Journal of Physics:
Conference Series

PURPOSE-LED PUBLISHING™

PAPER • **OPEN ACCESS**

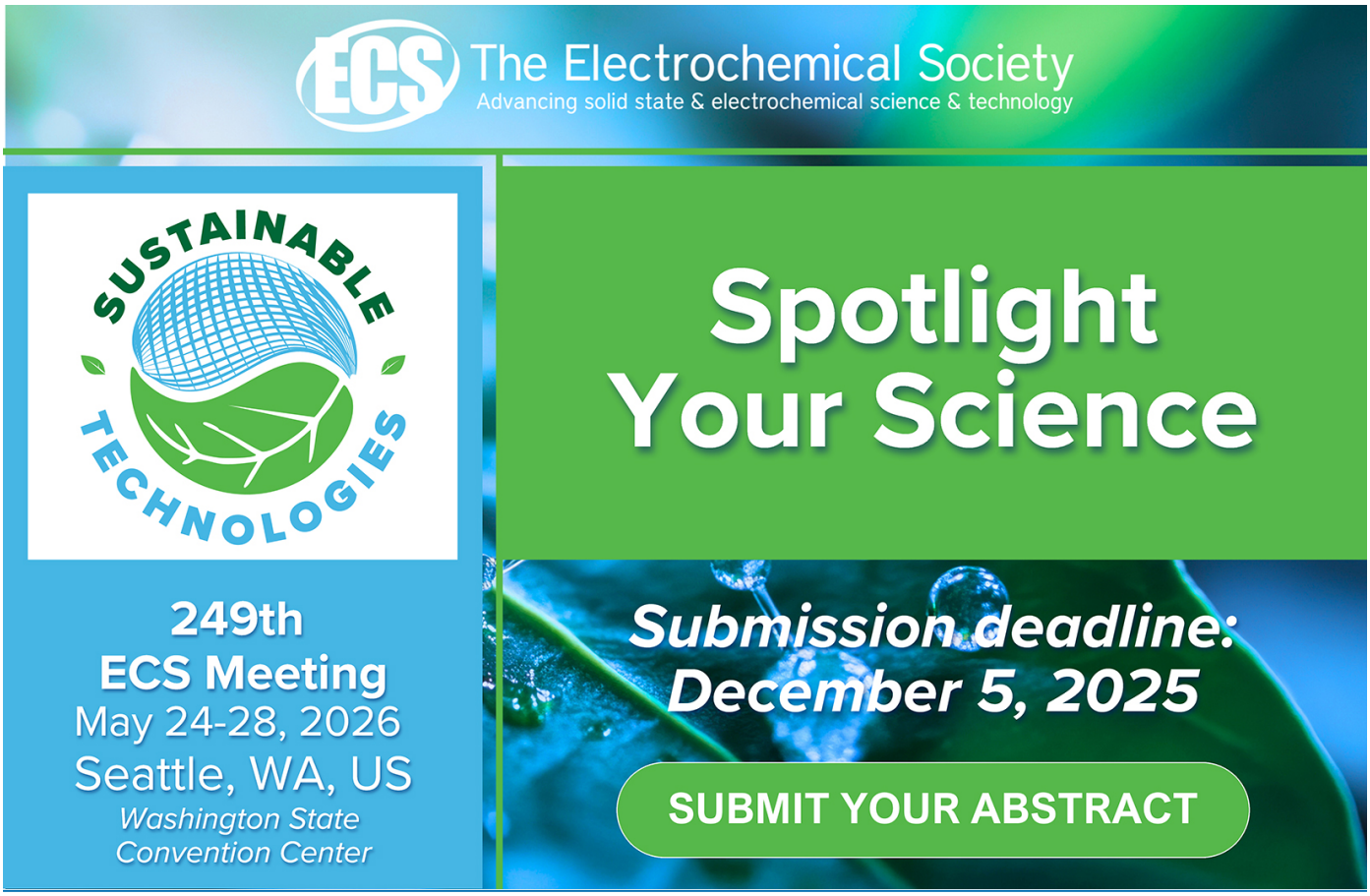
Recording of temperatures and heat accumulation in masonry in a continuous kiln used to produce ceramic materials

To cite this article: G Guerrero Gómez *et al* 2021 *J. Phys.: Conf. Ser.* **2073** 012011

View the article online for updates and enhancements.

