STUDY OF THE DRYING OPERATION OF CERAMIC TILE BODIES IN VERTICAL DRYERS

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ABSTRACT

Using different types of sensors, the operation in a steady and non-steady state of a vertical dryer used for drying ceramic tile bodies is studied. The evolution of tile body characteristics is analysed when the tile exits the dryer and after modifying burner temperature settings during stoppage, gas flow rate in the stack and recirculating gas flow rate.

In some drying facilities co-generation systems are used with internal gas combustion motors. In the present study a series of modifications is proposed regarding existing facilities in order to optimise current dryer use.

1. INTRODUCTION

During the tile manufacturing process one of the main stages is drying of the tile body [1,2]. The tiles are made by unidirectional pressing of a granulated powder that contains a certain amount of water (approximately 0,055 kg water/kg dry solid), which acts as a binder between the solid particles giving the body suitable consistency. After forming, the water must be removed from the body and its surface heated before decoration. At present, tile body drying is performed automatically and continuously in vertical or horizontal dryers.

The drying operation therefore has two objectives: to eliminate moisture found in the tiles and give them the appropriate temperature. Tile residual moisture fundamentally conditions the mechanical characteristics of the tile body [3,4,5]. If residual moisture is too low, the tiles are very rigid, not very elastic and can break very easily under any mechanical force. If residual moisture is high, its breaking strength is reduced. On the other hand, tile surface temperature principally affects its suction capability and therefore the glaze application on the body. A temperature that is too low reduces the suction capability of the body, causing curvature problems in green tiles, swamping of the tile, dimples, sticking in decoration, etc. However, a temperature that is too high can cause cracks in the glaze, pinholing, etc.

Furthermore, it is important for the characteristics of all the tiles to be the same, as different tile residual moistures and surface temperatures after exiting the dryer lead to different tile behaviour during the glazing operation and hence to a final product with different surface properties.

2. OBJECTIVE AND METHODOLOGY

At present very little information is available on the values of the drying process variables and their evolution with time. Even the fundamental characteristics of the dry body (residual moisture and surface temperature) are measured incidentally and discontinuously. There is no objective information on the effect of the different variables in the drying operation on the characteristics of the dry body. Furthermore, as heat consumption in the drying operation only accounts for 10% of total heat consumption in the tile manufacturing operation, the aspects relating to its thermal efficiency are neglected.

The present study seeks to measure the principal parameters of the drying operation, establishing the relation between drying operation variables and the properties of the dry bodies, and increasing dryer thermal efficiency.

The methodology used for carrying out this study first involved choosing and positioning the sensors in the vertical dryer in order to measure the main variables of the drying operation. Dryer operation under standard running conditions was then studied. Thirdly, a series of actions was carried out to analyse the effect of the principal dryer operating variables on the properties of the dry tiles, and finally the existing co-generation facilities associated with the dryers were studied to attempt to improve their use.

3. DESCRIPTION OF THE MEASURING SYSTEM

3.1 DESCRIPTION OF THE DRYER

A vertical dryer was used in the present study, equipped with two burners that use natural gas as fuel. Figure 1 shows the diagram of the dryer. It schematically illustrates gas and materials circulation inside the dryer.

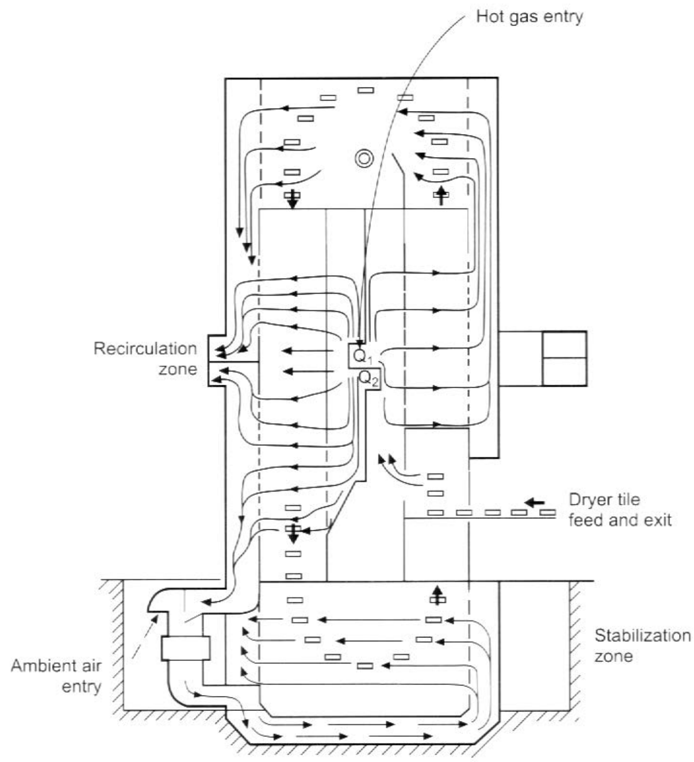

Figure 1. Diagram of gas and tile circulation in the dryer.

