ENERGY RECUPERATOR FOR THE ENERGY SAVING PROCESS IN THE CERAMIC TILE, BRICK, AND ROOFING TILE MANUFACTURING SYSTEM

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1. INTRODUCTION

In the realm of energy both in Spain and worldwide, there exist a multitude of issues that need to be taken very seriously into account, such as the lack of domestic resources, the dependence on foreign energy supplies, difficulties in building new infrastructures, etc. To date, these issues remain unsolved and indeed entail complex solutions. Furthermore, global warming is a matter of great alarm for the large majority of the scientific community and world population. The Kyoto Protocol and the European Union directive that regulates compliance with it in Europe stand as evidence of that fact.

For a number of years, the capital goods manufacturing sector for the ceramic industry has been implementing measures to reduce energy consumption in its machinery, as is illustrated by the evolution of energy consumption in the ceramic sector and by comparing the specific emissions for the floor and wall tile sector in Spain and Italy.

2. AIM

A heat exchanger is a system that enables heat energy to be recovered in order to warm ambient air. Once free of any contaminating particles (to prevent deterioration of the machine structure), this air is injected into the firing, drying and/or spraying processes, thereby allowing for significant reductions in fuel consumption. The system gives a quick return on capital outlay and therefore provides tangible earnings once fully depreciated.

This paper offers a detailed study of the technical and economic feasibility of implementing such a system in the ceramic manufacturing process, both for floor tiles and structural ceramics, to make use of the residual heat generated in firing in the subsequent drying and spraying processes.

Installing this technology provides very significant savings in natural gas consumption and consequently reduced CO_2 emissions.

3. CURRENT DIFFICULTIES INVOLVED IN RECOVERING ENERGY FROM HOT GASES

Exhaust gases from the combustion of natural gas generally but also from co-generation turbines, on which part of this paper has been developed, due to the flow rate and temperatures involved, are re-used in dryers (both tunnel and chamber dryers) for drying roof tiles.

However, using these exhaust gases entails the following problems for the factory:

3.1. Maintenance issues.

Exhaust gases are driven through tunnel and chamber dryers. The main problem lies in tunnel dryers. These tunnels require the use of metal structures that serve as trolleys to transport and move the roof tiles inside the dryers. Because of the composition of these exhaust gases, they have a high moisture content and also include a significant amount of corrosive elements. This in turn leads to the rusting of many of the trolleys and other, both static and mobile, metal parts that come into direct contact with them, which then leads to heavy maintenance costs to repair and/or replace rusted and corroded parts.

Therefore, corrective measures are being sought to address this problem.

3.2. Operator health and safety issues.

This problem arises mainly with chamber dryers. Operators involved in product handling in this type of dryer undergo discomfort as a result of exposure to the exhaust gases used in the machine. Such discomfort generally takes the form, among other symptoms, of eye irritations that hinder the operators in their work.

Operator exposure to exhaust gases is due to two main reasons:

- Firstly, these chamber dryers operate under pressure, so that it is highly likely that small leaks appear that pollute the operators' working environment.
- When the dryer is emptied and the doors opened, given that the inside of the machine has been working under pressure, a certain amount of exhaust gas is released throughout the factory, affecting not just the line operator but also workers in areas adjoining the chamber dryer.

Such exposure initially causes eye irritation for operators. However, prolonged exposure to such irritating gases may cause more significant damage to the tissue in the operators' respiratory system. The extent of such damage to the respiratory system depends on the intensity (gas concentration in the environment) and duration of the exposure.

3.3. Head loss issues.

A certain amount of pressure is lost when exhaust gases are transported from the co-generation engines to the various machines where the heat energy is to be used (steam boilers and dryers). This head loss determines the outlet pressure of the exhaust gases from the co-generation plant.

The loss of pressure between the co-generation plant outlet and the inlet to the mixing chamber is currently around 50 mbar. However, the machines can only withstand an outlet pressure of 65 mbar. If pressure loss were to exceed 65 mbar, the engines would stop. Therefore, adjustment needs to be made to allow for such head loss.

