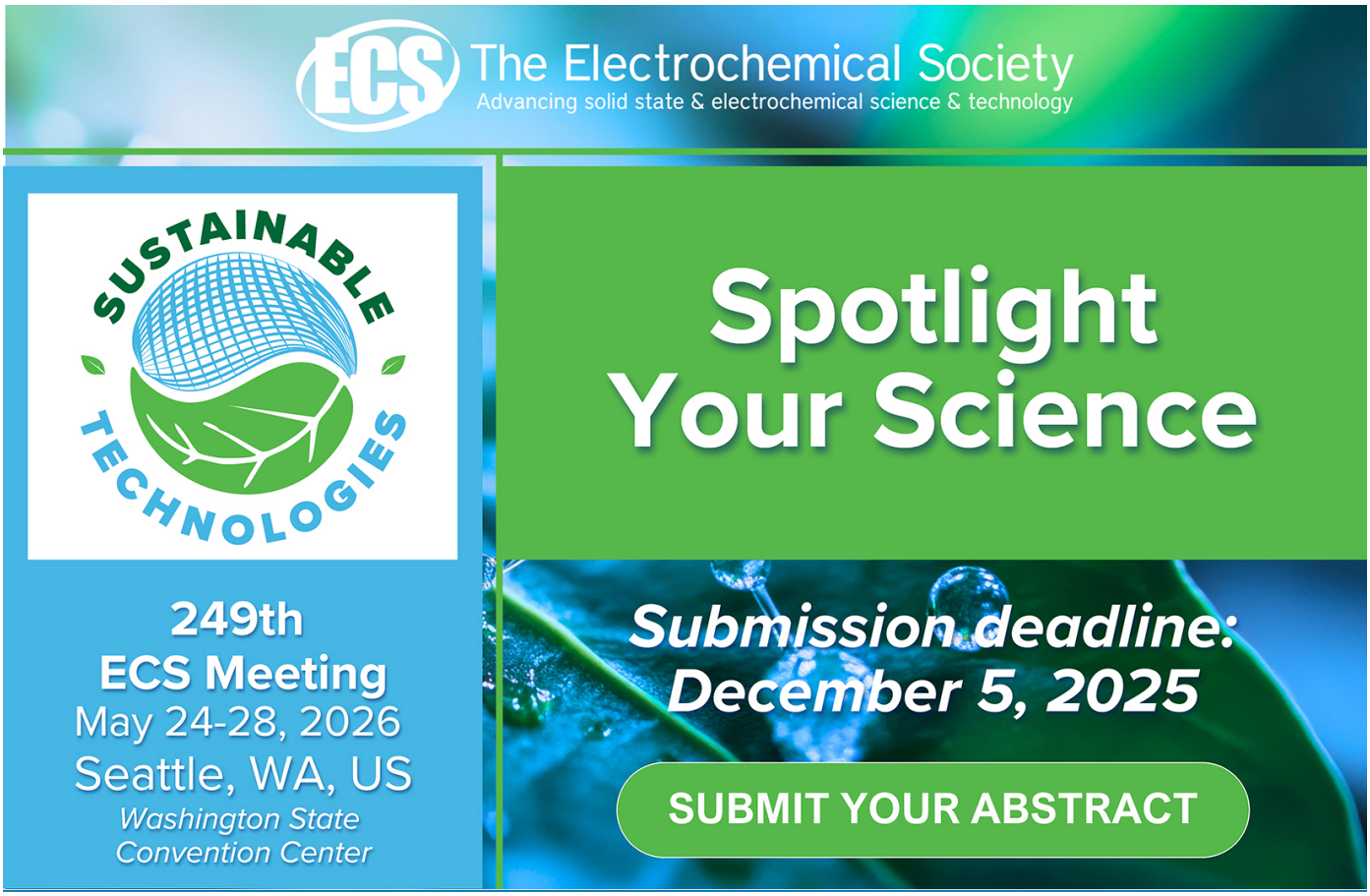
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Temperature acquisition and heat loss on the wall of an intermittent kiln

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Abstract. In the research the temperature acquisition was carried out inside and outside the wall an intermittent furnace and the evaluation of the energy loss on the wall during baking process, the first phase begins with the design, programming and implementation of an virtual instrument for data temperature acquisition and generation of temperatures profiles then, heat loss due to conduction on the furnace wall was determined considering one-dimensional heat flow, in radial direction and in a transitory state. The virtual instrument was programmed every 5 minutes and 1596 data were recorded, the input heat supplied to the furnace was $49.2x10^6$ KJ and the energy losses due to the furnace wall were $5.2x10^6$ KJ indicating the 10.57 percent of the supplied energy. Results of research have made it possible to establish trends in the temperature distribution, as well as identify thermal energy entering and leaving the furnace to propose improvements in performance of the furnace that increase its energy efficiency, reduce fuel consumption and gas emissions to the environment avoiding acute respiratory diseases.