The newly pressed tiles are placed in a deck in the dryer, replacing dried tiles in the same deck which leave the dryer for the glazing line. The moist (newly pressed) tiles in the deck move upwards. The decks in which the tiles are set consist of a plane of metal rollers, and a certain number of these decks forms a basket. Each basket is separated from the other by a metal sheet which prevents material from falling all over the dryer in case of breakage.

When the new tiles move upwards they come into contact with gases from the first burner (Q_1 in Figure 1). These gases are collected in a side duct and come into contact again with the tiles in the top zone of the dryer. Finally, they are led to the recirculation area. The tiles start descending and come into contact with the gases from the second burner (Q_2 in Figure 1). Part of these gases, after contact with the tiles, go towards the recirculation zone, the remaining gases are evacuated to the stabilisation area. In this part they are mixed with ambient air, holding the temperature in the area

Figure 2 shows a scheme of the hot gas recirculation zone. Most of the hot gases collected in the recirculation zone are used as fuel in the burners, as they have a high temperature and oxygen content exceeding 15%. The remaining gases are eliminated through the stack, purging the system.

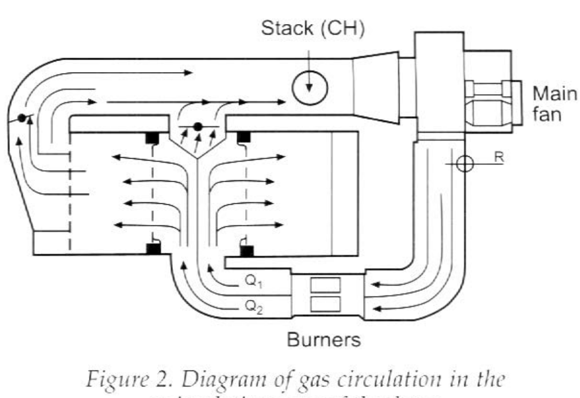

Figure 2. Diagram of gas circulation in the recirculation zone of the dryer.

3.2. MEASURED VARIABLES

With a view to better understanding dryer operation, a set of sensors was fitted in the dryer and the electric signal from each sensor was logged in a data acquisition system. This assembly allows establishing the values of the parameters in real time, visualising their evolution with time and storing them for analysis and processing. A total of 8 variables was measured continuously, using the sensors listed in Table 1.

Measured Variable	Sensor used	Position (figure 2)	Reference
Combustion gas temperature at the first burner	J thermocouple	Q_1	T_{Q1}
Combustion gas temperature at the second burner	J thermocouple	Q_2	T_{Q2}
Fuel temperature	J thermocouple	R	T_R
Gas dynamic pressure in the stack	Pitot tube Micro pressure gauge	CH	ΔP
Gas temperature in the stack	J thermocouple	CH	T_{CH}
Gas humidity in the stack	Capacitive hygrometer	CH	H_{CH}
Natural gas flow rate	Flow rate meter		Q_C
Temperature of tiles exiting the dryer	Infrared pyrometer		T_P

Table 1. List of variables measured continuously

Surface temperature of the tiles exiting the dryer is a key parameter. The continuous measurement of this variable presents difficulties owing to its heterogeneity, the high speed of the tiles at this point and the need to place the tile inside the dryer (basket and deck).

With a view to determining tile surface temperature an infrared pyrometer was used, with a high-speed response [6,7,8]. A specific data acquisition card for this application enables gathering and analysing the temperature values measured by the pyrometer. When the tile goes under the pyrometer, the measured temperature starts rising rapidly until it reaches the instrument's measurement range. Of all the values measured, the maximum value is stored in a file, while the others are discarded. The maximum temperature values detected in each tile are classified by means of software developed in the Instituto de Tecnología Cerámica, which enables associating the measurement obtained by the pyrometer with the position of the tiles inside the dryer.

As well as the variables measured continuously, residual moisture of the tiles exiting the dryer and their mass flow were determined in a discontinuous manner.

