ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 07, pp. 49043-49047, July, 2021
https://doi.org/10.37118/ijdr.22472.07.2021

RESEARCH ARTICLE OPEN ACCESS

ANALYSIS OF THERMAL LOSSES IN A CYLINDRICAL KILN IN THE DRYING OF HANDICRAFTS IN ALTO DO MOURA

Maycon Ferreira Silva*, Felipe Vilar da Silva, Carlos Antonio Cabral Santos, Igor Cavalcanti da Silveira, Acarcio Gomes de Almeida Junior and Victor Antônio Bezerra Melo Cavalcanti

Federal Institute of Education, Science, and Technology of Pernambuco

ARTICLE INFO

Article History:
Received 03rd April, 2021
Received in revised form
14th May, 2021
Accepted 06th June, 2021
Published online 30th July, 2021

Key Words:

Energy Losses, Energy, Kiln.

***Corresponding author:**
Maycon Ferreira Silva

ABSTRACT

The present work aims to study the thermal energy losses of a firewood kiln used in the production of clay craftwork in the district of Alto do Moura in Caruaru-PE. Firstly, a previous survey was carried out with the artisans regarding the amount of firewood used, through questionnaires answered by them. An experimental analysis of a kiln was carried out during its operation, measuring and marking several points on it. Subsequently, the temperature and speed of the recording of all the data obtained were periodically recorded. The kiln was treated as a control volume that operates in a transient regime based on the equations of Energy Conservation, Heat Transfer and in the equation of Stoichiometric Balance of firewood combustion with performed calculations aided by software like Excel, for an estimate of heat losses to the environment by convection and radiation. Finally, energy losses were evaluated, enabling the proposal to the artisans of modifications in the kilns, aiming at the increase of kiln efficiency.

Citation: ***Maycon Ferreira Silva, Felipe Vilar da Silva, Carlos Antonio Cabral Santos, Igor Cavalcanti da Silveira, Acarcio Gomes de Almeida Junior and Victor Antônio Bezerra Melo Cavalcanti.*** "Analysis of thermal losses in a cylindrical kiln in the drying of handicrafts in Alto do Moura*", International Journal of Development Research*, 11, (07), 49043-49047

INTRODUCTION

Known as the Capital of the Agreste, Caruaru is the largest city in the interior of Pernambuco; with a population of 342,328 inhabitants.According to the IBGE8, it is the fourth most populous municipality in the state. In recent years, the city has made considerable progress in terms of urban development and economy. It has an extremely rich and diverse cultural heritage.Musicians, writers, artists, and artisans such as Master Vitalino, who inserted Caruaru in the international cultural scene, emerged from its lands. (Intercom, 2015).

The art of clay in Alto do Moura: Alto do Moura is a neighborhood in Caruaru, a municipality in the rural region of Pernambuco, where a community of clay craft artisans is concentrated. Located about 7 km from the city center, it is considered, the largest figurative art center in the Americas by Unesco (GASPAR, 2011). According to data from the City Hall, more than 1,000 artisans make a living from the art of clay. In this community, clay is present as a "Living Culture" in face of the pieces manufactured by the artisans, who were unified in an association with AABAMM – Association of Artisans and Residents of Alto do Moura (RODRIGUES, 2013). The artisans work in their homes, modeling clay and creating various objects and figures of all kinds (Gaspar, 2011). The artisans' basic themes are folkloric motifs which portray the daily life of the backcountry man: the *Bumba-meu-boi*, the *Maracatu*, the fife bands, the drought migrants, the *Cangaço* and the *Cangaceiros*, especially the famous Lampião and Maria Bonita, the cowboy, the *Vaquejada*, marriage, and funeral in the rural area (Gaspar, 2011). It was in Alto do Moura that Vitalino Pereira dos Santos, or simply Mestre Vitalino, was raised. One of the greatest highlights of clay production, practicing his work worldwide. Mestre Vitalino expressed northeastern folklore through clay, and even though he passed away in 1963, his work still stands out around the world. The Mestre Vitalino House-Museum has artifacts from the life of Mestre Vitalino and is located in Alto do Moura; the same house where the clay master lived (Intercom, 2015). They use clay as their main raw material.Having it moistened, they sculpt in different ways. Later, they burn the sculptures in large firewood-burning kilns, which can be individual (when used by the artisan himself and, at most, his family) or collective (when used by a group of artisans). The firewood used is sold by third parties, who extract it in places close to the region. Lately, scraps of wood and furniture are also being used, which are available at sawmills and lumber companies, respectively. The wood kiln used by the artisans is cylindrical and can be divided into vaulted (closed cylinder at the top) and a cylinder with an opening at the top. Some have both types, others just one type, it depends on the category of the piece - that is, the type of sculpture, pot, or doll, for example, that the artisan works with.

