18èmes Journées Internationales de Thermique (JITH 2017)
Monastir (Tunisie), 25 - 27 Octobre 2017

Experimental thermal analysis of a Tunisian tunnel kiln used for firing bricks

Nahed Soussi[1*], Issim Kriaa[2*], Hatem Mhiri[3*], Philippe BOURNOT [4#]

[*]UTTPI, National Engineering School of Monastir, Monastir, (Tunisia)

[#]IUSTI, UMR CNRS 6595, 5 Rue Enrico Fermi, Technopôle de Château-Gombert, 13013 Marseille, France

[1]nahed.soussi@yahoo.fr

[2]kriaaiss@yahoo.fr

[3]hatem.mhiri@enim.rnu.tn

[4]bournot@univmed.fr

Abstract: A thermal analysis of a tunnel kiln used for making process of red brick is presented in this study. The experimental procedure carried out to collect plant data from the existing tunnel kiln is presented. The collected data allows understanding the thermal behavior of the studied tunnel kiln. A study of the preheating of combustion air was presented and the results show that the increase of air combustion temperature to 150°C provides 7.2 % of gas economy in the kiln.

Keywords: Brick manufacturing process, Experimental measurements, Energy balance, Tunnel kiln

1. Introduction

The process of manufacturing bricks involves four principles steps [1]. The first one is the preparation of brick clay followed by the brick modeling step. Once the bricks are formed, they are dried to remove excess moisture in brick body. Finally, bricks are fired at high temperatures in furnaces called kilns.

Tunnel kilns that use fossil fuel as combustible are widely used in brick manufacturing process. For this reason, several studies aimed at improving the efficiency of brick plants and reduce their fuel consumption to protect the environment and to improve the overall quality of products by a better control of the firing process. In this context, Sinem et al [2] presents an optimization study of the firing zone to minimize the fuel cost. Another work of these authors [3] was realized in order to improve the heat recovery in the cooling zone of a tunnel kiln.

The knowledge of the thermal behavior of tunnel kilns is an essential step before the suggesting of solutions that can improve efficiency. The temperatures of the air and of the products inside the oven must be supervised. Some works propose numerical studies where Temperature profiles and heat fluxes are reported [4-6].

The main objective of this study is to provide a better knowledge of the actual thermal behavior of a tunnel kiln installed in a Tunisian brick manufacturing industry by collecting and analyzing the plant data.

2. Material and Methods

2.1. Description of the tunnel kiln

The kiln investigated during this work is a tunnel kiln used for firing red bricks. A schematic diagram of the studied tunnel kiln is presented in Fig.1 and the physical dimensions of the kiln and bricks are reported in Table 1. In tunnel kiln operation process, brick and air flows are circulating in opposite direction (counter current flows).

The studied tunnel kiln is comprised at the beginning of the pre-kiln and preheating zones related directly to the firing zone and then followed by the cooling zone. Nine groups of burner are located on the roof of the firing zone. Two gas stacks are installed at the beginning of the pre-kiln and preheating zones. Another extractor is placed on the final cooling zone for the extraction of hot air, which is returned to the pre-kiln and dryer. Fresh air is injected inside the kiln in the fast cooling zone and at the brick exit side in backpressure to ensure brick cooling.

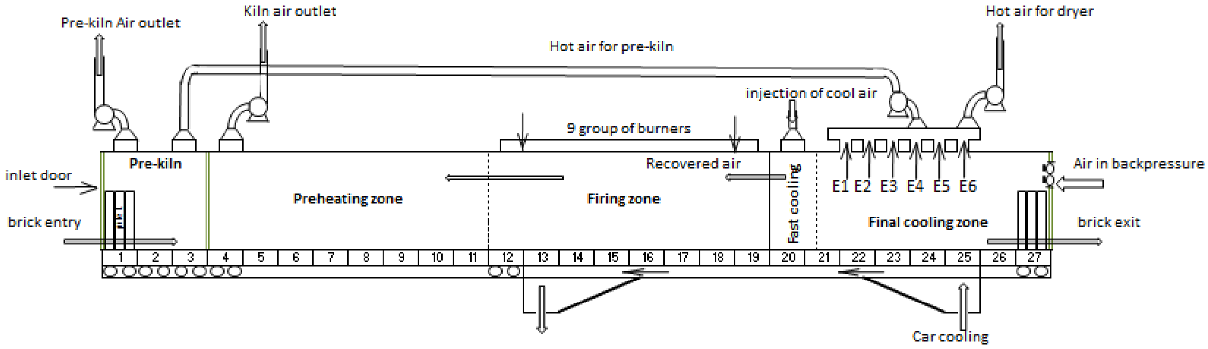

Figure 1: Schematic diagram of the studied tunnel kiln

Table 1: Physical dimensions of the tunnel kiln and bricks

Designation	Dimension *(m)*
Total kiln length	117.45
Length of pre-kiln zone	13.05
Length of preheating zone, firing zone, cooling zone	34.8
Length of fast cooling zone	5.8
Length of final cooling zone	29
Inlet section of the kiln	9.63
Brick width	0.2
Brick depth	0.15
Brick length	0.3

2.2. Presentation of the experimental method

The experimental method is aimed at collecting plant data required to determine energy distribution in the kiln. This method is carried out using four instruments: a Pitot tube, a hot wire anemometer, an infrared pyrometer and temperature sensors installed in the firing zone.