4. ANALYSIS OF DRYER OPERATION

Dryer operation under standard working conditions can be analysed by continuous measurement of the operating variables mentioned above. The study was carried out with tiles measuring 31x45 cm, so that each deck in the dryer was made up of two rows with six tiles in each one.

The evolution with time of the parameters involved in the working of the burners is plotted in Figure 3. The evolution of burner temperature with time (T_{Q1} and T_{Q2}) shows that, during the whole period of time considered, dryer operating is not steady. Stoppages occur in the dryer caused mainly by interruptions in glazing line operation.

During the periods in which drying operation is steady, gas combustion temperature is different in the two burners. In the first burner (Q_1) the combustion gases have an average temperature of 190 °C, whereas in the second burner (Q_2) the temperature is 170 °C. During the stops, the burners work differently, as the temperature setting established for periods of stoppage is lower than that programmed for working periods. On starting up the drying operation after a stoppage, a transition period is produced until the steady state is reached.

The temperature of the recirculating gases (T_R), used as oxidizing agent in the burners, is maintained at approximately 126 °C during the stable operating period. During the stops, this temperature decreases slightly, due to the fact that the drying gases are at a lower temperature. The difference between the fuel temperature (T_R) and the temperature of the combustion gases (T_Q) is given by natural gas combustion in the burners.

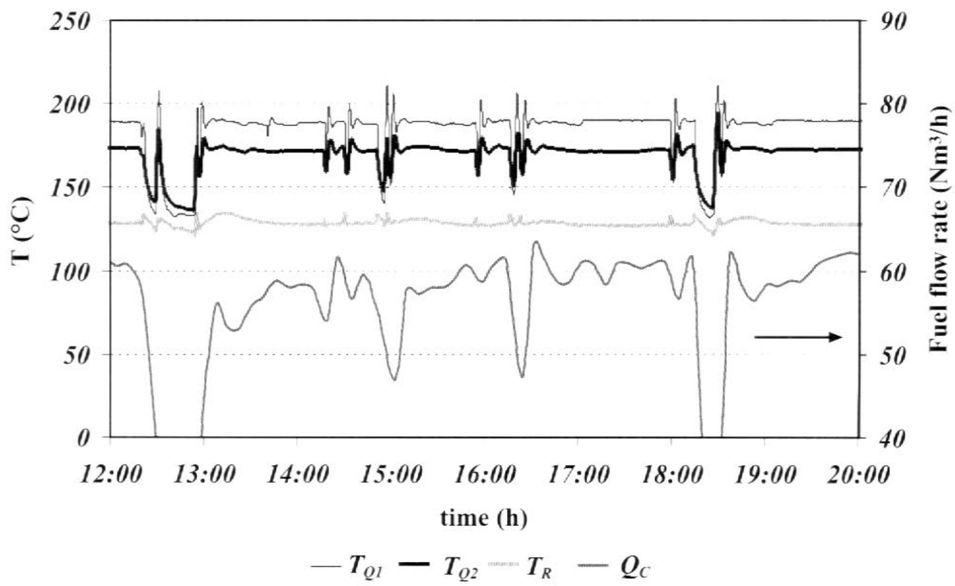

Figura 3. Evolution of combustion gases at both burners (T_{Q1} and T_{Q2}), of recirculating gas temperature (T_R) and of natural gas flow rate (Q_C).

The natural gas flow consumed at the burners is uniform while the dryer operates in a steady state, and lies at around 60 Nm^3/h; during the stops, fuel consumption is less due to the lower temperature setting of the burners.

The evolution during the same period of time of the gas variables in the stack is shown in Figure 4. It can be observed that in the absence of stoppages, the variables remain at an approximately constant value. During the stoppages, dynamic pressure (ΔP) decreases, so that the flow of gases circulating in the stack decreases and the temperature (T_{CH}) drops, because the temperature setting of the burners decreases. Gas humidity (H_G)

also decreases during stops, as no moist tiles enter the dryer, while natural gas consumption during stoppages also drops.