1. Introduction

The ceramic sector in Colombia uses fossil fuels in the firing process [1] and its energy consumption is unsustainable since the fuel deposits are being depleted [2] and their use is causing serious environmental problems [3], which are beginning to have severe repercussions on the planet.

The brick companies in the province of Ocaña, Norte de Santander, Colombia, use intermittent kilns for the production of ceramic materials [4]. These kilns are not very energy efficient [5] as they depend largely on the expertise of the operators in charge of the firing and the combustion is incomplete [6]. This results in poor product quality [7], increased fuel consumption [8], heat loss [9], and air pollution emissions [10]. Clays are used in the elaboration of the products, which have in their chemical composition silica [11], aluminum [12], and oxygen [13], among others.

Therefore, strategies are required that can improve the current problem and for this purpose a virtual instrument is designed, developed, programmed, and implemented for the acquisition of temperature data and generation of temperature profiles for the firing process of ceramic materials. This instrument will allow the thermodynamic evaluation of the combustion process in the kilns.

Research work is developed with the purpose of knowing the thermal behavior of the kiln wall and the evaluation of heat loss to the environment, establishing ideal temperatures and times in the firing process to achieve greater performance and better competitiveness in the market.

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2. Methodology

The study was carried out in the intermittent kiln of the brickworks "Ladrillera el Recreo", Ocaña, Colombia. This study contains the acquisition of temperature data of the internal and external wall of the kiln in the process of firing the products and the evaluation of heat loss by conduction in the kiln walls. The kiln has a circular cross-section with an internal and external diameter of 2.12 m and 2.60 m respectively and a height of 2.26 m the kiln has a door where products are loaded and unloaded, which is located at the top, 1 m high and 0.48 m wide. The thickness of the kiln wall is 0.24 m the consumption of coal for firing was 1.500 kg of coal [14] and 4.300 solid bricks were produced.

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, one acquisition cards equipped with 2 type K thermocouples each were used, which were located at a distance of 1.26 meters from the floor, recording the external and internal temperatures of the wall of the kiln. The readings were stored through the Labview software in the acquisition report, and allowed to generate the temperature profiles in the positions of the chamber chosen as a reference for the measurements.

2.2. Heat exchange in the kiln

The analysis of the heat exchange through the kiln is carried out considering the energy input and the energy losses by conduction in the kiln [15].

2.2.1. Input heat. It is the energy released in the combustion of the coal used during the firing [16]. The following Equation (1) given by [6], was used for the evaluation.

$$Q_H = P_c * m_c, \tag{1}$$

where Q_H is the input heat (kJ), P_C is the calorific value of coal in (kJ/kg), and m_C is the mass of fuel in (kg).

2.2.2. Heat loss through the walls. This conduction heat loss in the wall is caused by the difference in temperature between the wall and the environment [17]. For this evaluation, one-dimensional heat flow in the radial direction and in a transient state was considered. The following Equation (2) given by [6], was used for the evaluation.

$$Q_{pa} = U_{pa} * (T_{3i} - T_{7e}) * t, \tag{2}$$

where Qpa is the loss of heat through the walls of the kiln in (kJ), Upa is the overall heat transfer coefficient on the kiln walls in (W/K), T3i is the Interior wall surface temperature of the kiln in (°C), T7e is the external wall surface temperature of the kiln in (°C), and t is the operating time in (s). A time lapse every 30 minutes was considered for the evaluation. For the evaluation of the overall heat transfer coefficient for the kiln wall, the following Equation (3) given by [6], was used.

$$U_{pa} = \frac{1}{R_{k\,pa}}, \tag{3}$$

where Rk pa is the thermal resistance by conduction of the kiln wall in (K/W). For the evaluation of the thermal resistance by conduction of the kiln wall, the following given by [6], Equation (4) was used.

$$R_{k\,pa} = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\,\pi\,k\,h}, \tag{4}$$

where r_o and r_i are the outer and inner radius of the kiln respectively in (m), h is the height of the kiln in (m), and k is the thermal conductivity of the brick wall of the kiln (W/m K). The thermal conductivity of the common brick wall was considered to be homogeneous with a value of k = 0.72 W/m K [18].