You may also like

- Woody perennials as bio-monitors of air pollution around brick kilns in peri-urban ecosystem using pollution tolerance indices
Ali Ahmad, Sohaib Muhammad, Fahad Shafiq et al.
- New method for measuring and analyzing the deformability and eccentricity of the ferrule kilns
H S Amraoui, K I Janati and N Moujibi
- The connection between forest degradation and urban energy demand in sub-Saharan Africa: a characterization based on high-resolution remote sensing data
F Sedano, S N Lisboa, R Sahajpal et al.



This content was downloaded from IP address 8.243.64.131 on 23/10/2025 at 22:01

Recording of temperatures and heat accumulation in masonry in a continuous kiln used to produce ceramic materials

G Guerrero Gómez[1], N Afanador García[2], and R J Gallardo Amaya[3]
[1] Grupo de Investigación en Tecnología y Desarrollo en Ingeniería, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
[2] Civil Engineering Research Group, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
[3] Grupo de Investigación en Construcción, Geotecnia y Medio Ambiente, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia

E-mail: gguerrerog@ufpso.edu.co, nafanadorg@ufps.edu.co

Abstract. In Ocaña, Colombia, a traditional ceramic industry has been developed using low efficiency kilns without controls in the combustion processes, which generate large heat losses. As a result, it was necessary to implement a virtual instrument to monitor temperatures in the firing process. For the study, a continuous Hoffman kiln, and the temperature acquisition was carried out in two combustion chambers and lasted twenty-four hours. In the kiln firing process, the energy supplied due to coal combustion was 22198×10^6 KJ, while the heat accumulated in the kiln roof, walls and floor was 14452.6×10^6 KJ, 1085.71×10^6 KJ and 164.72×10^6 KJ respectively. The total heat stored in the masonry was 15703.03×10^6 KJ, representing 70.73 % of the energy supplied. Due to the material used in the construction of the kiln, the accumulated heat is high, and it is necessary to implement coatings using ceramic fibers on the kiln walls, keeping the temperature constant in the firing process and leading to a decrease in heat accumulation of about 20 %. Also, air, fuel, temperature, and pressure injection systems should be implemented.

1. Introduction

In Ocaña, Colombia, there are many companies in the clay industry, most of which carry out their production processes by hand [1], due to their low construction and maintenance costs [2] and intermittent operation [3], except for Ladrillera Ocaña, Colombia, which has technician its processes and operates continuously. The lack of controls on combustion processes [4], high emission rates [5], the failure to generate new products and, in general, the lack of technology to improve production processes [6], have the region's ceramics industry in a major crisis.

For this reason, strategies are required to ensure that the manufacturing process of ceramic materials in Ocaña, Colombia, is productive and efficient, to the point that it meets the standards of quality [7] and emissions of gases into the environment, to this also joins the national planning department that in its agenda of productivity and competitiveness for Norte de Santander department, Colombia, established that the ceramic sector should be the national leader in the field of production of high quality ceramic materials [8].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

In this research, a virtual instrument was designed, programmed, and implemented for the acquisition of temperature data, which generates temperature profiles, with which the evaluation of heat accumulation in masonry in the combustion process in the kilns is performed. This instrument will visualize the thermal behavior of the kiln, leading to a better combustion of the firing process, reducing fuel consumption, reducing the emission of gases into the environment, and improving the performance and competitiveness in the market. From this, implementations can be made with coatings using ceramic fibers on existing kiln walls that lead to less heat accumulation in masonry during the firing process. By using ceramic fibers on existing kiln walls, a decrease in heat accumulation of about 20% can be achieved.

2. Methodology

The research was carried out in the continuous Hoffman kiln of Ladrillera Ocaña, Colombia, is a highly productive continuous kiln that operates 24 hours a day, 365 days a year, which is an advantage over the traditional kilns used for the transformation of ceramic material in the municipality of Ocaña, Colombia. The Hoffman kiln consists of two combustion chambers in which the combustion gases are recirculated and utilized [9].