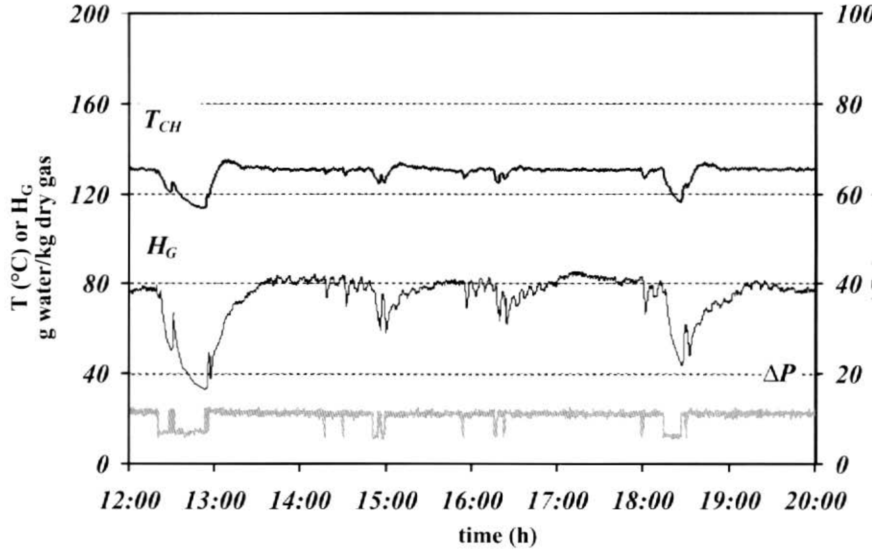

Figure 4. Evolution of temperature (T_{CH}), humidity (H_{CH}) and dynamic pressure (ΔP) of the gases circulating in the dryer stack.

Figure 5 shows the evolution with time of the surface temperature of the hottest tile (T_{P1}) and of the coldest (T_{P6}) in the deck, on exiting the dryer. It can be observed in the figure that, in the steady running periods of the dryer, the temperature of each tile with time is not constant, and that its value depends on its position in the dryer deck. After a stop, the tiles exit at a different temperature, first colder and then hotter than usual. In the following sections the evolution of tile temperatures on exiting the dryer will be analysed in more detail.

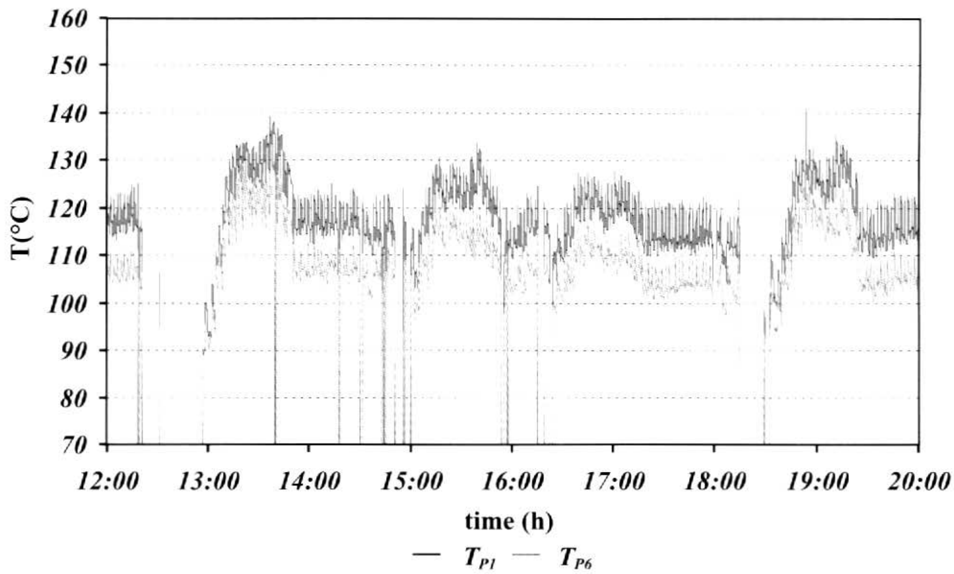

Figure 5. Evolution of tile temperature on exiting the dryer.

4.1 DRYER OPERATION UNDER STEADY CONDITIONS

This section presents and analyses the values of the parameters measured during the operating of the dryer in a steady state. The plot of the temperature evolution of the three tiles in the first row, as well as gas combustion temperature, is shown in Figure 6. During dryer operation in a steady state, drying gas temperature remains practically constant. Tile temperature, however, is not uniform; even the tiles in the same position in the deck show periodic swings, which are similar in all the positions in the deck. There are also differences between the different positions in the deck.

