Thermodynamic balance: Continuous oven

To cite this article: G Guerrero-Gómez et al 2018 J. Phys.: Conf. Ser. 1126 012025

View the article online for updates and enhancements.
Thermodynamic balance: Continuous oven

G Guerrero-Gómez¹, T Velásquez-Pérez¹ and N Afanador-García¹
¹ Grupo de Investigación en Desarrollo Tecnológico en Ingenierías, Universidad Francisco de Paula Santander, Ocaña, Colombia

E-mail: gguerrerog@ufpso.edu.co, velasquezp@ufpso.edu.co

Abstract: The energy evaluation of the cooking process of a Hoffman kiln was carried out at the Ocaña brickworks, through a virtual instrument with Lab View software using temperature sensors and data acquisition cards, which allowed the temperature monitoring and recording generating temperature profiles; then, we evaluated the amount of total heat added by the fuel and the heat loss present in the masonry, the material to be cooked, the moisture from the material, the chemical decomposition of clay, the moisture in coal, the water produced in the combustion, the air humidity, the unburned, the walls and the smoke, as well as the energy efficiency of the kiln and the yield per amount of cooked material.

1. Introduction
The ceramic industry in Colombia does not have any technification in its production processes, leading to a deficient combustion process that generates environmental and health issues due to its polluting emissions [1], as well as causing unnecessary costs for companies. An inadequate combustion process requires the use of larger amounts of fuel, and risks companies to the payment of fines by not complying with current environmental regulations [2].

In the province of Ocaña, the manufacture of ceramic materials is still mainly an artisanal method. These processes do not have temperature, air and fuel controls of the cooking process that lead to complete combustion [3]; on the other hand, the lack of equipment for monitoring, recording and control produces an increase in fuel consumption, low quality of its products [4] and high production costs.

2. Methodology
The kilns currently used in the ceramic sector in the municipality of Ocaña are open-pit handcrafted kilns built of ordinary brick, except the Ocaña brickworks, which has a continuous-type Hoffman kiln that is composed of 24 chambers or doors distributed of 12 per side, see Figure 1; in each door, up to 5 piles of 620 bricks are introduced, with a separation of 60cm among them.

Figure 1. Hoffman kiln.
The production process in the brickworks is mechanized, where the blocks are extruded and taken to the drying patio where they stay for 48 hours [5]; next, they are loaded in the kiln and the loading doors are sealed by means of a wall that is removed at the end of the cooking.

The fuel used in this kiln is a coal that is introduced into hammer mills transforming it into tiny particles that are transported to the top of the kiln using conveyor belts and are injected into the kiln with two Carbojet which are manually loaded. A Carbojet initiates the coal injection for preheating in the chamber; then, the second Carbojet burns the block [6]. The coal is injected using the holes located in the dome of the kiln through metal hoses at a rate of 8kg to 12kg of coal per minute, see Figure 2.

![Figure 2. Pile arrangement and fuel injection holes in the Hoffman kiln.](image)

2.1. Design, programming and installation of the temperature acquisition system
A virtual temperature acquisition instrument was designed, using an NI 9213 I/O data acquisition card assembled to the NI cDAQ-9184 chassis supported by National Instruments, in order to achieve the analog-digital processing of the information that is received from the thermocouples, to generate the temperature profiles.

The designed program shows on the monitoring screen in real time the temperature profiles of the positions where the thermocouples were located. When the acquisition process ends, a report is generated in which all the monitored temperature data and temperature profiles are recorded in a table using Excel.

The temperature acquisition equipments are placed in a monitoring room located close to the kiln for acquisition through the connection cable and are assembled in representative positions to subsequently carry out the thermodynamic balance. Type-K bulb thermocouples were installed to register the internal temperatures presented in the cooking process, and type-K wire thermocouples were selected in order to register the external temperatures in the kiln.

For the data acquisition, sixteen positions in the kiln were monitored using two acquisition cards with 8 thermocouples installed in each; in the first card or acquisition block, the inner temperatures in the kiln were recorded, registered from position 1i to position 8i (the thermocouples were installed simultaneously to the process of brick loading into the kiln); in the second acquisition card, external temperatures were registered from position 1e to 8e (the thermocouples were installed at the same time as the loading door was sealed), see Figure 3. The location of the thermocouples was as follows: 1 inner center, 2 inner floor, 3 inner wall, 4 inner dome, 5 external center, 6 external floor, 7 external wall, 8 external domes. In order to measure external temperatures, terminals with electrical insulation were made to protect them from humidity avoiding loss of voltage, which would lead to a wrong temperature record.

2.2. Energy evaluation of the kiln
The energy evaluation of the kiln was made calculating the total energy added by the fuel and the heat losses present in the masonry, the material to be cooked, the moisture from the material, the chemical decomposition of clay, the coal moisture, the water formed in the combustion, the air humidity, the unburned, the walls and the smoke, taking into account the temperature acquisition data.
3. Results

3.1. Validation of the virtual instrument in the selected kiln
After installing the temperature recording equipment, the configuration for the acquisition was made and the program was tested and executed. For this kiln, the software was programmed to record temperatures every 3 minutes for a total monitoring time of 22 hours and 38 minutes. 441 temperature data were recorded in each position in the kiln for a total of 7056 records in the cooking process. The obtained temperature profiles are shown in Figure 4.