Problems of fuel used by artisans and the importance of the study: As mentioned above, the artisans use firewood-based kilns to burn their sculptures and are extremely dependent on firewood for fuel. Decades of extraction of this material from nearby reserves– added to the extraction for other activities – resulted in the extinction of certain species of wood and, consequently, a ban on firewood extraction by IBAMA.

This has brought various difficulties for the artisans –who are already suffering from the crisis experienced throughout the country-, which has led artisans to seek scraps of wood or even furniture in lumberyards and timber companies. Other aggravating factors can be observed, such as the monopoly of the sales of firewood, which allows sellers to vary the price a lot, thus increasing it. Therefore, a study based on concepts and knowledge of thermal engineering can bring numerous benefits to artisans, both economic and social.

OBJECTIVES

Main objective: The main objective is the energetic study of the burning process of the Alto do Moura handicraft to estimate the energy losses. Therefore, modifications in the kiln will be proposed to the artisans to reduce their losses.

Specific objectives

- To carry out the experimental analysis during the operation of a kiln;
- To estimate the thermal energy losses of the kiln during the entire burning process based on the results of the experimental analysis, through the proposed equations;
- Propose measures to the artisans to improve their kilns, aiming to reduce losses based on the results obtained in the future.

3. METHODOLOGY

Data collection: Initially, a questionnaire was created, with 7 (seven) questions with pre-defined answers, to facilitate the statistical analysis of the data. These questions mostly aim to extract quantitative information from the production of handicrafts, except for three questions(the first two, which are subjective questions, and the last one, which asks whether the artisan uses an individual or collective kiln). The application is constantly being made on the main streets of the Alto do Moura neighborhood, such as Mestre Vitalino Street, seeking to reach as many artisans as possible. The name and work address of each artisan who answered the questionnaire was also requested.

Kiln Characterization: The analyzed kiln has a cylindrical shape with an opening at the top, through which the ceramic sculptures are placed.It also has a kind of a box in the front region, which serves as an entrance to the tunnel where the firewood is placed to be burned, as shown in Figure (1)-a. Furthermore, Figure (1)-b below shows the most important measurements of the kiln:

Experimental Analysis: The experimental analysis consisted of geometric measurement and division of the kiln into several regions (bands) and marking points with plaster in the entire external region of the kiln.

Six (6) bands were made in the kiln body named from band A to band F, where 2 (two) were marked with 7 (seven) points and 4 (four) with 12 (twelve) points, aligned and approximately 30° (thirty degrees) apart from each other, totaling 62 (sixty-two) points. Another 30 points were marked in the inbox, where the firewood is placed resulting in a total of 92 points marked, which were periodically measured with an Incoterm Thermopar.

Figure (2) below shows the kiln after being marked, on the day of the experimental analysis: A total of 5 regions were also marked with plaster in the upper air outlet for wind speed measurements, 4 at a distance of approximately 90° from each other and one in the center, forming a circle. And another at the entrance to the firewood box.

