Literature review for tunnel kilns optimization and energy saving

CEMEPE 2023

K. Tzikas, X. Spiliotis and D. Kasiteropoulou

University of Thessaly, Department of Environmental Studies, Gaiopolis

INTRODUCTION

Energy consumption represents a significant part in manufacturing industry such as ceramics, aluminum, steel, glass and cement. The present work focuses on the ceramic industry, and specifically in bricks manufacturing industry. The thermal processes, distinguished in three zones, that take place during the production of bricks are: preheating (drying), firing and cooling as shown in figure 1.

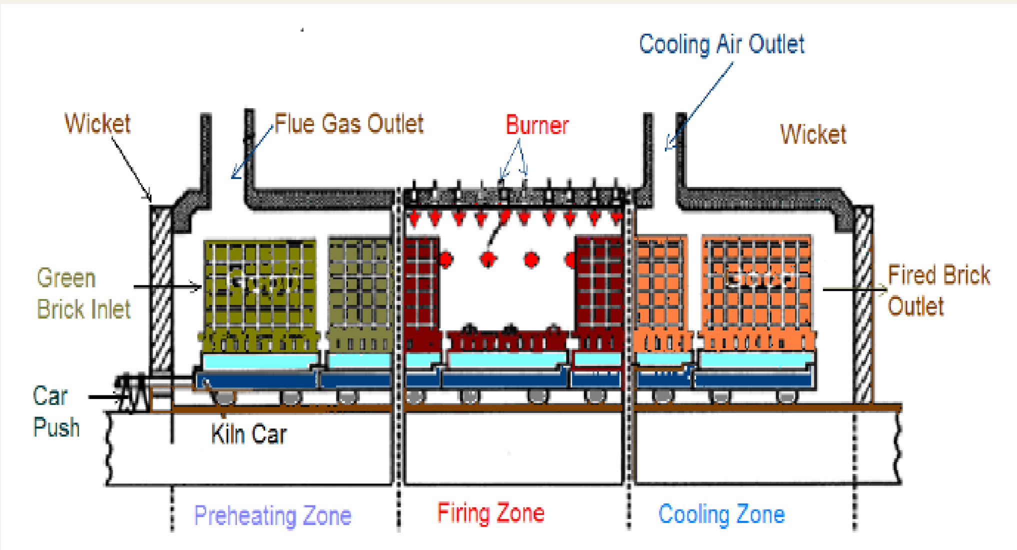


Figure 1: Zones in tunnel kiln [12].

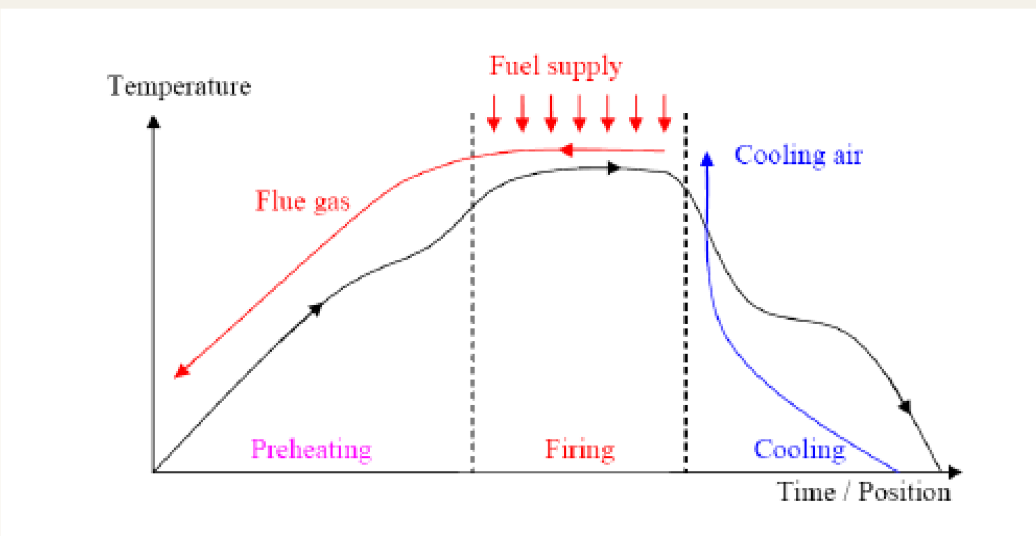
The purpose of this work is a review the existing literature focusing on the importance of developing a model which will include all the parameters that affect the process, as the dimensions of the tunnel kiln and the alternative placement of ceramic bodies in it. The placement of ceramics can significantly affect the distribution of heat within the tunnel kiln and therefore the fuel consumption and the quality of the final ware. In the present study, a holistic approach will be adopted, through the numerical simulation of the operation of the ceramic tunnel kiln. This includes a variability study of the geometrical characteristics of the kiln (length, width, height), modification of the stacking of the ceramic bodies to be fired, exhaust gas flow characteristics and their influence on energy consumption and ultimately the environmental footprint of the thermal processes. Stacking can have a stable structure (fixed height over the entire process length) or may consist of discontinuous surfaces (firing sections of different heights).