For the mass flow measurements of air injected and extracted, a Pitot tube (Testo 350 illustrated in Fig. 2.a) is used. While a hot wire anemometer is used to measure the mass flow rate of combustion air (Fig. 2.b).

The natural gas mass flow is determined using gas pressure value in each group of burners and the relationship between the pressure and mass flow rate is supplied by manufacturer data in form of curves.

Each group is characterized by an operating rate (C_{ft}) defined as the ratio of the operating time of each one by the push time of brick load equal to 10 min. The temperature reached in the vicinity of each group of burners is measured by temperature sensors installed on the roof of the firing zone and linked to a control unit which provides measured temperature values.

The inlet and outlet surface temperature of bricks are measured using an infrared pyrometer illustrated in Fig. 2.c.

Fig. 2.a : Pitot tube

Fig. 2.b : Hot wire anemometer

Fig. 2.c : Infrared Pyrometer

Figure 2: The used Equipments

The uncertainties using the Pitot tube in the measurements of mass flow rate and temperature are ±0.03 m/s and ±0.5°C, respectively. On the other hand, the uncertainties using hot wire anemometer in the measurements of mass flow rate are ±0.1 m/s and using the infrared pyrometer in temperature measurements is of about ±0.5°C.

2.3. Energy balance analysis

The main input and output streams of a tunnel kiln are presented in the simplified schematic diagram drawn in Fig. 3. The different quantities defining the energy balance are given in equations (1-7) [techniques de l'ingenieur]

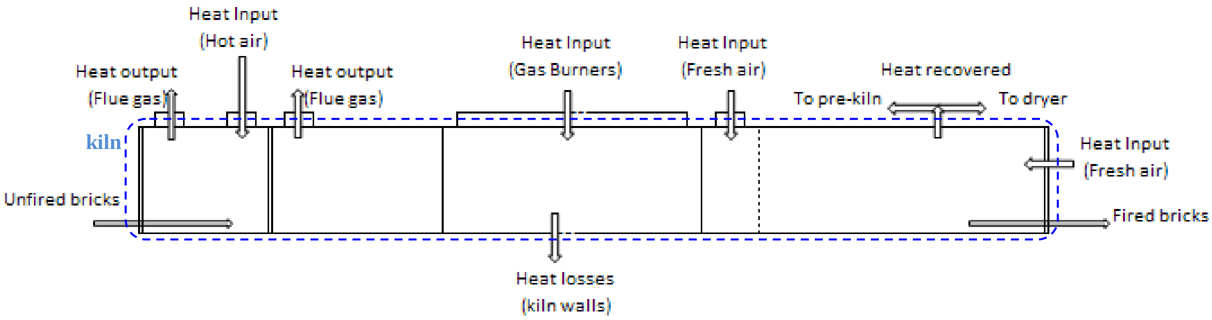

Figure 3: Schematic diagram of energy balance

For each group of burners, the heat released by combustion of natural gas and the heat brought by combustion air are given by equations (1) and (2), respectively:

$$Q_{NG} = C_{ft}.\dot{m}_{NG}.PCI \qquad (1)$$

$$Q_{ac} = C_{ft}.\dot{m}_{ac}.Cp_a(T_{ac} - T_r) \qquad (2)$$

The heat brought by bricks is given by the following equations:

$$Q_b = \dot{m}_b.Cp_b(T_b - T_r) \qquad (3)$$

The heat brought by air injected at ambient temperature is given in this equation:

$$Q_a = \dot{m}_a.Cp_a(T_a - T_r) \qquad (4)$$

The heat used in firing bricks; to produce chemical and physical changes and to heating the clay is presented as follows:

$$\begin{cases} Q_{evap} = \dot{m}_b . L_{v,H_2O} \\ Q_b = \dot{m}_b . Cp_b . \Delta T_b \end{cases} \quad (5)$$

The heat recycled to pre-kiln and dryer is given by this equation:

$$Q_r = \dot{m}_{ar} . Cp_a (T_{ar} - T_r) \quad (6)$$

The heat lost through flue gas stacks placed on the beginning of the pre-kiln and preheating zones is given as follows:

$$Q_f = \dot{m}_f . Cp_f (T_f - T_r) \quad (7)$$

3. Results and discussions

3.1. Collect of plant data

The purpose of the experimental procedure, detailed in a previous section, is to collect data characterizing the tunnel kiln in order to describe its thermal behavior.