3. Results

3.1. Validation of the virtual instrument

After installing the temperature acquisition and recording equipment, the software was programmed to record temperatures in all thermocouples installed in the kiln every 5 minutes from the start to the end of the firing process, then, the program was executed. The monitoring lasted two days and nineteen hours, 798 data were recorded in each thermocouple for a total of 1.596 readings. At the end of the cooling process, the acquisition was stopped and the report of monitored temperature profiles inside and outside of the chamber throughout the firing process were generated (see Figure 1).

The internal wall temperature of the kiln increases as the combustion progresses and in fifteen hours reaches a temperature of 283.48 °C. Then, it decreases to 161.31 °C within thirty-five hours of having started the firing process. It continues to rise until it reaches the maximum temperature of 453.87 °C in forty-one hours. Then, it decreases until it reaches room temperature in eighty-four hours.

The external wall temperature of the kiln increases as the combustion progresses and in fifteen hours it reaches a temperature of 140.10 °C. Then, it decreases to 85.47 °C within thirty-five hours of having started the firing process and continues to rise until it reaches the maximum temperature of 173.17 °C in forty-one hours. Then, it decreases until it reaches room temperature in eighty-four hours. There are four variations in the external and internal wall temperatures, but they occur at the same time in the external and internal wall. This is because combustion does not advance gradually in the kiln due to the way the coal is charged between each row of bricks. From the energy evaluation, the energy supplied in the firing process and heat loss by conduction through the kiln wall.

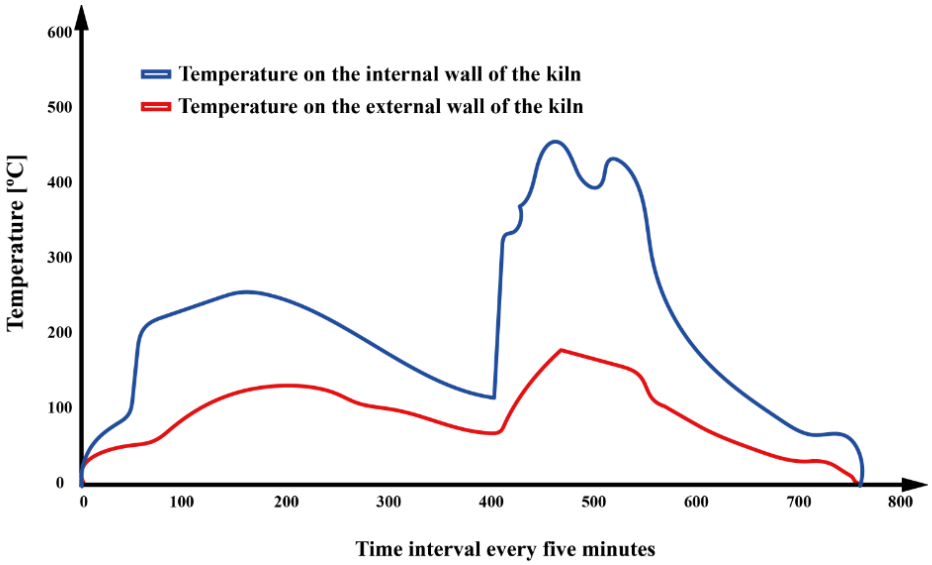


Figure 1. Temperature on the internal and external wall in the kiln.

The input heat supplied to the kiln of brickworks is $49.20*10^6$ kJ. Table 1 and Figure 2 show the results of heat loss accumulated on the kiln wall every three hours. Further, Figure 2 shows how the heat loss through of the furnace wall evolves. The first part evidences that there is a slow heating time with a duration of 12 hours approximately, followed by a decrease in the wall's internal temperature from 283.48 °C to 161.31 °C due to heat loss on the wall and upper surface of the furnace. Then a constant area between forty–eight and fifty– seven hours from start of the baking process and finely the cooling area between sixty-three and eighty-four hours from the start of the baking process.

