ENERGY OPTIMISATION IN CERAMIC TILE MANUFACTURE BY USING THERMAL OIL

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ABSTRACT

The ceramic tile manufacturing process consumes a great amount of energy, mainly thermal energy, which is obtained from natural gas combustion. The increased cost of this fuel and the current economic situation make cost a critical issue that can hurt company competitiveness.

The ceramic tile firing process in roller kilns does not exactly stand out for its energy efficiency, because about 50% of the energy input is lost through the kiln combustion flue gas and cooling gas stacks.

With a view to improving the reuse of the energy consumed in the firing operation, two heat exchangers were installed in the stacks of a kiln. In these heat exchangers, the kiln gases transfer their sensible heat to a thermal oil that then passes this on, through two other exchangers, to the drying gases in the recirculation ducts of a vertical dryer.

This study presents an experimental industrial plant in a fine-tuning test phase, in which the preliminary results indicate an energy efficiency improvement in a range of 60–90%, depending on the operating conditions and processed materials.

1. INTRODUCTION

The ceramic tile manufacturing process requires high energy consumption, principally thermal energy.

All the manufacturing process stages consume electric energy. Thermal energy consumption takes place mainly in three stages: spray drying of the ceramic suspensions, drying of the tile bodies, and tile firing. The thermal energy used in the process is mainly obtained by natural gas combustion.

Figure 1 presents a schematic illustration of the ceramic tile manufacturing process.

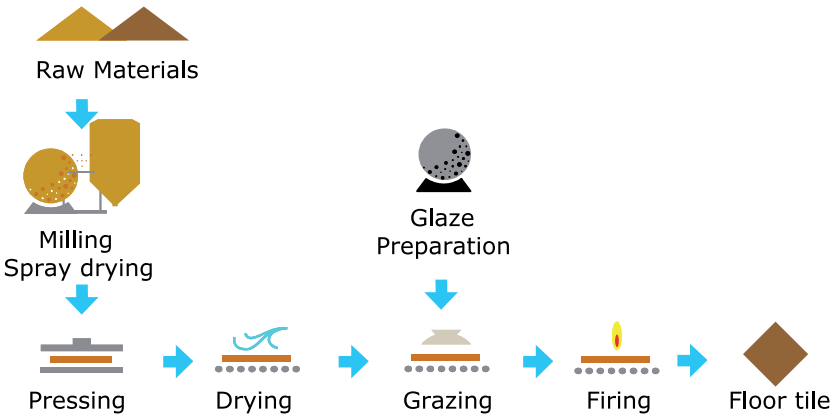

Figure 1. Ceramic tile manufacturing process.

Single-fired ceramic tiles are fired in Spain in roller kilns that use natural gas as thermal energy source. The average energy consumption in this process stage is estimated at 705 kWh/t fired product, of which between 5 and 20% is used in firing the product, while the rest is lost via the kiln stacks, through the kiln walls and cracks, and with the tiles that exit the kiln. A typical Sankey diagram of a roller kiln is shown in Figure 2, in which the percentage contribution of each stream in the kiln energy balance is schematically depicted.

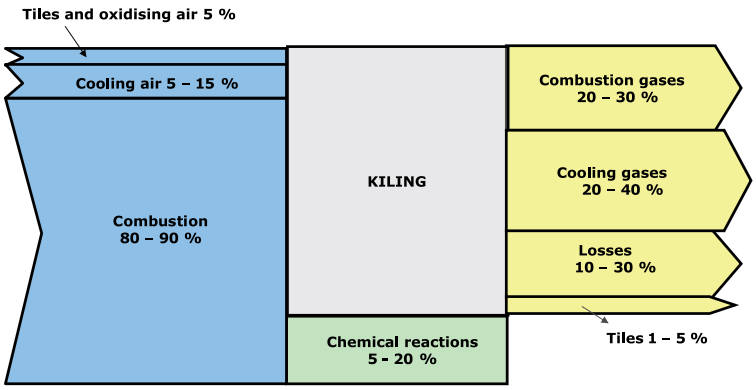

Figure 2. Standard Sankey diagram of a tile firing kiln.

It may be observed that about 50% of the energy input into the firing process is lost through the kiln combustion flue gas and cooling gas stacks.

The aim of this study was precisely to reuse this energy by installing heat exchangers.