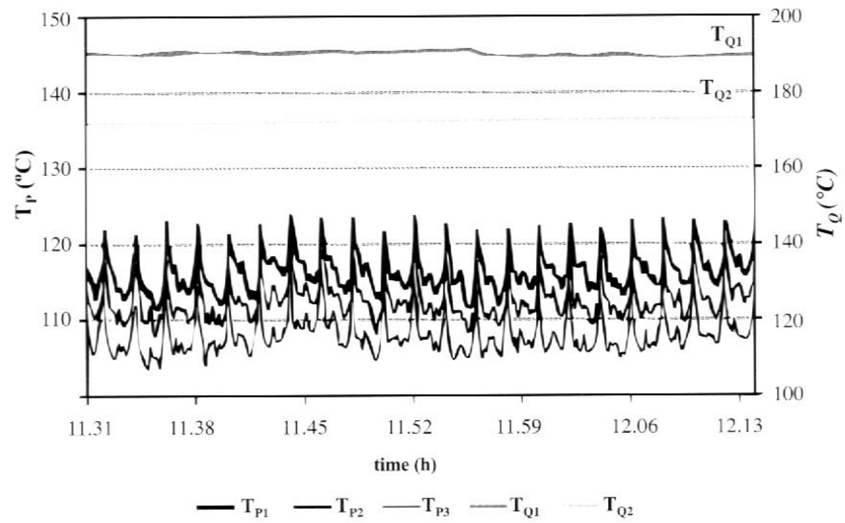

Figure 6. Evolution of combustion gas temperature (T_Q) and temperature of the tiles in the first row of the deck (T_P) under steady operating conditions.

Figure 7 plots the evolution with time of the temperature of the first tile in each deck. In this figure cyclic behaviour can be observed, with a peak at every 13 values, which is the number of decks a basket contains. The tiles set in the decks in the top part of the basket have a higher temperature than the others and, as the basket empties, tile temperature decreases.

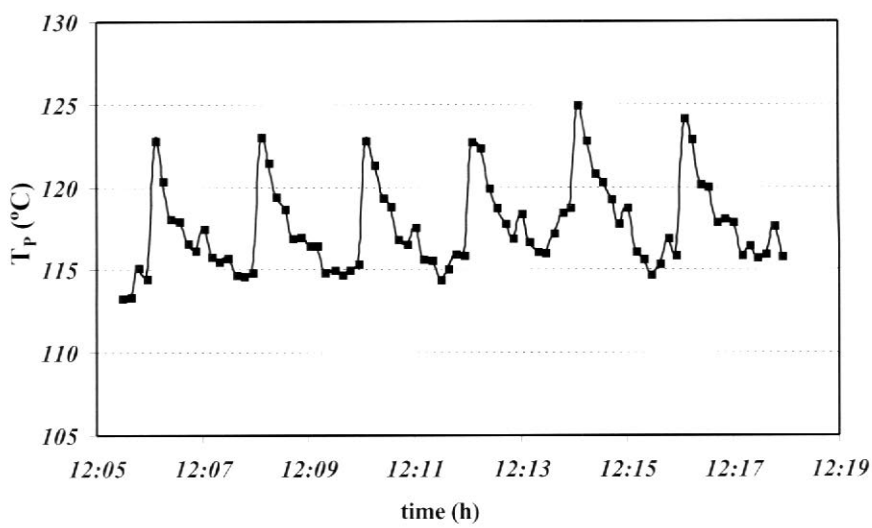

Figure 7. Temperature evolution of the first tiles in the first row of each deck (position 1).

This behaviour could be caused by the presence of the metal sheet at the top of each basket. The presence of this metal surface modifies gas distribution in the top region of the basket, producing the effect described. The maximum temperature difference between tiles set in the same position in the decks of a basket is approximately 10 °C.

As already mentioned, the tiles set in different positions in the decks present different temperatures (Figure 6). The greatest temperature differences are found between the first tiles of the front row (position 1) and the last tiles of the back row (position 6). Figure 8 shows the temperature evolution of tiles in these positions. It can be observed that the tile in position 1, first in the deck to leave the dryer, is hotter than the tile in position 6. In the period of time plotted in Figure 8, the maximum temperature difference between both tiles is around 20 °C. Therefore, the temperature of the tiles fed to the glazing line depends on their position in the dryer deck as well as on the position of the deck in the basket.