Compared to the research conducted in a beehive furnace of reverse shot located in the San José de Cúcuta city, Colombia, in which the baking process lasted 78.25 hours, the fuel used added 833.65*10^6 kJ of energy and a heat loss occurred on the wall and dome of 6.56*107 kJ, which represents the 7.87% of the total energy [6], on the other hand in the analyzed furnace the baking process lasted 84 hours, the fuel used added 49.2x10^6 KJ of energy and a heat loss occurred on the wall of 5.20*10^6 kJ which represents the 10.57% of the total energy indicating that 2.7% more of energy is being lost compared to the furnace used in the San José de Cúcuta, Colombia.

Table 1. Heat loss accumulated on the kiln wall every three hours.

t (3h)	1	2	3	4	5	6	7	8	9
Q *10^6 (J)	10.910	82.59	161.10	232.60	219.30	218.40	211.50	190	254.30
t (3h)	10	11	12	13	14	15	16	17	18
Q *10^6 (J)	161.40	211.10	180.20	120.90	109.20	201.10	363.10	410.50	349.60
t (3h)	19	20	21	22	23	24	25	26	27
Q *10^6 (J)	384.70	315.60	205.80	162.10	133.40	107.80	78.02	74.90	60.44

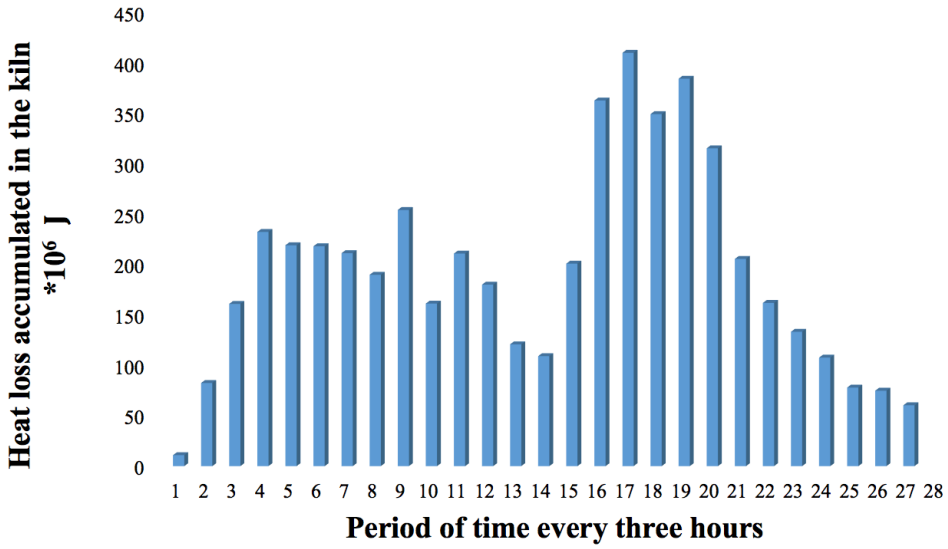


Figure 2. Heat loss accumulated on the kiln wall every three hours.

4. Conclusions

Heat loss trough kiln wall in the time between forty–five at sixty–three hours from start of the baking process reach the 43% of the total heat loss on the kiln wall. At fifty–one hours from the start of the baking process is presented the most heat loss with a value of 384.70 *10^6 kJ indicating the 7.38% of the total heat loss on the kiln wall. The amount of heat supplied by the fuel was 49.20*10^6 kJ and the heat loss in the kiln wall is 5.20*10^6 kJ, which represents 10.57% of the total energy supplied. The remaining 89.43% is used for the firing process, heat loss in masonry, and the energy of the gases emitted into the environment.

Heating of the kiln wall is very slow causing that the smoking time to be extended to twelve hours from the start of the baking process, these first twelve hours of baking can be considered misused time, which cause an increase in the water steam spread as well as the expansion of paste. Heat loss trough kiln wall remain constant in the time between forty–eight hours from the start of the baking process, it is indicating that the most significant shrinkage of the clay is occurring, so that is necessary to ensure a uniform temperature throughout kiln. To do the opposite will occur differences in shrinkage between the coldest and hottest areas of the kiln that would generate dangerous tensile stresses and crack.

Cooling time on the kiln wall lasted twenty–one hour between sixty–three and eighty–four hours from the start of the baking process, time longer than that established for said period, easily supporting the stresses caused by fast cooling.

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