Any system implemented to correct either of these problems (maintenance or operator health & safety) may affect head loss adjustment and therefore lead to machine downtime.

3.4. Solution to these issues.

In view of the situation described above, a profound study of the various options available was carried out and the implementation of a gas/air heat exchanger was chosen as a means of using hot ambient air instead of exhaust gases to eliminate both the maintenance problem and the risk for operator health. This system provides a solution that has no negative impact on drying machine performance or output.

4. HEAT EXCHANGER. DESCRIPTION OF SYSTEM PARTS

The components of the system are as shown below:

4.1. Type of heat exchanger.

The body of the heat exchanger is made up of a battery of steel pipes on an inner casing. This is a shell and tube air pre-heater, comprising a series of vertical pipes through which clean air flows, while flue gases circulate around the outer shell.

The heat exchanger is rectangular in shape, rather similar to the one illustrated below:

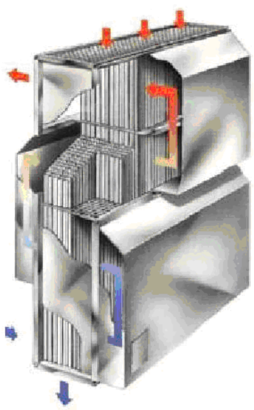

Figure 1. Shell and tube heat exchanger.

In order to meet process specifications, which call for a clean air outflow temperature of about 150ºC, a heat exchange surface area of about 536 m^2 is required. This type of heat exchanger is characteristically used in a number of applications, including oil refineries, power plants, air conditioning and freezer installations.

As can be seen in the next illustration, flue gases flow across the tube bundle inside the casing and pass across the pipes containing the clean air three times. The direction of the flue gas is controlled by means of two bafflers or flow separator plates on the outside of the casing.

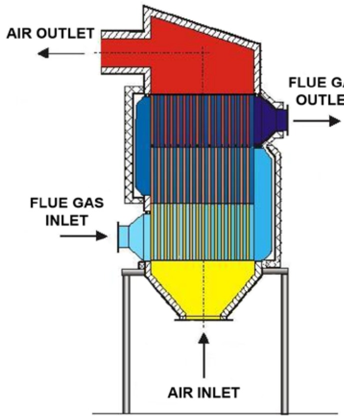

Figure 2. Flow direction for outside air and flue gas flow direction in heat exchanger.

Both flue gas and air speeds are adjusted to prevent vibration and tube erosion or the build-up of ash and soot. The unit is insulated to avoid heat loss and enhance worker safety.

4.2. Exchanger tubes.

The tubes are arranged vertically and supported by two tube plates at both the inlet and outlet ends. The ends are welded to the tube plates to guarantee gas tightness and ensure the machine is suitably rigid.

The exchanger comprises a nest or bundle of vertically-arranged carbon steel pipes, as illustrated below:

Figure 3. View of heat exchanger tubes.

4.3. Adjusting the system.

To ensure proper performance of a gas/air exchanger, two control loops are required to regulate:

- The operation of the drawing fan on the exhaust gas inlet line, and
- The operation of the ambient air fan that impels the air around the inside of the exchanger.

These controls are carried out as follows:

- Inlet drawing fan control: a PID controller is used to control a frequency shifter that responds to the signals fed by a pressure sensor fitted on the exhaust gas line before the entrance to the exchanger. The frequency shifter is coupled to the motor that drives the inlet (tail) fan, turning it on and off as required. The PID compares the pressure reading signals with a pre-set constant negative pressure setting. If the pressure reading from the sensor differs from the pre-set pressure, the PID activates the tail fan until the pressure read by the sensor reaches the pre-set level.
- Impeller fan control: the clean air impeller fan is controlled in much the same way as the exhaust gas inlet fan, the only difference being that the fan is fitted on the head rather than the tail and the pressurestat is installed on the ambient air outlet line from the exchanger. In this case, the pre-set constant pressure is positive. Hot clean air temperature at the outlet can be adjusted by controlling this fan.