In conclusion a more recent review and understanding of energy efficiency technologies in ceramic industry units is needed, as a prerequisite to detect the parameters that affect the operation of ceramic tunnel kilns [6], aiming to reduce fuel consumption and simulate exhaust gas flow together with ensuring or improving the quality of the final product, reducing as a side effect the environmental footprint.

DESCRIPTION OF THE TUNNEL KILN

The tunnel kiln technology is considered to be the most advanced brick making technology. The heat transfer from the bricks and the flowing air is significant during the process. To reduce the temperature of the burnt bricks, cooling air is used, and because of this, the temperature of the entering air starts to rise. As the air flows from the end of the kiln to the start, its temperature starts to fall when the air finds the bricks that are coming inside. There are also exit routes above the kiln, which are used both for the air and the fuel gas to get out of the kiln. During the preheating process, warm air is also released to improve this part of the procedure. The waste gases are extracted from the preheating zone with a gas outlet. A tunnel type furnace is 35m-250m long and 1m-6m wide [12]. A tunnel kiln has three different variable temperature zones: Preheating zone, firing zone and cooling zone. During the entering in the preheating zone (before the firing zone) temperature starts to raise because of the contact with the hot flue gases coming from the firing zone. In the firing zone where the fuel is fed the products are heated and the temperature in this zone is more stable (900 – 1050°C). Fuel (granulated/pulverized coal) is fed into the firing zone of the kiln through feed holes provided in the kiln roof. The firing zone usually extends up to 8 wagons. Then follows the cooling zone where the fired bricks are cooled by the cold air flowing into the kiln (see figure 2). The wagons are moved inside the kiln intermittently at fixed time intervals. The duration of the firing cycle can range from 30 to 72 hours.

Figure 2: Temperature zones in tunnel kiln [12].



LITERATURE REVIEW AND DESCRIPTION OF THE CURRENT SITUATION

Abbakumov [13] used a mathematical model to study the temperature variance inside the kiln. It was mentioned the importance of large parts in the kiln expect for this in the initial entry of the products. The large contribution of the heat emitted also referred. Dugwell and Oakley [14] proposed a model to investigate the temperature profile in the firing zone. The effect of fuel combustion on the products was studies and the longitudinal positioning of the products examined. Boming Yu [15] studied the impact of heat transfer between the products. For this purpose a mathematical model was developed to describe the various situations that take part during the kiln operation. These mathematical equations also agree with the real operating situation. Essenhigh [16] analysed the energy entering the kiln and the energy coming out, by calculating enthalpies and using energy balance equations. This model has more practical application to the burning zone but it can not include the kiln heat transition outside wall and only theoritical estimations shall be taken into account. Durakovic and Delalic [17] focused on the temperature change inside the kiln, considering as main parameter the gas variability. A temperature diagram with the variations during the process was issued. Gol'tsova et al. [18] studied the parameters that affect the product before the firing zone. Mancuhan et al. [19] also investigated the conditions affecting the air temperature before the firing zone. The temperature profile is not affected with the air amount inside kiln and the products humidity must be low after the preheating zone.