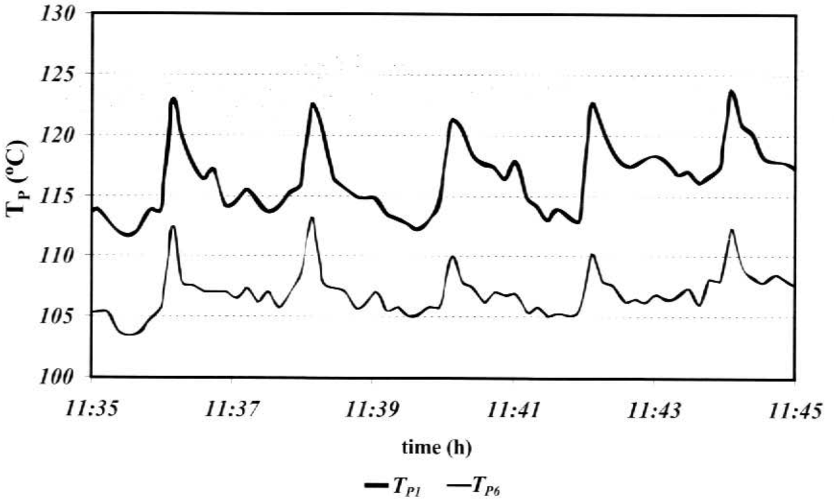

Figure 8. Temperature evolution of the hottest tile (TP1) and of the coldest tile (T_{P6}) in the deck.

With the measured temperature values, the average temperature of each tile can be calculated in the different deck positions. The result obtained is orientational, since as already mentioned previously, the temperature of the tiles in the same position is not constant. The values found are shown in Figure 9. It can be observed in this Figure that the maximum difference between the average measured temperatures in a deck is around 10 °C.

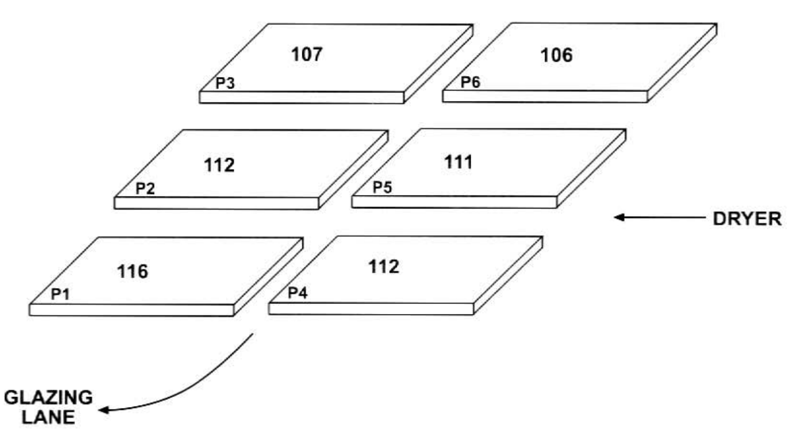

Figure 9. Average tile temperature in a dryer deck.

4.2 ANALYSIS OF DRYER OPERATION UNDER NON-STEADY CONDITIONS

The analysis of dryer operation during several days of work showed the existence of stoppages, fundamentally caused by standstills in the glazing line. The effect of the stops on the working of the dryer differs depending on the length of the standstill. When analysing the results, it was considered convenient to classify the stoppages in three groups according to their duration: short (< 1 minute), intermediate (between 1 and 5 minutes) and long (> 5 minutes).

The actions performed by a dryer at an incidental moment of stoppage depend on the type of dryer. In all dryers, when a stoppage occurs, the burners operate with a different temperature setting from the one programmed for normal running times, and the baskets stop. In the dryer involved in this study, if the stoppage is over two minutes four baskets descend to the stabilisation zone. When the dryer starts again the tiles that were about to leave the dryer before the stoppage exit the dryer, and the burners start operating at the usual temperature setting.

Figure 10 plots temperature evolution of the combustion gases from burner 2 (T_{Q2}) and the temperature of the tiles in position 1 (T_{P1}) on exiting, during a period of time in which several short stoppages occurred.