The cross section of the kiln is composed of an outer wall 1.80 m high and 0.90 m thick, where 9 loading doors and an equal number of gas extraction doors are located. A solid central wall of 1.20 m thick and an elliptical dome of 2.70 m of semi-major axis and 1 m of semi-minor axis. From where the dome begins to the top where the furnace ends, there is a height of 1.90 m covered with brick [10]. Figure 1 shows the kiln roof as well as the orifices through which pulverized fuel is injected into the kiln. In total for the analysis, there are 168 holes with a diameter of 0.165 m and an average length of 1.21 m, while the furnace floor is 2.70 m wide and 0.15 m thick.

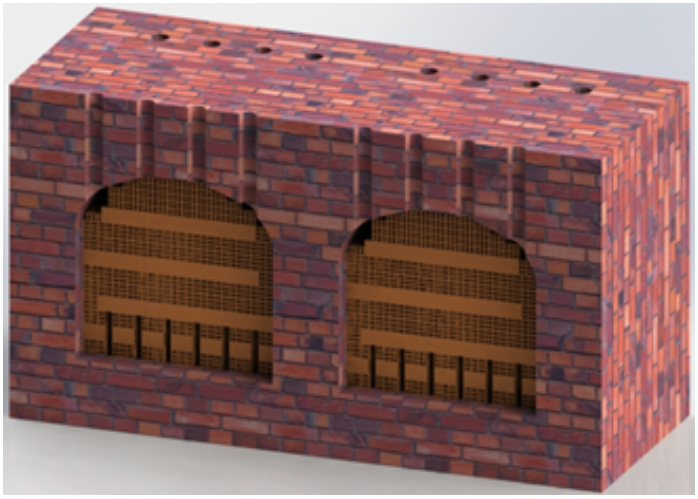


Figure 1. Combustion chambers in the kiln and combustion chambers in the kiln and cross-section combustion chambers, injection holes, and product stacks.

2.1. Temperature data acquisition and generation of temperature profiles

The research work begins with the design, development, programming, and validation of a virtual instrument for the acquisition of temperature data and generation of temperature profiles for the firing process in kilns to produce ceramic materials [11]. Temperatures were measured inside and outside the wall, roof, and floor of the kiln. For the measurement of internal temperatures, chrome aluminum alloy bulb thermocouples type K with ceramic insulation were used [12], and for the measurement of external temperatures, wire thermocouples type K were used. Once the thermocouple assembly was completed, the thermocouple terminals were connected to the NI 9213 I/O module attached to the NI 9184 chassis, and the program was tested and executed, starting the temperature data acquisition.

The research aims to estimate the heat exchange taking into account the heat generated by fuel combustion and heat accumulation in the kiln masonry, which will allow improving the thermal processes in the kilns, ensuring greater thermal efficiency, which will reduce fuel consumption.

2.2. Heat input

The heat input is the energy released by the combustion of the coal used during the burning process and is equal to the calorific value of the coal multiplied by the coal consumption during the firing process [13], for the evaluation of this heat, the following expression is used see Equation (1).

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

where Q_H is heat input in (KJ); P_c is calorific value of coal in (KJ/Kg); and m_c is fuel mass in (Kg).

2.3. Heat storage in masonry

The heat released inside the furnace is transferred to the roof, walls, and floor of the kiln [14]. For the evaluation of this heat, the following expression is used see Equation (2), Equation (3), Equation (4), and Equation (5).