![Image](a)

![Image](b)

**Figure 3.** Location of thermocouples in the Hoffman kiln.

**Figure 4.** Temperature profiles in the Hoffman type kiln.

3.2. Energy evaluation and heat losses in the Hoffman kiln
To perform the energy balance, we took into account the recommendations established by the British Standard Test Code standards [7] for the calculation of the thermal balance in brick kilns as well as the emission factors of the Colombian fuels published by the Colombian Mining and Energy Planning Unit UPME [8] for the elemental composition of coal. The energy supplied to the cooking process was determined and the heat flows present in the kiln were subtracted [9]; for this, we used the temperature profiles generated in different positions in the kiln in the cooking process, the clay properties [10], the kiln dimensions and volumes, and the products to be loaded into the kiln.

Figure 5 shows the thermodynamic balance for the kiln, associated with the heating and cooling processes. The first part is associated with the heating of the kiln parts including the load, and the last...
part is the total energy lost to the surroundings throughout the heating and cooking processes. We got a 78.73% of efficiency per heat used for the material cooking, calculated as the relation between the heat used for the material cooking and the heat contributed by the fuel; in addition, the yield per amount of cooked material was evaluated obtaining a value of 1521.91 kJ/kg material.

Figure 5. Thermodynamic balance in the Ocaña brickworks.

4. Conclusions
The data acquisition system using the Lab View software proved to be a very useful, versatile and reliable tool in the analysis of the thermal behavior of the production kiln of the ceramic material that can be used to predict the influence of a number of variables in the cooking process. Beyond the comparison with the firing curve of the clay, the acquisition system allows to obtain different loading temperatures in different positions in the kiln.

The obtained temperature profiles for the kiln were very similar to industrially technician processes because the maturation phase of the modelling clay is in the range from 900°C to 1000°C which indicates that the bricks were well cooked.

The consumption of pulverized coal in the Hoffman-type kiln is 0.28kg per brick, compared to 0.34kg-0.36kg for the handcrafted kilns according to the Program on Energy Efficiency in Artisanal Brick Kilns in Latin America [11]; this indicates savings in the coal consumption in this kiln, due to the recirculation of the combustion gas.

The thermodynamic balance in the kiln at the Ocaña brickworks showed that the amount of heat used in the clay cooking is $189.69 \times 10^6$ kJ which represents 23.05% of the supplied energy, the heat accumulation in the masonry of the kiln is $582.20 \times 10^6$ kJ that represents 70.73% of the supplied energy, and the energy loss in the kiln wall and dome is $15.54 \times 10^6$ kJ, that is 1.89% of the supplied energy; this energy loss can be reduced by adding a layer of insulation on the kiln walls and dome. Through the kiln chimney are ejected $2.73 \times 10^6$ kJ, which represents 0.33% of the energy released in combustion.

The energy lost by intangibles in the kiln is $99.21 \times 10^6$ kJ which represents 29.17% of the consumed energy, so this loss is quite high. The heat efficiency in the kiln is 78.73% and the yield per amount of cooked material is 1521.91 kJ/kg material, values that are in the range from 1000 to 2200 kJ/kg material [12] that is high for Hoffman-type kilns.
By performing the energy balances, it was possible to determine the destination of all the thermal energy supplied to the kiln, including the rate of available energy that is released to the environment and that may be used in other stages of the process, such as drying of the products, or directly in the kiln itself, or to heat the combustion air.

References

[1] Dirección General de Electricidad 2008 Elaboración de proyectos de guías de orientación del uso eficiente de la energía y de diagnóstico energético, Guía N°14 (Perú: Ministerio de Minas y Energía)

[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 (Bogotá: Ministerio De Ambiente, Vivienda y Desarrollo Territorial)

[3] Sánchez J, Gelves J and Ramírez R 2012 Revista Colombiana de Tecnologías de Avanzada 2 80-85

[4] 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)

[5] Carrillo D, Acosta M and Flórez E 2015 Revista Colombiana de Tecnologías de Avanzada 1 56-61

[6] Guerrero G, Marrugo D and Gómez J 2015 Revista Ingenio 8 47-58

[7] British Standards Institutions (BSI) 1987 Normas para el cálculo del balance térmico en hornos de ladrillo, British Standards, BS 476-13:1987 (United Kingdom: British Standards Institutions)

[8] Academia Colombiana de Ciencias Exactas, Físicas y Naturales (ACCEFY) 2003 Factores de emisión de los combustibles colombianos (Colombia: Academia Colombiana de Ciencias Exactas, Físicas y Naturales)

[9] Meneses J and Vera L 2003 Evaluación de las pérdidas de energía en los hornos tipo colmena de tiro invertido en la ladrillera Cúcuta (Cúcuta: Universidad Francisco de Paula Santander)

[10] Peña G, Peña J and Gómez M 2014 Revista Ciencia y Desarrollo 5 15-20

[11] Herrera P et al 2011 Caracterización de los hornos usados en la industria ladrillera (Colombia: Programa Eficiencia Energética en Ladrilleras Artesanales - EELA)

[12] Jahn T, Dadam A and Nicolau V 2002 Influência da temperatura e velocidade de queima nas propriedades de tijolos común (São Paulo: Anais do 46º Congresso Brasileiro de Cerâmica)