Calculation of thermal losses: The kiln was modeled as a control volume that operates in a transient regime. The Energy Conservation equation was applied as in Equation (1) below:

$$\Delta E = Q_{in} - Q_{out} \tag{1}$$

Where Q_{ent} was defined as the amount of energy released in the complete combustion of firewood, according to Equation (2):

$$Q_{in} = m_L . PCI \tag{2}$$

Where:
m_L= firewood mass [kg];
PCI = lower calorific value of firewood [kj/kg];
Δt = total burn time variation [s];

In turn, the Q[sai] is defined as the sum of the amount of heat transferred by convection and radiation at all points, according to Equation (3) below:

$$Q_{in} = \sum q_{conv} + \sum q_{rad} \tag{3}$$

To calculate the thermal energy losses transferred by convection and radiation throughout the kiln, each point was modeled as the center of a rectangle. For heat transfer by radiation, according to the Incropera literature (2007), Stefan Boltzmann's Law was demonstrated in Equation (4) below:

$$q_{rad} = \varepsilon . \sigma . (T_s^{\ 4} - T_{viz}^{\ 4}) . \Delta t \tag{4}$$

Where:

q_{rad}= amount of thermal energy transferred by radiation at point [W];
σ = Stefan Boltzmann constant;
ε = kiln surface emissivity
T_s= surface temperature;
T_{viz}= neighborhood temperature;
Δt = periodic time interval between the measurement of each point [s];

As for the calculus of the convection heat transfer, it was primarily necessary to find the value of the convection heat transfer coefficient (h_{conv}) that varies with temperature. According to the literature, Morgan's expression is defined according to Equation (5) below:

$$h_{conv} = \frac{Nus.k}{D} \tag{5}$$

Where:
k= thermal conductivity of the material of the kiln [W/(m.K)];
D = kiln diameter [m];
Nus = Nusselt number;

Therefore, to obtain the Nusselt number, the Churchill and Chil expression was used for the Rayleigh number defined as Equation (6) below:

$$Nus = \left\{ 0.6 + \frac{0.387 . Ray^{\frac{1}{6}}}{(1+(0.559/Pr))^{\left(\frac{9}{16}\right)^{\left(\frac{8}{27}\right)}}} \right\}^2 \tag{6}$$

Where:
Pr= number of Prandtl;
Ray=Rayleigh number;

Measurement Schedule (in hours and minutes)							
1	2	3	4	5	6	7	8
17:20-17:45	18:00-18:34	18:50-19:25	19:48-20:35	20:45-21:20	21:35-22:10	22:25-22:55	23:00-23:25

Table 2. Values of constants, properties, and area considered

k (W/m.K)	PCI (kJ/kg)	D (m)	Gr	Nu	Ray	Pr	Area (m²)
0.9	14644	1.092	534177-5.276exp8	11.06-86.63	374549-3.893exp8	0.7012-0.7379	0.02-0.087

Table 3. Types and values of the obtained energy

COMPLETE FIREWOOD COMBUSTION ENERGY (MJ)	7322.00
AMOUNT OF ENERGY LOST BY CONVECTION (MJ)	74.46
AMOUNT OF ENERGY LOST BY RADIATION (MJ)	15.20
TOTAL ENERGY LOSS (MJ)	89.65
PERCENTAGE OF LOST ENERGY	12.24%

Thus, to obtain the Prandtl number, the values available in the Incropera table (2007) were interpolated with those measured in the experiment. The empirical relation for the Rayleigh number was used according to Equation (7) below, and in turn, as deemed necessary, for the Grashof number the relation of Equation (8) was used:

$$\mathrm{Ra} = \mathrm{Pr.Gr} \quad (7)$$

$$\mathrm{Gr} = \mathrm{g}.\beta(\mathrm{T_s} - \mathrm{T_{inf}}).\frac{(\mathrm{L_c}^3)}{v^2} \quad (8)$$

Where:
Gr = Grashof number;
g = gravity acceleration;
β = thermal conductivity;
v = kinematic viscosity;
L_c= characteristic length;

Finally, for convection heat transfer, Newton's Cooling Law was used, as shown in Equation (9) below:

$$\mathrm{q_{conv}} = \mathrm{h_c}.\mathrm{A}.(\mathrm{T} - \mathrm{T_{amb}}).\Delta\mathrm{t} \quad (9)$$

Where:
q_{conv}= amount of energy transferred by convection at point [W];
h_c= convection heat transfer coefficient [W/(k.m2)];
A= Area of the analyzed rectangle around the point [m2];
T= Temperature of the set point in the kiln [K];
T_{amb}= Ambient temperature [K];

RESULTS AND DISCUSSION

Initially, the measurement of all points at regular intervals of 15 (fifteen) minutes was proposed. However, because there are many points and most of the burning took place at night, which made it difficult to record temperatures in the notebook, the measurements and recording of temperatures took around 30 minutes.