$$Q_o = Q_{o_{pa}} + Q_{o_{tec}} + Q_{o_{pis}}, \tag{2}$$

$$Q_{o_{pa}} = \rho_o * C_o * V_{pa} * T_{m_{Pa}}, \tag{3}$$

$$Q_{o_{tec}} = \rho_o * C_o * V_{tec} * T_{m_{tec}}, \tag{4}$$

$$Q_{o_{pis}} = \rho_o * C_o * V_{P_{is}} * T_{m_{Pis}}, \tag{5}$$

where Q_o is heat storage in masonry in the kiln in (KJ); $Q_{o_{pa}}$ is heat stored in the kiln wall in (KJ); $Q_{o_{tec}}$ is heat stored in the kiln roof in (KJ); $Q_{o_{pis}}$ is heat stored in the kiln floor in (KJ); V_{pa} is kiln wall volume in (m^3); V_{tec} is kiln roof volume in (m^3); V_{Pis} is kiln floor volume in (m^3); $T_{m_{Pa}}$ is average kiln wall temperature in (°C); $T_{m_{tec}}$ is average kiln roof temperature in (°C); and $T_{m_{Pis}}$ is average kiln floor temperature in (°C). To evaluate the heat storage in the masonry, the maximum temperatures during the test are taken [15], with the temperatures of the outer surface T_7 and inner surface T_3 of the wall, the average temperature of the kiln wall $T_{m_{Pa}}$ is evaluated; with the temperatures of the outer surface T_8 and inner surface T_4 of the kiln roof, the average kiln roof temperature $T_{m_{tec}}$ is evaluated, and with the temperatures of the outer surface T_6 and inner surface T_2 of the kiln floor, the average kiln floor temperature $T_{m_{Pis}}$ is evaluated.

A working length of 44.10 m was taken for the heat storage analysis. The volume of the exterior wall will be evaluated by subtracting the volume of the 9 loading and unloading doors and the 9 smoke doors from the volume of the exterior wall. To evaluate the volume of the kiln wall, the following expression is used (see Equation (6)).

$$V_{Pa} = V_{P_e} + V_{P_c} - V_{P_u} - V_{P_h}, \tag{6}$$

where V_{Pa} is kiln wall volume in (m^3); V_{P_e} is outer kiln wall volume in (m^3); V_{P_c} is volume of the kiln center wall in (m^3); V_{P_u} is volume of the product loading and unloading doors in (m^3); and V_{P_h} is volume of flue doors in (m^3). To evaluate the volume of the kiln's outer wall, the following expression is used Equation (7).

$$V_{P_e} = L * h * t_{P_e}. \quad (7)$$

To evaluate the volume of the kiln's central wall, the following expression is used Equation (8).

$$V_{P_c} = L * h * t_{P_c}. \quad (8)$$

To evaluate the volume of the kiln loading and unloading door wall, the following expression is used Equation (9).

$$V_{P_u} = a * H * t_{P_e}. \quad (9)$$

To evaluate the volume of the flue door wall, the following expression is used Equation (10).

$$V_{P_h} = b * z * t_{P_e}, \quad (10)$$

where V_{P_e} is outer kiln wall volume in (m^3); V_{P_c} is volume of the kiln central wall in (m^3); V_{P_u} is volume of the product loading and unloading doors in (m^3); V_{P_h} is volume of flue doors in (m^3); L is kiln working length in (m); h is kiln wall height in (m); t_{P_e} is outer wall thickness in (m); t_{P_c} is center wall thickness in (m); a is width of kiln loading and unloading door in (m); H is kiln loading and unloading door height in (m); b is width of flue door in (m); and z is flue door height in (m). To evaluate the kiln roof volume, the following expression is used Equation (11).

$$V_{tec} = V_{sup} - V_{cup} - V_{tub}, \quad (11)$$

where V_{tec} is kiln roof volume in (m^3); V_{sup} is kiln top volume in (m^3); V_{cup} is kiln dome volume in (m^3); and V_{tub} is volume of fuel supply pipes in (m^3). To evaluate the kiln loading and unloading door wall volume, the following expression is used: to evaluate the kiln top volume, the following expression is used Equation (12).

$$V_{sup} = L * h_{sup} * d_{sup}. \quad (12)$$

To evaluate the kiln dome volume, the following Equation (13) is used.

$$V_{cup} = \frac{\pi * a_{cup} * b_{cup} * L}{2}. \quad (13)$$

To evaluate the volume of the fuel supply pipes, the following expression is used Equation (14).