The following figure is a sketch of these control loops:

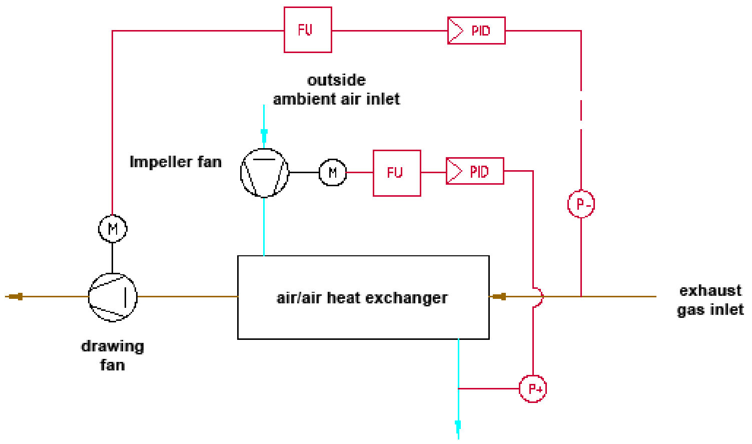

Figure 4. Operating control system for impeller and drawing fans in an air/air exchanger.

4.4. Drawing fan.

The drawing fan is fitted after the gas/air exchanger has been installed. It is set to supply a flow rate of 45,800 kg/h of exhaust gas to generate a negative pressure equal to the head loss caused by the heat exchanger halfway along the gas flow. This head loss is about 70 mm water column.

In this case, the selected fan had been manufactured to perform correctly with high-temperature exhaust gases.

Therefore, as far as head loss is concerned, the system is invisible, in the sense that its installation does not increase pressure loss along the gas flow and therefore outlet pressure from the engines is not affected. The purpose of this fan is to ensure that the heat exchanger system does not have a negative impact on engine performance.

Furthermore, the fan can be oversized to produce a negative pressure greater than the head loss caused by the exchanger. The drawing fan would thus absorb head loss on the gas flow ducts that is currently being borne by the outlet from the co-generation engines. Such a system would protect the operation of the co-generation engines even further by absorbing any head loss peaks that might arise when the gas flow ducts were opened or closed.

4.5. Impeller fan.

The impeller fan should be installed on the other line of the gas/air heat exchanger. This fan produces a flow rate of 52,000 kg/h of outside air at ambient temperature at a specific pressure, sufficient to overcome the head loss produced by gas flow through the exchanger or in the lines from the exchanger to the mixing chamber. Head loss inside the heat exchanger for exhaust gases is calculated to be 80 mm water column.

At this point, special mention should be given to the fact that the head loss due to the flow ducts from the heat exchanger site to the mixing chamber would no longer have to be borne by the outlet pressure from the engines, as is the case at present, but rather would be offset by the impeller fan. This means that outlet pressure from the co-generation engines would be lower, which has a positive impact on their operational performance.

There is no need for any special type of fan, as it is only required to work with outside air at ambient temperature.

4.6. Commissioning and maintenance work.

Before start-up, it is imperative to make sure that the exhaust gas and outside air are able to flow freely through the tubes and shell. In the event that buffers have been fitted, they must move freely and be properly adjusted.

Furthermore, checks should be made to ensure the whole system has been properly installed and that the system value limits (temperature, pressure difference, material, etc.) have not been exceeded.

As far as maintenance of the heat exchanger is concerned, once it has been installed, only visual inspection is required. Where buffers have been fitted, they must continue to move properly. Initially, such checks should be carried out once a month. After three months, these checks can be performed once a year.

To facilitate assembly and installation of the heat exchanger, it is fitted with hoisting lugs and side rests on which the casing can be supported in a suitable place.

The equipment is supplied with inlet and outlet flanges to connect the outside air and exhaust gas lines and all joints are bolted, so that they can be assembled and dismantled as often as may be required.

5. INDUSTRIAL USE. SPECIFICATIONS AND RESTRICTIONS

This heat exchanger was installed at a roof tile manufacturing plant as detailed below. Initially, the order was for the design and set-up of an air/air heat exchanger to recover heat energy from the exhaust gases at 270ºC from combustion engines.