1) The mass flow rates of air

In the present section, the air flow rates injected inside the kiln and extracted from the cooling zone are determined using air velocity (measured by means of the Pitot tube) and duct section value in each injection or extraction location. The following flow rates values are summarized in Table 2.

Table 2: Air mass flow rates

Designation	Mass flow rate *(kg/s)*
Air in Backpressure	14.43
Hot air saved for dryer	11.53
Hot air saved for pre-kiln	2.53
Injection of air (fast cooling)	0.64
Recovered air from the cooling zone or the firing zone	1.01
Kiln air outlet	3.56

2) The natural gas and combustion air mass flow rates in the firing zone:

The combustion system is located at the firing zone which is divided into 9 portions. Each of these portions contains a group of 10 gas burners. The operating rates, the gas and air mass flow rates in each group of burners are determined and results are reported in Table 3.

It is noted that the operating rates of the five first groups of burners, situated at the beginning of the firing zone, are equal to the unity. These values explain the fact that in the first portions, burners operate for a long time and need to consume a great quantity of fuel to raise temperature of bricks entering from the preheating zone.

While, in the last group of burners, the purpose is to maintain the peak temperature in the firing zone. For this reason, the energy provided by these burners is less than that of the first burners which is confirmed by their operating rates less than 1.

Table 3: Natural gas and combustion air mass flow rate

Group of burners	Mass flow rate *(kg/s)*		C_{ft}
	Combustion Air	Natural gas	
1	0.296	0.011	1

2	0.296	0.011	1
3	0.256	0.011	1
4	0.256	0.011	1
5	0.326	0.0151	1
6	0.325	0.0151	0.95
7	0.327	0.0166	0.8
8	0.326	0.015	0.8
9	0.326	0.0142	0.8

3) The brick temperature:

The brick setting is composed of three stacks arranged on cars. There are 27 cars in the studied tunnel kiln; each one contains 2160 bricks type B12.

The values of inlet and outlet brick temperatures are given in Table 4 basing on the experimental measurements using the infrared pyrometers. Several measurements are made at different positions in brick stacks and an average value is calculated.

Table 4: Brick temperature

Brick temperature	value (°C)
Kiln Entry	30
Kiln Exit	45

4) The air temperature evolution

The air temperature evolution, along the whole length of the tunnel kiln, is represented in Fig. 4. The highest air temperature generated is of about 880°C, in the firing zone and the lowest temperature is 30°C.

In the cooling zone, the ambient air cools the bricks coming from firing zone, so that the cooling air temperature increases as shown in Fig. 4. On the other hand, the same figure demonstrates the heat exchange between flue gases and bricks in the firing, preheating and pre-kiln zones. In fact, the heat from hot air preheats the brick load; therefore the flue air temperature inside the kiln decreases.

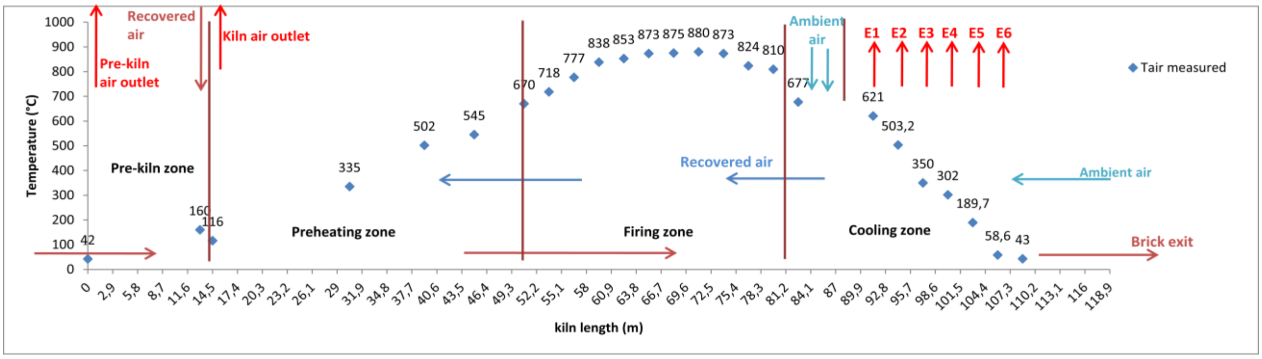

Figure 4: Air temperature evolution

3.2. Energy balance

The overall of energy balance are computed around the tunnel kiln by using the plant data and the results are given in Table 5. The energy input is divided into different energy paths as schematized in Fig. 5 by the Sankey diagram.