Thus, adding the interval between each measurement, the standard time of 45 (forty-five) minutes was considered. The artisan who allowed the use of his kiln for experimental analysis startedburning his pieces in the late afternoon. The burning started at 17:00 (seventeen hundred hours), after placing the pieces and the firewood. Table (1) below shows the start and end times of the measurement sessions:

Figure (3) below shows a graph of Temperature (in Kelvin) versus the number of the measurement time, for a point in range A – the innermost range – showing the maximum temperature reached at that point:

The room temperature measured in the schedule ranged between 17°C and 18°C, with an approximate average of 18°C. The meteorological systems provided a minimum of 18°C. Thus, an ambient temperature of 18°C was considered during the burning. Subsequently, all temperatures and the respective measurement times were recorded on an Excel spreadsheet. The same software was also used for the linear interpolation of the Prandtl number provided by Incropera (2007) at restricted temperatures. Table (2) below presents the values of thermophysical properties, the range of the number of Rayleigh, Prandtl, Nusselt, Grashof for the considered temperatures, and also the area range of the rectangles centered on the marked points, all obtained from the literature or articles:

The room temperature measured in the schedule ranged between 17°C and 18°C, with an approximate average of 18°C. The meteorological systems provided a minimum of 18°C. Thus, an ambient temperature of 18°C was considered during the burning. Subsequently, all temperatures and the respective measurement times were recorded on an Excel spreadsheet. The same software was also used for the linear interpolation of the Prandtl number provided by Incropera (2007) at restricted temperatures.

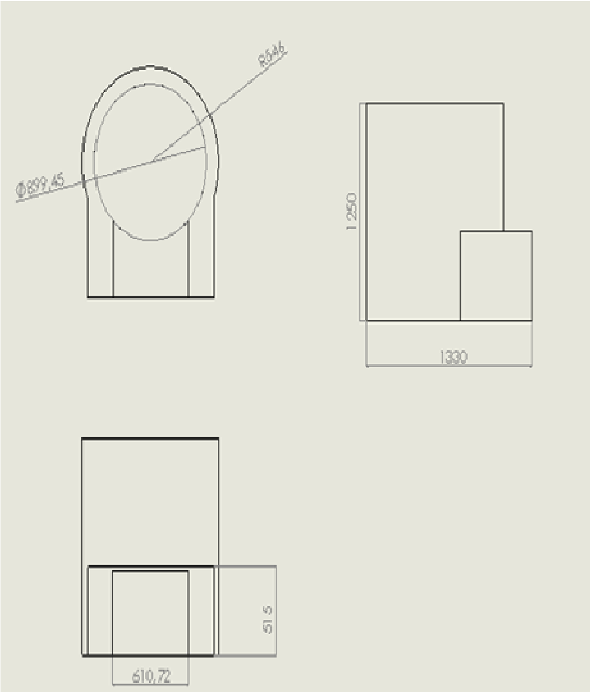
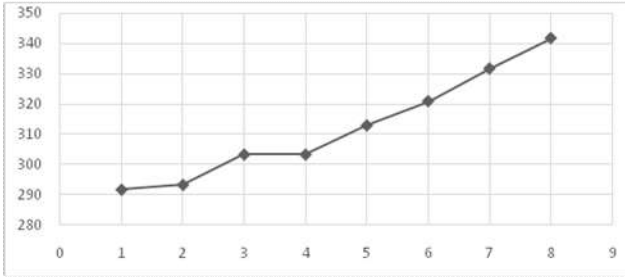


Figure 1- a) Cylindrical type kiln with opening at the top and front "box" b) Side, front and top view of the kiln with main measurements

Source: own authorship.