At present it is the residual heat of the gases from the cooling stack that is mainly reused, because these gases consist of air without pollutants as they result from the direct contact of the air used to reduce tile temperature in the cooling zone.

However, owing to the fact that ceramic tiles undergo chemical reactions during firing, the gases from the combustion flue gas stack bear pollutants as they contain by-products from natural gas combustion and the chemical reactions produced by the material during the firing process. As a result, in order to be able to reuse these gases, pre-treatment is required.

The possibilities of reusing combustion gas residual heat are as follows:

- Installation of a cleaning system

It would be possible to clean the combustion gases and reuse them, together with those from the cooling zone, in the dryers.

The constraint entailed in this option is gas temperature, since bag houses usually cannot withstand temperatures above about 180–200 ºC, depending on the type of bag material.

- Installation of heat exchangers

The option addressed in this study was the installation of heat exchangers with an intermediate fluid that conveyed heat from the kiln to the dryer.

In addition, since combustion gas temperature decreased after the heat exchanger, it would be possible to install a gas treatment system.

2. OBJECTIVE

The objective of this study was to improve the use of the energy consumed in the firing operation by installing an innovative heat recovery system to reduce heat losses via the stacks and reuse the heat in the drying stage.

3. DESCRIPTION OF THE PROCESS

3.1. Description of the installation

The installation consisted of joint heat recovery from the kiln combustion flue gas stack and the cooling air stack to a dryer, using heat exchangers (one in each stack), so that the energy was transferred from the kiln to the dryer, using oil as thermal fluid. The thermal oil heated in the two kiln exchangers was brought together in a single stream and fed into the dryer.

The thermal oil circulated from the kiln to the dryer through an insulated pipe to minimise energy losses. The heat in the dryers was transferred to the dryer recirculation air through two additional exchangers, one for each burner.

The thermal oil was used in a closed circuit, so that after transferring heat to the dryer gases it returned to the kiln heat exchangers to start the process again. The circuit was fitted with a system of valves and a bypass, which allowed oil temperature to be maintained at the optimum value, thus enhancing overall process efficiency.

Depending on the needs of the system, the hot drying gases can be preferentially fed into the dryer either to one or to both the dryer burners.

A general scheme of the installation is depicted in Figure 3.

