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Mathematical model to investigate the influence of circulation systems on the firing of ceramics

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Abstract

Relatively large amounts of exhaust gas at low temperature level, especially from the cooling of the ware, leave the tunnel kiln and cause significant heat losses. This gas is normally used for drying purposes, but some studies recommend the decoupling of the firing process and drying process in order to optimize them separately. To reduce the heat losses and to improve the efficiency of the firing process, the heat transfer between the gas and the ware, especially in the cooling zone, has to be increased.

Therefore, a mathematical model is used to simulate the kiln process. Roof tiles are used as a reference product. Process parameters such as throughput, energy consumption, material properties for tiles and cassettes, geometrical data of the furnace and the setting are oriented on a real production line. Within the model the modes of heat transfer, consisting of forced convection, and gas radiation are considered to investigate the influencing parameters such as gas velocity.

Especially in the cooling zone, there is high potential to improve the convective heat transfer with circulation systems. In order to reduce the amount of cooling gas radically and to think about a decoupling of firing process and drying process, the required mean flow velocity through the setting should be in the range of 20 m/s for roof tiles.

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Keywords: Ceramic; Tunnel kiln; Heat transfer; Convection; Circulation systems

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Nomenclature

Symbol		*Index*	
$\dot{M}$	Mass flow rate, kg/s	0	Standard
$\dot{Q}$	Heat flow rate, W	CONV	Convection
R	Resistance	G	Gas
T	Temperature, °C or K	RAD	Radiation
c	Specific heat capacity, J/kg/K	S	Solid
h_u	Lower heating value, J/kg	f	Fuel
k	Node	i	Element
s	Gap width, m	p	Heat capacity of a gas at constant pressure
w	Flow velocity, m/s		
Δ	Difference		
λ	Heat conductivity, W/m/K		

1. Introduction

In industry, more and more effort has to be made to save energy. On the one hand, the consumption of energy has to be reduced for economic reasons. On the other hand, the demands of European governments to reduce greenhouse gas emissions must be met. The use of renewable energies and biogenic fuels does not appear to be viable in the long term. The ceramic industry has already taken many energy saving measures in recent years [1-3]. Energy losses caused by poorly insulated walls and ceilings could be almost eliminated. The historical firing curves with several hundred degrees of temperature difference between the top and bottom of the tunnel kiln were successfully prevented by high speed burners, hot and cold air injections. Flat settings, increasing throughput, good mechanical handling and low vulnerability to failures make the tunnel kiln an ideal firing unit for coarse ceramics such as bricks or roof tiles. However, a relatively large amount of exhaust gas remained at low temperature level. Actually, the entire hot air generated during the cooling of the bricks is sucked out of the tunnel kiln and is transferred to the asynchronous working dryer. This so-called combined air binds more than 50% of the primary energy in most cases, which is needed for the kiln process as shown in Fig. 1.

Secondly, for the energy optimization of the dryer, the drying air temperature must have the highest possible values. However, the cooling air does not have such high temperatures. If the dryer is operated autonomously, the drying air can always be adjusted to the optimal condition by mixing with combustion air. The results are described in detail in e.g. [4,5].

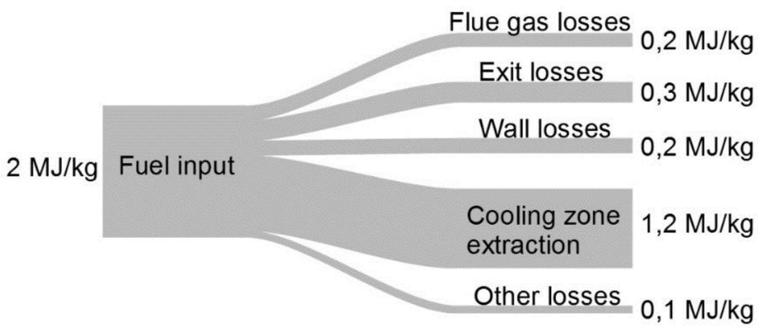

Fig. 1: Typical energy input and outputs of a tunnel kiln for production of building ceramics [6]