Shvartsman et al. [20] proposed a relation between the products layout and the burners placement aiming to energy saving. When the combustion is done from the upper part of the kiln and the products pass in a massive way, the production becomes for financial beneficial. Mancuhan and Kucukada [21] compared the possible fuels used in burning zone. For this purpose different kind of fuels included gas and solid with their components were tested during the combustion in combination with the cost for each case. However the cost is a constantly changing parameter. Kaya et al. [22] tried to meliorate the function of firing zone so as to reduce fuel consumption. The fuel content and the air supply for energy efficiency of the kiln was studied. De Paulo Nicolaou and Dadam [23] used CFD to study the thermal analysis inside a typical tunnel kiln and asses the waste heat during the process. The density of the outer wall and the heat transfer inside the kiln is a major factor for saving energy (see figure 3). The air circulation would be also helpful to this direction. Oba et al. [24] proposed a model, limited to certain dimensions, for the appraisal of the temperature profile inside the kiln and the energy consumption. The mechanism that describes all these complex thermal factors in combination with the fuel combustion shown in figure 4. Chen et al. [25] used CAD to develop an intelligent model for tunnel kiln. This kind of model relied more on better customization for easier use. Michael and Manesis [26] used fuzzy logic systems to create a mechanism in their effort to control the different parameters that affect the process in a tunnel kiln. The use of this mechanism as a process supervisor is done by using the mathematical expression as a dominant medium to automate the process. Carvalho and Nogueira [27] applied steady state and dynamic models to study the energy consumption considering the emissions and temperatures during the firing process. The values during the process are a crucial factor for process improvement and the strategies for emission reduction.

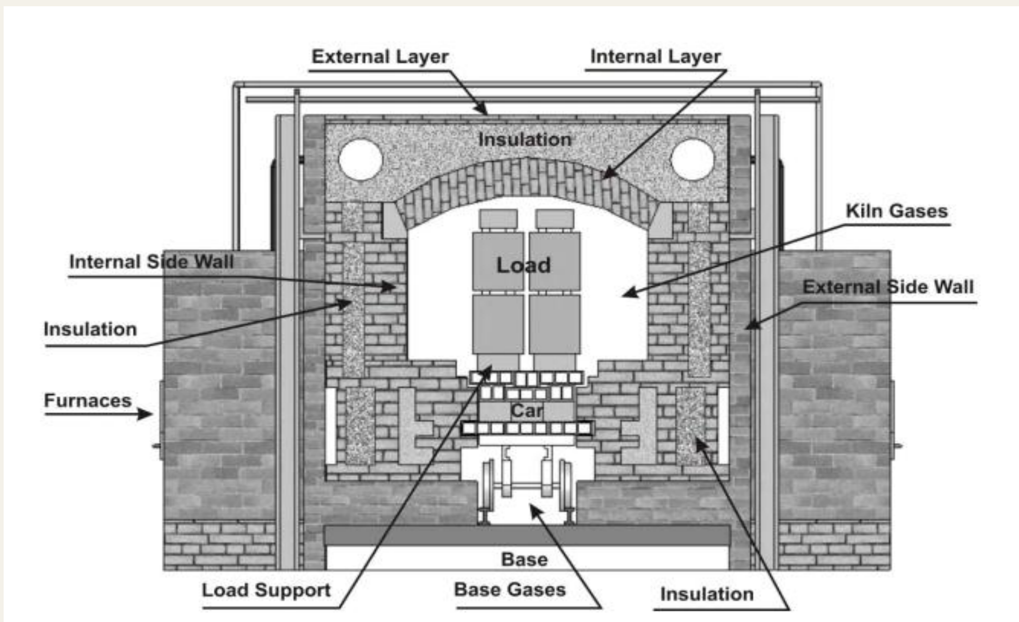


Figure 3: Typical section of a tunnel kiln [23].

Tehzeeb et al. [6] assumed specific dimensions for the tunnel kiln and developed a model by using CFD, by recording the deviation of temperature inside the kiln and the emissions - all these data compared with real values. Possamai et al. [28] used for their model both CFD and Fortran to calculate the temperature inside a tunnel kiln and also the other variables which take part to the function. Their results were confirmed by experimental data and determined reliable results by modifying certain parameters. Naccache et al. [29] used Fluent software to analyze the temperature within the kiln and other major aspects that affect the quality of the final product. Zhanxu et al [30] focused their research on a coal brick kiln with main subject the heat losses and the transport phenomena inside the kiln. Additionally, they studied the glue gas impact on the process in the preheating zone. Oba et al. [31] studied the temperature profile of a tunnel kiln and the waste energy during the combustion, mentioning the importance of heat radiation.