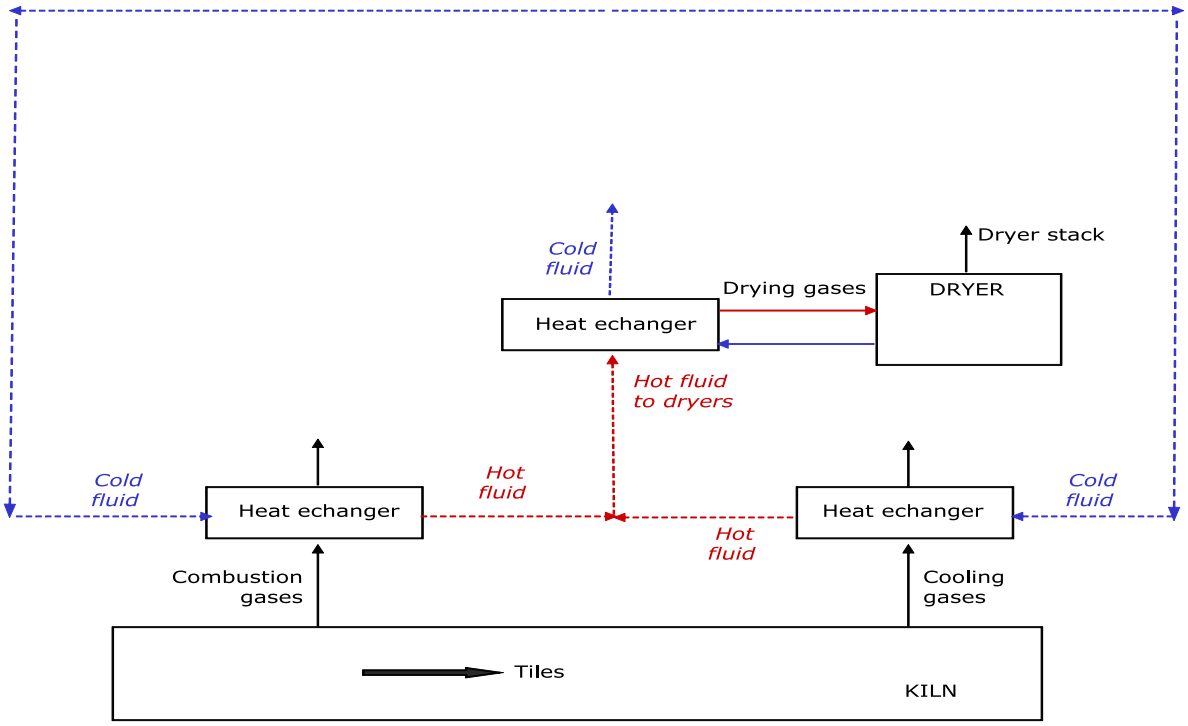

Figure 3. General scheme of the heat recovery installation.

3.2. Description of the main elements

3.2.1. Dryer

The studied dryer was a vertical dryer and heat was provided by natural gas combustion via two burners located in the two air recirculations.

The studied dryer is schematically depicted in Figure 4.

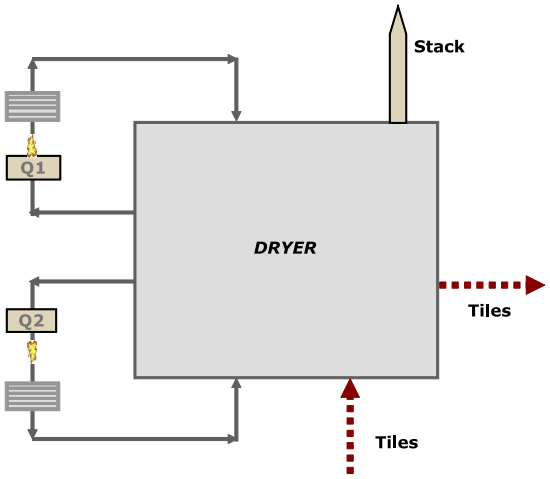

Figure 4. Scheme of the dryer.

After tiles enter this dryer, they are first conveyed upwards and, after passing through the high zone of the dryer, they descend towards the stabilisation area.

After the drying gases enter into contact with the tiles, part of the gases is re-circulated again towards the dryer by two independent recirculations in which the air vein burners are located. The rest is exhausted into the air through the stack. In this study, the two oil heat exchangers, which heated the recirculating drying gases after the burners, were positioned in these two recirculations.

The burner temperatures for the drying gases that left the dryer were set such that the heating elements (heat exchanger and burners) heated the gases that were fed into the dryer sufficiently for the temperature at the exit to match the required temperature.

The gases from the combustion flue gas stack had a temperature of about 210 ºC, just like the gases from the cooling zones.

Each of these streams was passed through its respective heat exchangers, in which thermal oil circulated counter-current, which reached temperatures of the order of 190 ºC, transferring part of its heat to the drying gases through two heat exchangers located in the dryer recirculation ducts.

3.2.2. Kiln

The studied kiln was a single-deck roller kiln, divided into a heating, firing, and cooling zone.

The heat was provided by natural gas combustion in high-speed burners, which were arranged along the side walls of the kiln, above and below the roller plane in the heating and firing zones.

Before the recovery system was installed, the kiln combustion gases had been diluted with ambient air and directly released into the atmosphere. After the installation of the recovery system, the gases were no longer diluted with ambient air and the heat was transferred to the thermal fluid.

The cooling gases were initially collected from the fast cooling, indirect cooling, and final cooling zones. From this stack, a part was recovered to the pre-kiln dryer, another part to the kiln burners, and the rest was released into the atmosphere.

The cooling zone heat exchanger was installed in the duct containing the fast cooling gases, since these were the gases with the highest temperature.

3.2.3. Heat exchangers and thermal fluid

Four heat exchangers were installed counter-current: two positioned in the kiln and the other two in the dryer.

The refined oil had been specially formulated as heat exchange fluid, and contained appropriate additives to provide it with thermal stability and higher oxidation resistance, in order thus to be able to respond to temperature rises during its use and to the spacing of the oil change times.

Its refined bases provide this thermal fluid with high thermal resistance, as well as anti-oxidising properties, considerably reducing the formation of insoluble material and deposits in the pipes, thus assuring perfect circulation and heat transmission of the fluid, avoiding blocking of the circuits.