$$V_{tub} = \pi * r^2 * L_t * n, \quad (14)$$

where V_{sup} is kiln top volume in (m^3); V_{cup} is kiln dome volume in (m^3); V_{tub} is volume of fuel supply pipes in (m^3); L is kiln working length in (m); h_{sup} is kiln top wall height in (m); d_{sup} is width of kiln cross section in (m); a_{cup} is semi-major axis parabola of the dome in (m); b_{cup} is semi-minor axis parabola of the dome in (m); r is radius of the fuel supply pipes in (m); L_t is length of fuel supply pipes in (m); and n is number of fuel supply pipes. To evaluate the kiln floor volume, the following expression is used Equation (15).

$$V_{Pis} = L * s * t_{pis}, \quad (15)$$

where V_{Pis} is kiln floor volume (m^3); s is width of the kiln floor cross section; and t_{pis} is kiln floor thickness (m).

3. Results

The temperature data acquisition lasted twenty-two hours and 38 minutes. The virtual instrument was programmed to record temperatures every 3 minutes, so each thermocouple recorded 441 data for a total of 2646 temperature records. Figure 2 shows the temperature profiles inside and outside the kiln roof, wall, and floor.

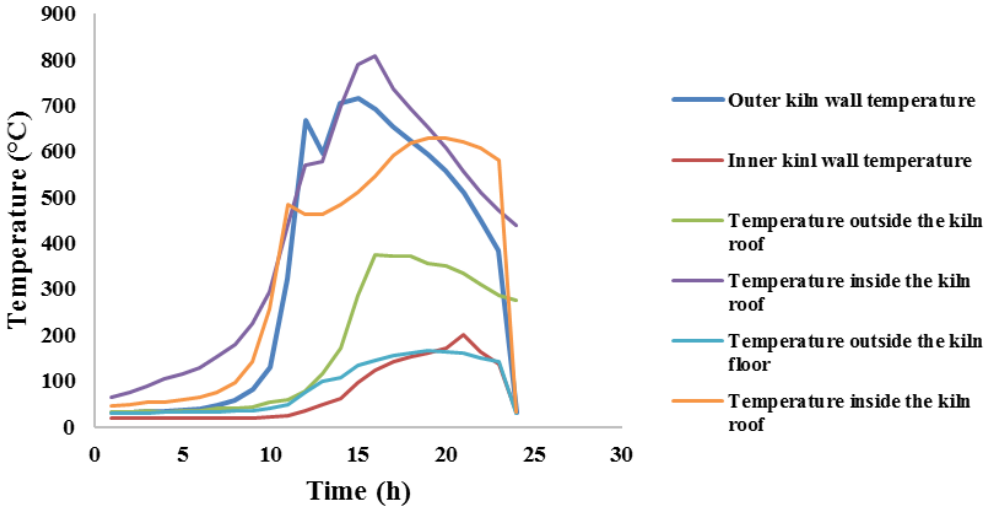


Figure 2. Temperature profiles inside and outside the kiln roof, wall, and floor.

The kiln walls begin to reach temperature 10 hours after the start of firing, with a maximum temperature on the internal and external walls of 800 °C and 200 °C respectively, and the temperature gradient is in the range of 200 °C to 700 °C. Since fuel is injected through the roof for combustion, the phenomenon of heat transfer by convection and radiation of the flame means that this position acquires temperature faster and has higher temperatures than in other positions of the kiln, with a maximum temperature inside and outside the roof of 850 °C and 400 °C respectively, with a temperature gradient in the range of 100 °C to 450 °C, resulting in a better temperature distribution for this position.

The maximum temperature inside and outside the floor is 600 °C and 150 °C respectively. The temperature difference between the inside of the roof and the kiln floor is approximately 200 °C, which means that the products in the lower part of the kiln do not achieve complete firing, resulting in deficient firing and a decrease in the quality of the products. In the firing process, the energy supplied to the kiln from coal combustion was 22198×10^6 KJ. To determine the heat stored in the kiln masonry, radial heat flow in a transient state was considered, the results of the external and internal temperatures of the kiln, the properties of the clay [16], the dimensions of the kiln and for the calorific value of the coal were considered. For the calorific value of the coal, a sample was pulverized and analyzed in the metallurgical laboratory of Universidad Industrial de Santander, Colombia, which was tested according to ASTM D5865 standard [17].