Heat is transferred from this exhaust gas flow to a separate stream of clean air from outside the factory. The installation is based on the customer's own specifications and restrictions regarding the product to be manufactured and the actual site of the installation.

5.1. Specifications.

The specifications provided for this installation can be sorted into several groups:

5.1.1. Specific customer requirements.

a) Maintain current work conditions. The customer would like to maintain the work situation currently in place at his factory. At present, the exhaust gas flow is used to feed two systems: one part of the gas flow goes to the mixing chamber where a series of flows from other manufacturing processes meet, while the rest of the gas flow is used to feed the drying chambers.

These exhaust gases cause eye irritation for the operators in the drying chamber area; therefore, the heat exchanger has to be capable of delivering hot clean air to keep the dryers working without upsetting the workers.

Therefore, these specifications demand that:

- The flow of clean air/hot air from the heat exchanger equals the current flow of exhaust gas.
- The temperature of the clean air needs to be greater than 150ºC.

b) Cause minimum head loss. The electricity generating motors can only accept a certain outlet pressure (maximum 65 mbar). Any modifications carried out must ensure the motors continue working, so that the outlet pressure from the motors needs to be less than 65 mbar.

c) Eliminate the problems involved with using exhaust gases. Recovering energy from exhaust gases in drying sections (both tunnel and chamber dryers) causes two types of problems (maintenance and occupational health) which are analysed in the following section.

5.1.2. Operating flow specifications.

a) Operating flows to be used. The heat exchanger is to be designed to enable the exchange of heat energy between the plant's operating flows, namely:

- Clean air flowing from outside the factory.
- Exhaust gas flowing from the company's own electricity generator, which uses four natural gas-fired engines.

b) Operating flow properties. The exhaust gas has the following properties:

- Exhaust gas flow rate: 45,800 kg/h.
- Exhaust gas inlet temperature: 270 ºC.

Clean air from the atmosphere:

- Ambient air flow rate: 52,000 kg/h.
- Inlet temperature of ambient air: depends on time of year.

6. SYSTEM DESIGN

For the design of the exchanger, the worst case scenario was determined to be the requirement to heat 52,000 kg/h of air. Taking ambient temperature to be 20ºC, this shell and tube heat exchanger needs to increase the temperature of 52,000 kg of air from 20ºC to 151ºC each hour. Therefore, an exhaust gas flow rate of 45,800 kg per hour would be required to enter the exchanger at 270ºC and cool down to 137 ºC.

The two flows (air and exhaust gas) would not come into direct contact or mix with each other as circulation fluid flows through the heat exchanger are gas-tight. Heat is transmitted via the tubes (one gas cools while the other fluid is heated). The temperature exchange graph is as follows:

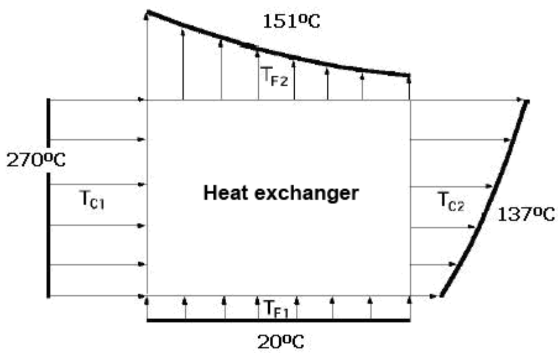

Figure 5. Temperature evolution for hot and cold flows at exchanger inlet/outlet.

7. EXAMPLE OF HEAT RECOVERY IN TILE KILN FOR TWO DRYERS.

7.1. Technical and economic data

Machine from which heat energy is recovered: Porcelain tile kiln (Temp: 1200ºC)
Machines destined to use heat energy: Dryer at the press exit

Nº of kilns: **1**
- Daily output: 7.500 m^2/day.
- Product format: 45 x 45 cm.
- Stack temperature: 200ºC.
- Flow rate in stack: 16.500 Nm^3/h.