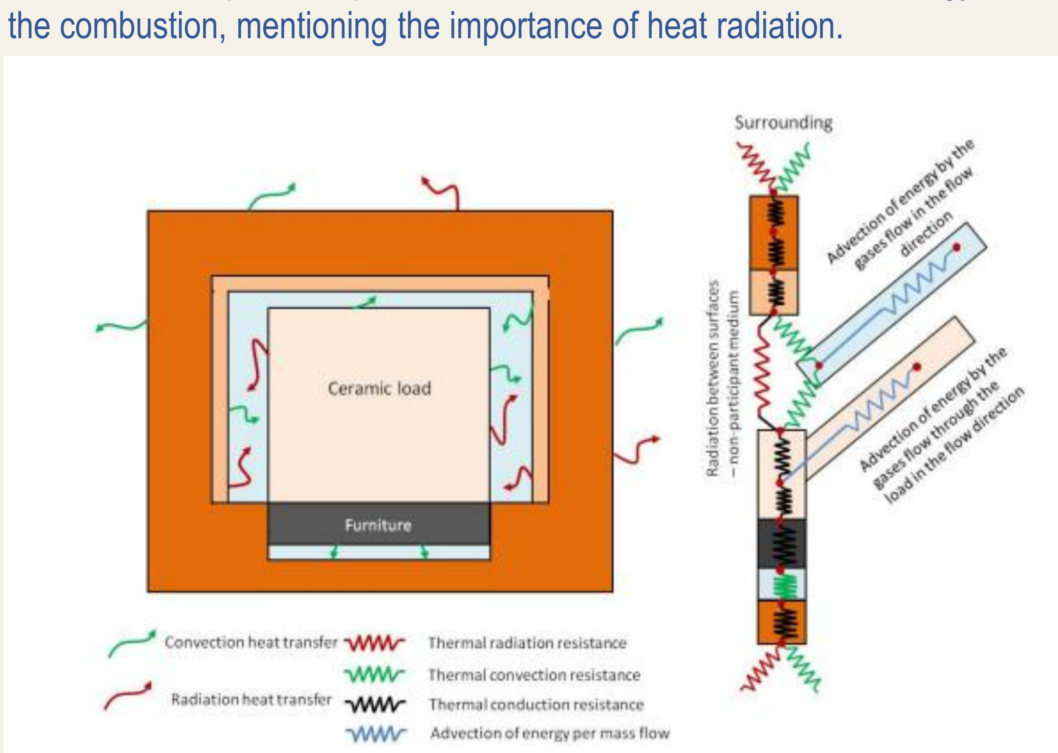


Figure 4: Radiation, convection and heat transfer [24].

More recently Refaey et al. [32] used MATLAB to study the energy consumption within the tunnel kiln, concentrating their research on the preheating and firing zone. However, as mentioned in their work, the result needed additional processing with a CFD software, to include observations on the flow parameters in the kiln. Refaey et al. [33] created an experimental scale tunnel kiln emphasizing in the cooling zone. Their research aimed to establish a relation between Nusselt and Reynolds number, considering the brick productivity, the different placement of the bricks and the spaces between the gaps.

Tuaamah et al. [34] used CFD to relate the injection and the flue gases flow through the ceramics in the preheating zone. For these reasons different scenarios were chosen to study the flow rate and the temperature at this point of the kiln to have a better understanding of this part of the kiln. Redemann and Specht [35] proposed a model to study the contribution of the forced air circulation to energy consumption, especially in the cooling part of the kiln however, further CFD analysis needs to be done for more investigation and improvement. Refaey et al. [36, 38] conducted experimental research using a block of bricks with different placement, to study the thermal processes taking place in the cooling zone, the attack angle with Reynolds number and temperature during the process helped guide these studies. Hussnain et al. [37] installed heat recovery systems on the cooling zone and observed the flue gas consumption and oxygen variation. However numerical simulation for verification needs and further study of other variables must be considered for the model to be more realistic [39,40,41,42,43,44]. Alrahmani et al. [45] used CFD to study tunnel kilns brick surface roughness influence on the heat transfer. For this reason, the different placement and direction of the bricks during the process were investigated, while certain assumptions were made to be compatible with the model (see figure 4). Refaey [47] did research for a ceramic furnace, and the research focused mainly on the firing zone and the combustion zone, the temperature distribution and energy consumption were studied using a mathematical model.

In general, industrial energy consuming processes in the European Union (EU) are responsible for the use of large amounts of energy [1,2,3]. Contrary to EU, in the US heat losses and energy consumption seem to be less, so in the EU new techniques and strategies need to be developed [4]. Additionally, in the EU, heat losses are approximately 17% of the consumed industrial energy in thermal processes and approximately 10% of total industrial energy consumption [5]. Ceramic industry as a large energy consumer attracts researchers to improve its efficiency in energy consumption, as it happens with similar industries in function [7].