In addition, this fluid has a low viscosity, which allows immediate start at low temperatures, and optimum heat transmission, thus providing enhanced pump performance. The foregoing assures flawless operation and high performance in closed installations without any direct contact with the air, which are fitted with mechanical circulation systems.

The thermal oil properties are set out in Table 1.

Property	Standard	Value
Maximum operating temperature (ºC)	---	350
Kinematic viscosity at 40 ºC (cSt)	ASTM D 445	20 – 25
Viscosity index	ASTM D 2270	95
Density at 15 ºC (g/cm^3)	ASTM D 1298	0.860
Flash point (ºC)	ASTM D 92	210
Freezing point (ºC)	ASTM D 97	-14

Table 1. Characteristics of the thermal oil used.

4. EXPERIMENTAL PROCEDURE

4.1. Determination of the energy saving

The measurement and verification of the energy saving were performed according to the methodology described in the International Performance Measurement and Verification Protocol (IPMVP) promoted by the Efficiency Valuation Organization (EVO).

Measurement and Verification (M&V) is a process that consists of using measurements to reliably establish the actual saving obtained in an installation in an energy management programme.

Energy saving cannot be directly measured since it represents the absence of energy consumption. For this reason, energy saving is determined by comparing consumption or demand before and after the implementation of an energy efficiency project, while simultaneously making the appropriate adjustments as initial conditions vary.

Dryer energy consumption was performed from readouts of the natural gas flow meter installed in the dryer. These readings were carried out in short periods of time, with a view to recording the arising incidences, and always in total time periods longer than 3 hours.

In addition to the consumption readout of the gas flow meter, natural gas pressure and temperature in the duct were also recorded. These data enabled the gas flow rate to be normalised by means of the following expression:

$$Q_N = Q \cdot \left(\frac{T_0}{T_{gas}} \right) \cdot \left(\frac{P_{gas} + P_{atm}}{P_0} \right) \quad \left(m_N^3 / h \right)$$

Equation 1.

where:

- Q: is the flow rate obtained from the direct readout of the flow meter (m^3/s).
- T_{gas}: is the natural gas temperature in the duct (K).
- T_0: is the reference temperature (273 K).
- P_{gas}: is the gas pressure in the duct (N/m^2).
- P_{atm}: is the average air pressure (N/m^2).
- P_0: is the reference pressure ($1.013 \cdot 10^5$ N/m^2).

4.2. Determination of dryer operating conditions

In order to validate that the heat recovery system did not affect drying operation conditions, the temperature distribution inside the dryer in the different

analysed situations, and the gas flow rates at the dryer exit were experimentally determined.

The drying cycle was experimentally determined using the device shown in Figure 5, which consists of a metallic receptacle, measuring 33 cm x 33 cm, 2.5 cm thick, and externally covered with ceramic fibre insulation. It contained a data logging system, to which 4 K-type thermocouples were connected. Two bags of water were located next to the data logging electronics, the water being frozen before the test started to ensure that the data logging system did not heat up above 50 ºC.

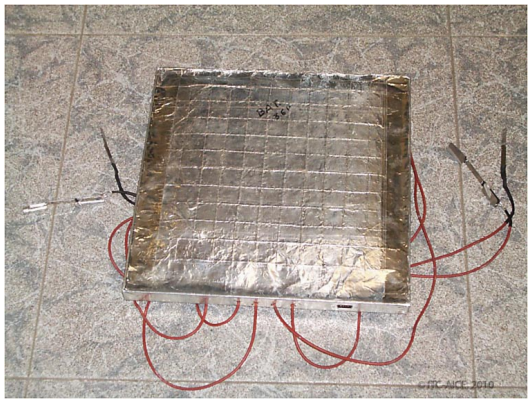

Figure 5. Device used to determine the drying cycle.

Data logging start and stop, as well as the downloading of the stored values, was performed by a computer using devoted software.

The gas flow rates were determined with an S-type pitot tube.

This was performed according to standard UNE 77225:2000.

5. RESULTS

A preliminary study was made of the operation of the installation with the major product. The measurements without and with heat recovery were performed under conditions similar to production conditions in order for the comparison to be accepted and the IPMVP criteria to be taken into account.

The results obtained in the two analysed operating situations are set out below.

The operating parameters of the studied dryer in the analysed situations are detailed in Table 2.