The volume of the outer wall, center wall, kiln loading and unloading door wall and flue door are 71.44 m^3, 95.26 m^3, 1.76 m^3 and 0.083 m^3 respectively, so the volume of the kiln wall is 150.11 m^3. The volume of the top, kiln dome and fuel supply pipes is 402.19 m^3, 93.52 m^3 and 17.39 m^3 respectively, so the volume of the roof is 291.28 m^3 and the volume of the kiln floor is 17.86 m^3. The heat stored in the roof, walls and floor of the kiln was 14452.6×10^6 KJ, 1085.71×10^6 KJ, and 164.72×10^6 KJ respectively, for a total storage in the masonry of 15703.03×10^6, representing 70.73% of the energy supplied.

On the other hand, comparing the heat accumulation in masonry in the continuous furnace of 157.03×10^8 KJ with the data reported for a beehive kiln of 2.172×10^8 KJ [18], which was built with refractory brick, indicates that using refractory reduces heat accumulation by 72.36%. In similar studies using a three-row conventional brick wall of 345 mm thickness, which is exposed to an internal temperature of 1000 °C and an external temperature of 120 °C, a heat accumulation of 67100 Kcal/m^2 is obtained. On the other hand, in a three-row conventional brick wall of 345 mm thickness covered with ceramic fiber of 50 mm thickness and density 128 Kg/m^3 exposed to an internal temperature of 1000 °C and an external temperature of 99 °C, a heat accumulation of 52895 Kcal/m^2 is obtained, reaching a decrease in heat accumulation of 20% [18].

4. Conclusions

In the temperature profiles located inside the kiln, it can be observed that in the first instance the kiln accumulates heat in the roof, because through the holes located in the roof the coal is injected for combustion and as the flame descends, the temperatures on the walls and floor increase due to the phenomenon of heat transfer by convection and radiation. This means that in this position the temperature rises faster, and the temperatures are higher than in other positions of the kiln, with a maximum temperature inside the kiln of 850 °C, a temperature gradient in the range of 100 °C to 450 °C, and a better temperature distribution for this position.

The temperature difference between the inside of the floor and the ceiling of 200 °C, makes the current firing deficient, as the products that are closer to the fuel injection ducts may melt and the bricks on the floor may not be fired. To maintain a constant temperature during the kiln firing process, it is essential to use thermal insulation through ceramic fibers that have low thermal conductivity and reduce the flow of heat. An important operating variable in the firing process was the rate of descent of the combustion gases, which has a determining influence on both the average temperature and the distribution of the temperature profiles of the brick in the kiln.

In the firing process in the kiln, the energy supplied to the kiln due to coal combustion was 22198×10^6 KJ. The heat stored in the roof is 14452.6×10^6 KJ which means 92.03% of the heat accumulation in masonry, followed by the walls with 1085.71×10^6 representing 6.9% of the heat accumulation in masonry and the floor with 164.72×10^6 KJ representing 1.07% of the heat accumulation in masonry of the kiln. The total heat accumulation in masonry is 15703.03×10^6 kJ, which is equivalent to 70.73% of the energy supplied. This heat accumulation in masonry does not occur in practice, since the firing process in this kiln is continuous, operating 24 hours a day, 365 days a year, and this heat should be considered as a loss of energy only when the kiln was turned on.

For this reason, ceramic fibers should be used on the current kiln walls, which will lead to less heat accumulation in masonry, due to their low density, and low flame propagation index. Also, their physical-chemical properties do not alter throughout their use nor do they tend to react chemically with other materials during their use, and they have low hygroscopocity. The Hofmman kiln takes advantage of the residual heat coming from the firing of the previous chambers to preheat the adjacent chambers and dry the products loaded in this chamber, saving time and energy in this initial stage of the firing, generating savings in fuel consumption.