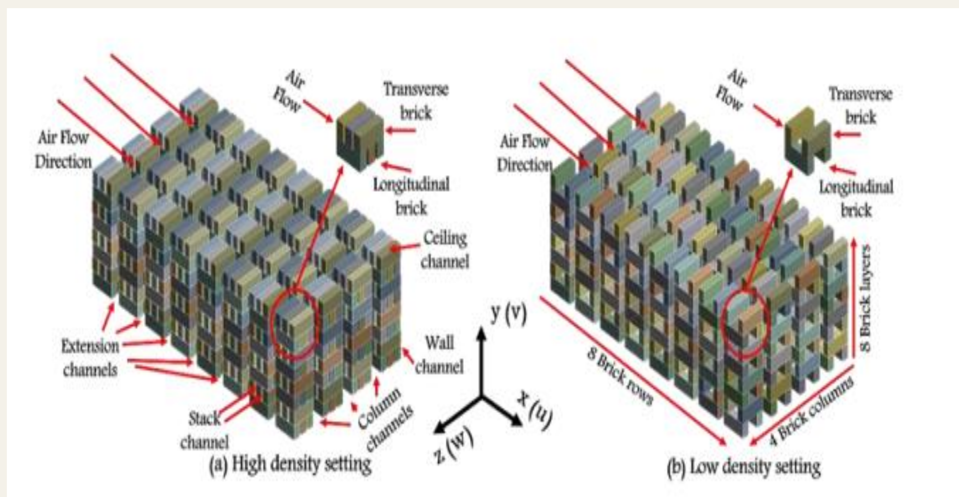


Figure 4: Different placement and direction of the bricks [45].

According to European Commission document, referred to Best Available Techniques for the Ceramic Industry, improved ceramic kiln design focusing in the dryer design, heat losses from kilns (mainly in the cooling zone), use of an alternative fuel in the kiln and modification of ceramic object design, need to be reconsidered in the EU for ceramic industry to improve its performance [8,46]. Improvements in this area are certainly costly and changes in the operation mode must be well studied [9,46]. However, despite the progress made over the last two decades for recovering waste heat, the requirement for improvements in energy consumption and novel design of tunnel kilns, through the better understanding of the conditions held during the processes taking place in the tunnel kiln, need more investigation [10,11]. New strategies need to be applied and new methods taking into account the adaptation cost according to new improvements in ceramic kilns. A

DISCUSSION

According to the literature review, there are several recent studies that refer to ceramic kiln studies by either using CFD or mathematical or modern programming methods. However, some refer to the preheating zone, some to the heating zone, and some to the cooling zone, but no study has been carried out considering the tunnel kiln as a whole. Generally, many problems related to temperature distribution, heat transfer and waste heat, product quality related to temperature distribution and energy consumption have been recognized. The contribution of fuel placement through the burning zone and the emissions as a result of the burning fuel were studied. Some models are focusing on the geometrical characteristics of the kiln but verification is needed with real measurements.

The up to date studies focus only on a few parameters whilst the need of an integrated model that will combine all the parameters affecting the final product, the constant need to improve the quality of the products, with simultaneous energy efficiency and reduction of energy consumption, according to the directives both at EU and global level, is a strong request. Further improvement of ceramic kilns, using CFD, will take into account brick placement on the wagons, fuel consumption, air releasing in the tunnel kiln and geometrical parameters, by optimizing scenarios both in the production line and in the reduction of energy consumption during the process. Verification of these models in pilot conditions is also important.

REFERENCES

Eurostat. Consumption of Energy. https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Archive:Consumption_of_energy (accessed on 30 October 2019).

Bendig, M., Maréchal, F., Favrat, D., 2013. Defining "Waste Heat" for industrial processes. *Applied Thermal Engineering*, **61 (1)**, 134–142.

Agathokleous, R., Bianchi, G., Panayiotou, G., Aresti, L., Argyrou, M., Georgiou, G.S., Tassou, S.A., Jouhara, H., Kalogirou, S.A., Florides, G.A., et al., 2019. Waste Heat Recovery in the EU industry and proposed new technologies. *Energy Procedia*, **161**, 489–496.

U.S. Department of Energy Industrial Technologies Program, 2008. *Waste Heat Recovery: Technology and Opportunities in U.S. Industry.*