Nº of dryers: **2**
- Working temperature: 140ºC.
- Flow rate in stack: 21.284 Nm^3/h – 30.000 Kg/h
- Hours in operation: 8.000 hours/year (per dryer).
- Natural gas consumption: 80 Nm^3/h (per dryer).
- Annual natural gas consumption: 640.000 Nm^3/year (per dryer).

CALCULATION DATA

Price natural gas	0.34	€/Nm^3
Price KWh electricity	0.12	€/KWh
Hours in operation per year	8.300.00	hours

HEAT ENERGY

Hot air flow rate	18.146.00	kg/h
Inlet temperature	20.00	ºC
Outlet temperature	170.00	ºC
Energy savings	656.004.15	Nm^3/year

ELECTRICITY

Fan motor power rating	36.01	KW
Annual electricity consumption	298.897.86	KWh/year

Gros energy saving on NG	223.041.41	€/year
Electricity expenditure	35.867.74	€/year
Annual O&M cost	6.072.83	€/year
Total energy savings	**181.100.83**	**€/year**

8. EXAMPLE OF HEAT RECOVERY IN TILE FIRING KILNS FOR A SPRAY DRYER

8.1. Technical and economic data.

Machine from which heat energy is recovered:	4 ceramic tile firing kins.
Machines destined to use heat energy:	1 spray dryer.
Materials fired in kilns:	white-body stoneware & porcelain tile.
Firing temperatures:	1.120ºC – 1.200ºC.
Nº of kilns:	**4**
Operating flow temperature:	200ºC (each).
Flow rate in stack:	52.000 Nm³/h (all 4 kilns).
Daily output:	7.000 m²/day (per kiln).
Nº os spray dryers	**1**
Water evaporation capacity:	6.600 l/h.
Clay production:	16.500 kg/h.
Inlet air flow rate:	41.500 Nm³/h.
Operating temp.:	520 - 600 ºC.
Hours in operation:	8.300 h/year.
Natural gas consumption:	616 Nm³/hour.
Annual NG consumption:	5.112.800 Nm³/year.

CALCULATION DATA

Price natural gas	0.34	€/Nm³
Price KWh electricity	0.12	€/KWh
Hours in operation per year	8.300.00	h

HEAT ENERGY

Hot air flow rate	66.368.00	kg/h
Inlet temperature	20.00	ºC
Outlet temperature	170.00	ºC
Volume gas savings	2.399.299.20	Nm³

ELECTRICITY

Fan motor power rating	104.00	KW
Annual electricity consumption	407.613.00	KWh/year
Gross saving on natural gas	815.761.73	€/year
Electricity cost	103.584.00	€/year
Annual O&M cost	7.894.68	€/year
Total energy savings	**704.283.04**	**€/year**

9. CONCLUSIONS REGARDING INSTALLATION

The gas/air heat exchanger installation detailed herein has the following characteristics:

- **Current working and operating conditions maintained,** given that it uses a flow rate of 45,800 kg/h at 270ºC and with the shell & tube gas/air heat exchanger, the flow rate will be 52,000 kg/h at a temperature of 151ºC, i.e. higher than the 150ºC required to operate the dryers.
- **100% exhaust gas usage has been eliminated** in the dryers and has been replaced with hot air, which represents a solution to the issues both of maintenance and worker health.
- The stability of the materials used in the heat exchanger guarantee that it will not suffer from the corrosion and rusting problems of static and moving metal parts typical in drying machines.
- The installation of the heat exchanger **does not pose any risk** to engine performance as it will only have a positive impact on exhaust gas outlet pressure, so that it will help to keep the co-generation engines in service. It can therefore be said that the exchanger **will be an aid** to safeguard their useful service life.
- **Equipment has very low installation and maintenance costs** thanks to the fact that it practically has no component parts.
- Economic feasibility for our companies and business sector thanks to the fact that the **investment-profitability-saving** ratio is fulfilled in each and every variable.
- Environmental repercussions. Reusing energy allow for **savings of huge amounts of energy**, which in turn implies a reduction in greenhouse gas and CO_2 emissions.