Figure 2. Kiln with marked points, front image (left), and right side image of the kiln (right)



Source: own authorship

Figure 3. The temperature in Kelvin X temperature measurement range for the first point of range A

Table (2) below presents the values of thermophysical properties, the range of the number of Rayleigh, Prandtl, Nusselt, Grashof for the considered temperatures, and also the area range of the rectangles centered on the marked points, all obtained from the literature or articles:

Conclusion

This work is part of a project that is still in the execution phase, but until then it can be concluded that:

- The kiln´s efficiency is low in relation to the amount of energy released in the combustion of firewood;
- Most energy is lost by convective heat transfer. In this way, the greater insulation of the kiln can allow for a reduction in thermal losses;
- The amount of energy lost by radiation is insignificant compared to the amount lost by convection.
- The results of the estimates will open up a range of measures that can be taken to reduce thermal losses and consequently increase the efficiency of the artisans' kiln, resulting in firewood and financial savings.

SUGGESTIONS FOR FUTURE WORK

These study results open up the possibility of using other renewable energy sources to reduce the consumption of firewood in the kilns, contribute to fighting deforestation and solve the community's fuel problem. Solar concentrators could be used. In this sense, the PCC is a viable option as it can be practically stationary, not requiring solar tracking, which greatly reduces the cost of manufacturing and when used with the proper working fluid, it can reach high temperatures capable of performing at least drying the craft before the firing step.

ACKNOWLEDGMENTS

- First of all, I would like to thank God, who is responsible for everything and holds all my ability and intelligence. Without Him, I could do nothing;
- My advisor, for all his support and help, in addition to being largely responsible for the project;
- IFPE, for all financial, instrumental, and informational support;
- The artisans of Alto do Moura, both those who answered the questionnaires and those who participated in the experiment. For the helpfulness, warmth, and friendliness.

REFERENCES

Cengel, Yunus A. Transferência de Calor e Massa, Uma Abordagem Prática. 4ed**. Porto Alegre: AMGH, 2011.

Çengel, Y. A.; Boles, M. A. Termodinâmica. 7. ed. Porto Alegre: Amgh, 2013. 1048p.

Conem, 6., 2010, Campina Grande-PB. Análise Comparativa Da Perda De Calor Entre O Forno Caieira E Forno Abóbada Com Isolamento. Campina Grande – PB: ABCM, 2010.

GASPAR, Lúcia. Alto do Moura, Caruaru, Pernambuco. Pesquisa Escolar Online. Fundação Joaquim Nabuco. Recife. Disponível em: http://basilio.fundaj.gov.br/pesquisaescolar. Acesso em: 02 de novembro de 2016.

Imcropera, Frank P. Fundamentos de Transferência de Calor e de Massa. 6ed.**. Rio de Janeiro: LTC, 2008.

Intercom – Sociedade Brasileira de Estudos Interdisciplinares da Comunicação, 17, 2015, Natal-Rio Grande do Norte. O Cenário Cultural de Caruaru: Uma Perspectiva Sobre Cidade Criativa. Natal-Rio Grande do Norte: Intercom, 2015. 14 p.

OBA, Renato. Análise térmica numérica e experimental de um forno túnel. Florianópolis: UFSC, 2011. 86 p. Dissertação (Mestrado em Engenharia Mecânica) – Programa de Pós- Graduação em Engenharia Mecânica, Universidade de Santa Catarina, Florianópolis, 2011.

Gaspar, Lúcia. *Alto do Moura, Caruaru, Pernambuco. Pesquisa Escolar Online.* Fundação Joaquim Nabuco. Recife. Disponível em: http://basilio.fundaj.gov.br/ pesquisaescolar. Acesso em: 25 de janeiro de 2017.

ReCont. Um Estudo Sobre A Perspectiva Do Conhecimento Empírico Para O Controle Patrimonial Em Caruaru – Pernambuco. Recife-PE: Re Cont, 2013, 19p

Schurhaus, Patrick. Produtos e propriedades energéticas da madeira. Centro Universitário União da Vitória: 2007. Disponível em: www. hasten.eng.br. Acesso em: 20 de outubro de 2017.

****