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Energy saving in ceramic tile kilns: Cooling gas heat recovery

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HIGHLIGHTS

- Some energy input (30–35%) in ceramic roller kilns is lost through the cooling gas stack.
- Cooling air is directly recovered in the combustion chamber, providing oxygen.
- This energy recovery from the cooling gas stack has been quantified.
- It has been proven that the proposed methodology to estimate energy savings is valid.

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ABSTRACT

A great quantity of thermal energy is consumed in ceramic tile manufacture, mainly in the firing stage. The most widely used facilities are roller kilns, fuelled by natural gas, in which more than 50% of the energy input is lost through the flue gas and cooling gas exhaust stacks.

This paper presents a calculation methodology, based on certain kiln operating parameters, for quantifying the energy saving obtained in the kiln when part of the cooling gases are recovered in the firing chamber and are not exhausted into the atmosphere. Energy savings up to 17% have been estimated in the studied case.

Comparison of the theoretical results with the experimental data confirmed the validity of the proposed methodology. The study also evidenced the need to improve combustion process control, owing to the importance of the combustion process in kiln safety and energy efficiency.

1. Introduction

The ceramic tile manufacturing process consists of various stages, which differ as a function of the product made. The main tile production stages are: the raw materials preparation, the tile forming, drying, glazing and decorating, and firing [1].

When the tile body and glaze are fired together, the manufacturing process is known as single firing. Sometimes, however, the tile body is fired first; the fired body is then decorated and subjected to a second thermal cycle to fire the glaze. This process is called double firing. The most common ceramic tile manufacturing process is the single-firing process, which is schematically illustrated in Fig. 1.

Several ceramic tile manufacturing stages require thermal energy [2]. Thermal energy consumption takes place mainly in three process stages: spray drying of ceramic slurries, drying of the freshly formed tile bodies, and tile firing. Fig. 2 shows the average percentage distribution of thermal energy consumption in these three stages. The greatest energy consumption occurs in firing, which accounts for 55% of all thermal energy used in tile manufacture [3].

Average thermal energy consumption in ceramic tile manufacture is estimated to be 4608 kJ/kg fired tile, relative to the lower heating value (LHV) of natural gas. As noted, the firing stage consumes the most thermal energy, with an average value of 2556 kJ/kg fired tile.

The energy required in the process is obtained by combustion of natural gas, which is a fossil fuel. Natural gas combustion gives rise to air emissions of carbon dioxide, a greenhouse gas, the emissions of which are internationally subject to control and abatement measures. Ceramic tile manufacture is one of the activities envisaged in the European legislation on greenhouse gas emission allowance trading (see Annex I of Directive 2003/87/EC) [4]. According to this Directive, before 2013 most European ceramic tile companies did not exceed the thresholds set and were therefore not affected by this directive. However, the new Directive 2009/29/EC, in force since 2013 establishes a new legal framework through which most tile companies are becoming part of the emissions trading system [5].

The CO_2 emissions produced by natural gas combustion in ceramic tile manufacture are estimated to be about 265 kg CO_2/t

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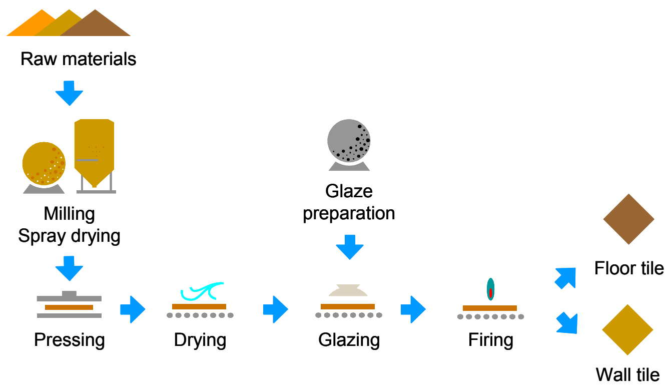

Fig. 1. Schematic illustration of the single-fired ceramic tile manufacturing process.

fired tile [6]. These emissions account for about 90% of all CO_2 emissions in the tile manufacturing process, while the emissions from the decomposition, during firing, of the calcium and/or magnesium carbonates present in tile bodies account for about 10% of all CO_2 emissions in the process.

Thermal energy costs currently make up about 15% of total ceramic tile manufacturing costs. However, this figure varies, basically owing to changes in fuel prices, which depend on political and market situations beyond the industrial process.