Parameter		Without heat recovery	With heat recovery
Product	Type of composition made	Porcelain tile	
	Size (cm x cm)	30 x 60	
	Production (kg dry solid/h)	2.30	2.36
	Input moisture content (% dry basis)	6.35	6.35
	Output moisture content (% dry basis)	0.05	0.06
Dryer	Burner 1 temperature setting (ºC)	125	125
	Burner 2 temperature setting (ºC)	120	120

Table 2. Dryer operating parameters without and with heat recovery.

With a view to validating the operation of the heat recovery system, the drying gas properties were analysed while heat was being recovered from the kilns, and without heat recovery, in order to establish whether gas properties were affected by the recovery system.

The properties of the dryer stack gases in the analysed situations are detailed in Table 3.

Parameter	Without heat recovery	With heat recovery
Temperature (ºC)	120	120
Absolute humidity(kg water/kg dry air)	0.100	0.090
Gas flow rate (m/h)	7100	7900

Table 3. Characterisation of the dryer stack gases without and with heat recovery.

It may be observed that the drying gas conditions were hardly modified by the recovery system.

The lower absolute humidity of the drying gases with the heat recovery system was consistent with the lower natural gas consumption of the dryer, since water vapour is a natural gas combustion product.

The experimental drying cycle was carried out using the device indicated in section 4. The results obtained, without recovery and with heat recovery, are presented in Figures 6 and 7, respectively.

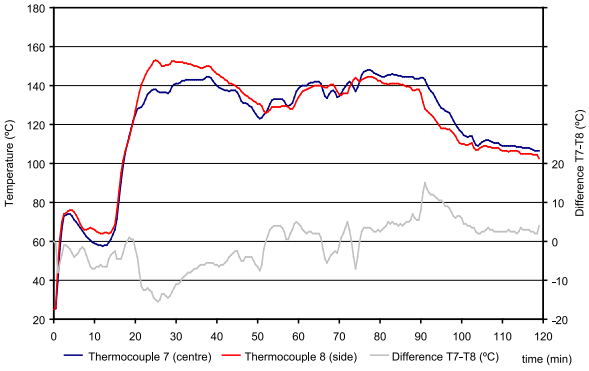

Figure 6. Drying gas temperature without heat recovery.

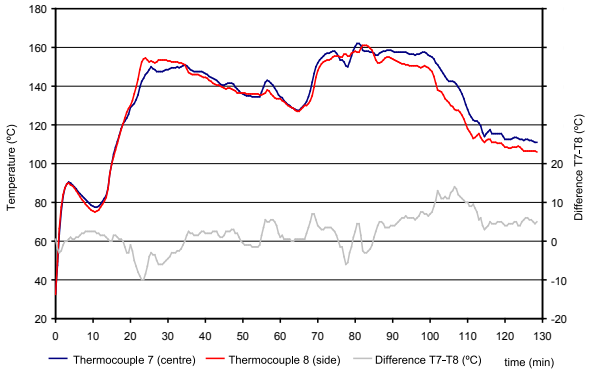

Figure 7. Drying gas temperature with heat recovery.

The results show that there were no important temperature differences between the centre and side zones of the dryer. In the dryer's rising section, the gas temperature at the side of the dryer was slightly higher than in the centre in the two situations; this circumstance was reversed in the descending section. The maximum temperature difference observed was about 15 ºC.

It may be noted that when the heat recovery was operating, higher temperatures were reached in the second half of the drying cycle.

The drying cycle was formally similar in both situations. It may be concluded, therefore, that the approach used to recover heat from the kiln hardly affected the drying cycle.

6. CONCLUSIONS

The main conclusions drawn from the study were as follows:

- An experimental heat recovery installation was fine-tuned, which allows simultaneous recovery of energy from a kiln combustion flue gas stack and a cooling gas stack in a single stream, using thermal oil, to a vertical dryer.
- It was verified that the installation of this system did not affect dryer operating conditions, so that the properties of the product did not change.
- At the time this paper is submitted, the preliminary studies indicate that 60 to 90% reduction can be achieved in natural gas consumption, depending on the material processed, together with a similar reduction in dryer carbon dioxide emissions.

ACKNOWLEDGEMENTS

This study was funded by the Valencian Institute of Small and Medium-sized Industry (IMPIVA) in the Research and Technology Development Programme through project IMIDTF/2010/179.

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