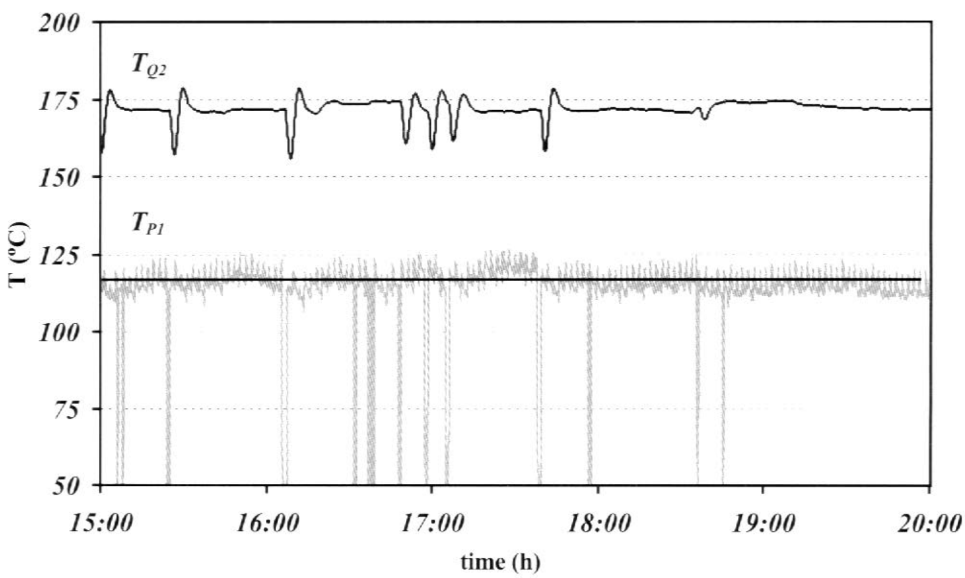

Figure 10. Influence of short stoppages on tile temperature.

It can be observed that tile temperature hardly changes when a short stoppage occurs. If several short stoppages occur one after the other, tile temperature increases slightly, but after a few minutes it returns to its normal value. Therefore, dryer operation scarcely alters after a short standstill.

Figure 11 plots the behaviour of the dryer during an intermediate stoppage. After the stoppage the burner tries to reach the programmed temperature setting to work under steady conditions, but it takes some time before it can reach this temperature, as swings occur around the set value. Tile temperature drops approximately 10 °C after the stoppage and after a few minutes returns to the value it had before the stop. A relation appears between the time it takes the burner to reach the set temperature and the time that elapses until the tiles leave the dryer again at the desired temperature. In the example considered, this time is 15 minutes.

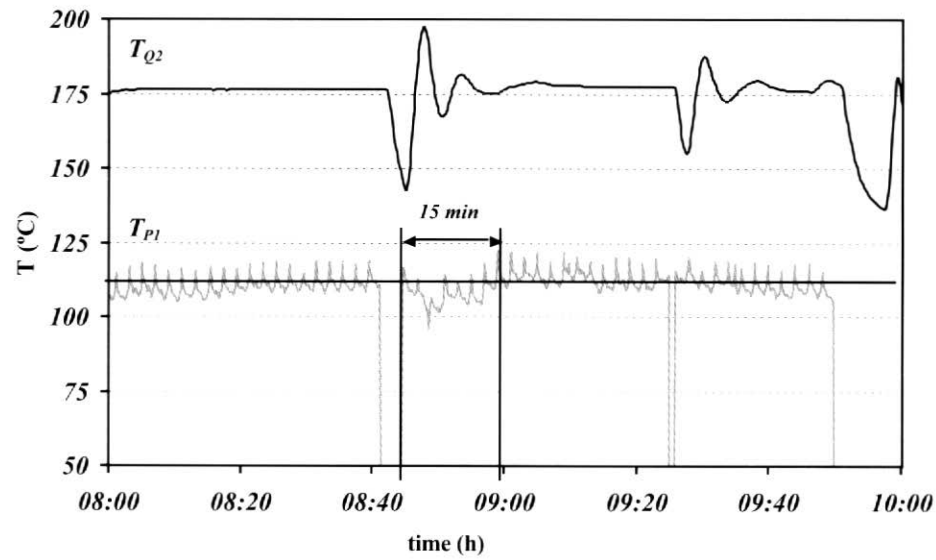

Figure 11. Influence of a stoppage of intermediate duration on tile temperature.

Figure 12 shows the behaviour of the dryer during a long stoppage (15 minutes). When the stoppage occurs, the temperature of the burners drops to the temperature programmed for stops. When the dryer starts running again, the burners try to reach the temperature setting for steady operation, but the burners need time to stabilise the temperature.