Reducing kiln energy consumption decreases energy costs and CO_2 emissions. On the other hand, owing to the EU legislation on emissions trading, CO_2 emissions can also entail an economic cost for companies. Consequently, lowering thermal energy consumption decreases manufacturing costs and enhances company competitiveness [7]. Moreover, lower natural gas consumption means that better use is made of natural resources, thus contributing to international policies aimed at reducing fossil fuel consumption [8], following the roadmap to move to a competitive low carbon economy [9].

Most ceramic tiles are fired in continuous roller kilns, in which the tiles are conveyed through the kiln on rollers. Heat is produced by natural gas combustion in the burners. The combustion gases are exhausted from the kiln through a stack located at the kiln entrance [10]. After crossing the peak temperature zone, the tiles are cooled by direct contact with the ambient air that is fed into the kiln. Cooling gases are usually exhausted through the cooling stack, though they are sometimes recovered in other process stages [11], principally in drying, or as combustion air in the burners of the same kiln, as it is done in other industrial processes [12].

Energy balances drawn up on ceramic tile kilns, based on thermodynamic analysis [13], have shown that kiln efficiency is low, because only 5–20% of the energy input is used in firing the tiles (that is, in the chemical reactions involved in material transformations). The rest is lost through the flue gas stacks (20–25%) and cooling stacks (30–35%), with the fired tiles (5–10%), and through the kiln walls and vault (10–15%).

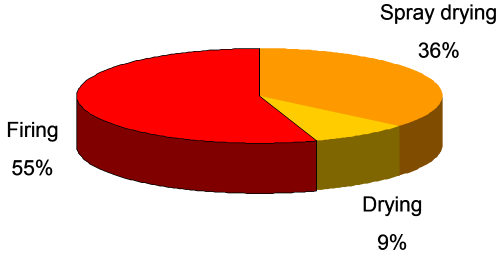

Fig. 2. Breakdown of the main thermal energy consumption in ceramic tile manufacture.

The main input and output streams of a ceramic tile kiln and the context on which the energy balance is drawn up are illustrated in Fig. 3.

Previous studies have examined the influence of certain firing process variables such as static pressure and oxygen content in the combustion chamber on kiln energy consumption [14]. To date, the energy saving obtained from heat recovery of part of the cooling gases in the ceramic tile kilns has not been evaluated [15]. However, the optimisation of heat recovery have been studied for tunnel kilns [16], and the hot air sent from the cooling zone to the firing zone has been considered in mass and energy balances made in studies developed for tunnel kilns [17].

2. Objective and scope of the study

This study was undertaken to quantify the energy saving achieved by direct heat recovery of the cooling gases in the combustion chamber.

The procedure developed is applicable to natural gas-fuelled roller kilns for firing ceramic tiles.

3. Description of the facility

The studied ceramic tile kiln was a single-deck roller kiln, 90 m long, made up of 43 modules, each of which was 2.10 m long. The plane formed by the rollers conveying the tiles divided the kiln into a top and a bottom chamber, in which different firing temperatures could be set. The product being manufactured during the study was porcelain tile.

Heat was produced by natural gas combustion in the kiln burners, into which air and gas were fed through different openings. The combustion products were propelled at great speed (above 100 m/s) through the burner nozzles into the kiln, which facilitated heat transmission by convection towards the ceramic tiles [15].

The burners were arranged in rings. Each ring consisted of a group of burners that were regulated and controlled as a function of the temperature recorded by a kiln control thermocouple. The thermal firing cycle was, thus, controlled by a series of thermocouples that regulated the power input of the different kiln burner rings.

The studied kiln contained 168 burners. These were arranged in 22 rings, of which 2 contained 12 burners, 16 contained 8 burners, and 4 contained 4 burners.

The oxidiser used in the burners was air recovered from the cooling stack and diluted with ambient air to a working temperature of 105 °C. The oxidising air was fed into the burner rings through an insulated duct at a constant pressure, regulated by an impeller fan fitted with a frequency inverter. The combustion air flow rate could be regulated manually at every burner with a valve located in the air supply duct to each burner. However, the most common industrial practice is to work with a similar air pressure in all kiln burners.

The flue gases produced by natural gas combustion in the burners were exhausted through the flue gas stack at the kiln entrance. A pressure transducer was fitted in the maximum temperature zone (at about 45 m from the kiln entrance) to continuously monitor the static pressure in that kiln zone. The flue gas exhaust fan was fitted with a frequency inverter and control system that automatically regulated fan rotation speed to keep the static pressure at the programmed setting.