Future research can implement an air injection system necessary for the firing process to improve the combustion process, reducing the amount of fuel used, thermal losses in the kiln and maintain constant temperature in the kiln. Another implementation is to automate the fuel supply and continuous monitoring system in the firing process through acquisition sensors and monitoring through thermocouples in the kiln, improving fuel dosing conditions, as well as recording firing curves for the products and the combustion pressure of air in the process.

References

[1] Santiago D, Cañizares H 2012 *Diagnóstico de los Procesos de Combustión Ejecutados en la Industria Cerámica en el Área Metropolitana de San José de Cúcuta* (San José de Cúcuta: Universidad Francisco de Paula Santander)
[2] Ministerio de Ambiente, Vivienda y Desarrollo Territorial 2008 *Normas y Estándares de Emisión Admisibles de Contaminantes a la Atmósfera por Fuentes Fijas, Resolución 909* (Colombia: Ministerio de Ambiente, Vivienda y Desarrollo Territorial)
[3] Guerrero G, Espinel E, Flórez E 2017 Medición de emisiones atmosféricas en hornos a cielo abierto en el Municipio de Ocaña, Norte de Santander *Revista Ingenio* **14(1)** 53
[4] Beleño Mier O, Velosa Ariza Y 2011 *Diagnóstico del Desempeño Térmico de la Hornilla Piloto "Ward-Cimpa" Utilizada en el Proceso de Producción de Panela en Corpoica* (Bucaramanga: Universidad Industrial de Santander)
[5] Garrett C W 1992 On global climate change, carbon dioxide, and fossil fuel combustion *Progress in Energy and Combustion Science* **18(5)** 369
[6] Osorio J, Ciro H, Espinosa A 2010 Evaluación térmica y validación de un modelo por métodos computacionales para la hornilla panelera GP150 *DYNA* **77(162)** 237
[7] Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC) 2000 *Unidades de Mampostería de Arcilla Cocida. Ladrillos y Bloques Cerámicos, Norma Técnica Colombiana, NTC 4205* (Colombia: Instituto Colombiano de Normas Técnicas y Certificación)
[8] Departamento Nacional de Planeación 2007 *Agenda Interna para la Productividad y la Competitividad: Norte de Santander* (Bogotá: Departamento Nacional de Planeación)
[9] Guerrero G, Espinel E, Velásquez T 2017 Análisis isocinético y corrección a condiciones de referencia en horno a cielo abierto en el municipio de Ocaña, Norte de Santander *Revista Ingenio* **14(1)** 43
[10] Guerrero G 2017 *Hornos de Combustión: Alternativas de Reducción de Emisiones e Incremento de Rentabilidad* (Bucaramanga: Universidad de Santander)
[11] Marrugo D, Guerrero G, Gómez J 2015 Desarrollo de instrumento virtual enfocado en la adquisición de datos para generar perfiles de temperatura en hornos *Revista Ingenio* **8** 47
[12] Ramajo-Escalera B, Espina A, García J, Sosa-Arnao J, Nebra S 2006 Model-free kinetics applied to sugarcane bagasse combustion *Thermochimica Acta* **448(2)** 111
[13] Cengel Y, Boles M 2012 *Termodinámica* (México: McGraw-Hill)
[14] Ribelles J 1990 *Termodinámica: Análisis Energético* (Bogotá: Editorial Reverté)
[15] British Standards Institutions (BSI) 1987 *Fire Tests on Building Materials and Structures. Method of Measuring the Ignitability of Products Subjected to Thermal Irradiance, British Standards, BS 476-13:1987* (United Kingdom: British Standards Institutions)
[16] Peña G, Peña J, Gómez M 2014 Determinación experimental de la conductividad térmica efectiva en bloques extinguidos de arcilla roja *Ciencia en Desarrollo* **5(1)** 15
[17] Academia Colombiana de Ciencias Exactas, Físicas y Naturales (ACCEFYN) 2003 *Factores de Emisión de los Combustibles Colombianos* (Bogotá: Academia Colombiana de Ciencias Exactas, Físicas y Naturales)
[18] Jácome S 2015 *Evaluación Termodinámica del Proceso de Cocción y Análisis de Gases en Hornos a Cielo Abierto y Hoffman en Ocaña* (Ocaña: Universidad Francisco de Paula Santander)