The energy required to firing bricks is provided by gas burners by combustion of natural gas with air at ambient temperature. The experimental results show that a portion of 15.5% of energy input is needed to evaporate the water present in bricks body and another portion of 22.2% needed to raise brick temperature to the appropriate sintering temperature. In the present case, 44 % of the total energy employed in the kiln is recycled to the dryer.

Table 5: Energy balance

Designation	Value *(kW)*	*(%)*
Energy out		
Heat in firing ware : To evaporate water from green ware	732.24	15.5
Heat in firing ware : To raise temperature of ware	1048.05	22.2
Heat returned to ware (pre-kiln)	394.07	8.4
Heat recovered to dryer	2093.53	44.4
Heat in ware exit	87.84	1.9
Heat in cars exit	12.39	0.3
Heat in flue gas	363.91	7.7
Heat losses	374.98	8
Total Input	4712.95	100

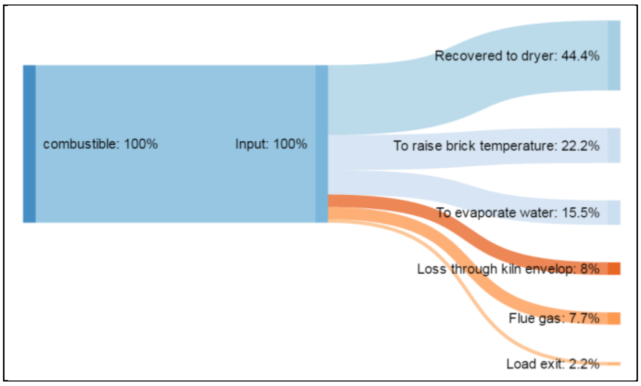

Figure 5: Sankey diagram

3.3. Estimation of gain by preheating the combustion air

In this section, the influence of preheating combustion air temperature on the fuel consumption is analyzed. The results indicates that increasing combustion air temperature improve natural gas economy. In fact, when the combustion air is preheated to 150°C, 7.2 % of gas economy is noted as shown in Table 6.

Table 5: Economy energy by preheating combustion air

Combustion air inlet temperature (°C)	Natural gas Economy (kg/s)	Natural gas Economy (%)
50°C	0.0013	1.2
70°C	0.0026	2.4
100°C	0.0046	4.1
150°C	0.0076	7.2

Conclusion

An experimental study is performed in this work and the following results are conducted:

- The real firing curve is plotted basing on the collected plant data aiming to understand the thermal behavior of the kiln.
- The effect of preheating air combustion, fed by the gas burners in the firing zone, on the energy consumption of the kiln is studied.
- It is demonstrated that the preheating of combustion to 150°C provides 7.2 % of gas economy in the kiln.

Nomenclature

		Subscripts	
C_p	Heat capacity, $(J/kg.K)$	a	air
C_{ft}	Operating rate of a group of burners, (---)	ac	combustion air
$L_{v_{eau}}$	Latent heat of vaporization, (kJ/kg)	ar	recycled air
$\dot{m}$	Mass flow rate, $(kg/m^2.s)$	b	brick
PCI	Heating value, (kJ/kg)	f	flue gas
Q	Heat, (kJ)	NG	natural gas
T	Temperature, $(°C)$	r	reference

References

[1] Matériaux de terre cuite, Michel KORNMANN : Matières de base et fabrication. In : Techniques de l'ingénieur, vol.C 905
Techniques de l'ingenieur (differents étapes de fabrication des briques)

[2] S. Kaya, K. Kucukada, E. Mancuhan. Model-based optimization of heat recovery in the cooling zone of a tunnel kiln, Appl. Therm. Eng. 28 (2008) 633-641.

[3] S. Kaya, K. Kucukada, E. Mancuhan. Model-based optimization of heat recovery in the cooling zone of a tunnel kiln, Appl. Therm. Eng. 28 (2008) 633-641.

[4] R. Oba, T.S. Possamai, V.P. Nicolau. Thermal analysis of a tunnel kiln used to produce roof tiles, Appl. Therm. Eng. 63 (2014) 59-65.

[5] D.R. Dugwell and D.E. Oakley. A model of heat transfer in tunnel kilns used for firing refractories, Int. J. Heat and mass Transfer 31 No 11 (1988) 2381-2390

[6] R. Oba, T.S. Possamai, A.T. Nunes, V.P. Nicolau. Numerical simulation of tunnel kilns applied to white tile with natural gas, in: Proceeding of the 21st Brazilian Congress of Mechanical Engineering, Natal, RN, Brazil, 2011.

[7] Thermique des fours, Gérard PANIEZ: Eléments de thermique des fours. In: Techniques de l'ingénieur, vol. BE9 510