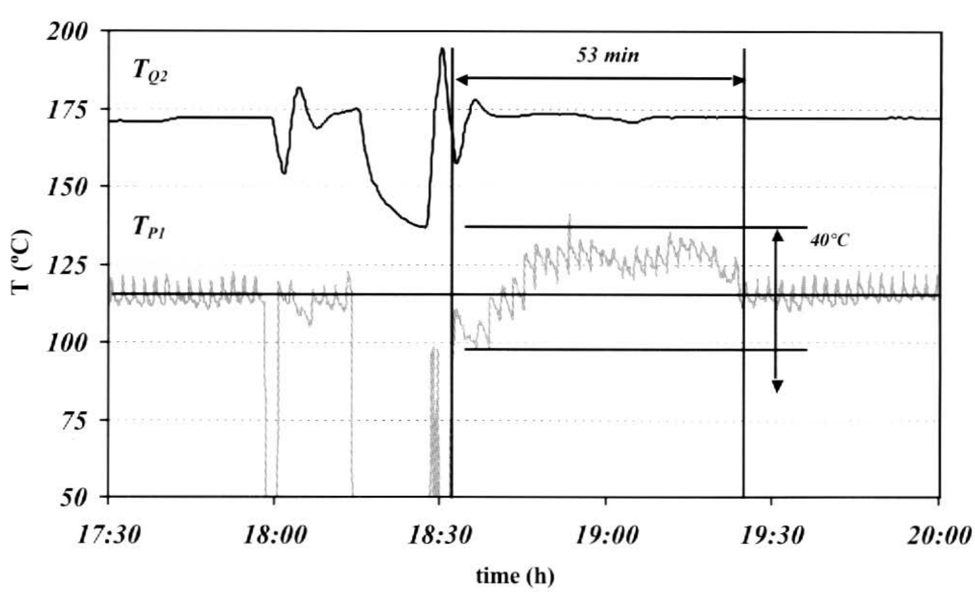

Figure 12. Influence of a long stoppage on tile temperature.

In this case tile temperature is greatly affected by the stop. The first tiles leaving the dryer are colder than usual, as they were in the stabilisation zone during the stoppage, and in this part of the dryer the temperature is lower. The temperature of the tiles leaving the stabilisation area afterwards is higher. This is because the set temperature of the burners during stoppage, although lower than the working temperature, is higher than that required by the tiles leaving the dryer. Residence time of the tiles inside the dryer at this temperature makes them hotter than usual on exiting the dryer.

The effect of the stop continues until the tiles are totally replaced inside the dryer. In the case analysed, this took 53 minutes after resuming dryer operation, which is practically a complete drying cycle. The maximum temperature difference between tiles leaving the dryer after the stoppage, until the steady state is re-established, is approximately 40 °C.

4.3. ACTIONS PERFORMED

This section presents the results of the actions carried out on modifying some dryer operating variables. In the analysis of the results, the effect of the new working conditions on exiting tile characteristics, surface temperature and residual moisture content was assessed.

The actions performed consisted of modifying the burner temperature settings in the stoppage situation, decreasing the flow rate of gases circulating in the stack and reducing the flow rate of recirculating gases. In all the cases after making a change, enough time was allowed to pass to enable the dryer to reach a steady state, then recording the stable values of each measured parameter.

4.3.1. Modification of the burner temperature setting for stoppage

The objective sought with this action is to reduce the effect of long stoppages on exiting tile temperature. In order to reduce this effect, described in section 4.2, the temperature setting during stoppage of the first burner (T_{Q1}) was lowered and that of the second burner (T_{Q2}) was raised.

The first tiles to leave after the stoppage had been in a dryer area during the stoppage where the temperature is fundamentally affected by combustion gases from burner 2 (stabilisation zone). Increasing the set temperature during stoppage of this burner (T_{Q2}) was intended to relieve the temperature decrease of the first tiles exiting the dryer (Figure 12). On the other hand, the tiles subsequently exiting had remained during the stop in dryer zones where the temperature is mainly determined by gases from burner 1 (T_{Q1}). The temperature setting of this burner during stoppage was lowered to try and decrease the temperature rise experienced by these tiles after stoppage.

	Initial	Action 1
T_{Q1} (°C)	135	100
T_{Q2} (°C)	130	160

Table 2. Set temperatures programmed during stoppage.

The concrete values of the temperatures are set out in Table 2. Figure 13 plots the result of the adjustments. It can be observed in the figure that the temperature of the first tiles leaving after stoppage remains practically at working values. Furthermore, peak temperature reached by the tiles after stoppage, is not as high as in the initial situation (Figure 12).

Raising the temperature setting for stoppages of the second burners succeeds in maintaining the temperature of the first tiles exiting the dryer. The temperature decrease of the first burner reduces the heat received by the tiles found in the intermediate zone of the dryer during stoppage and therefore their temperature when leaving. However, temperature of the gases in the zone affected by the first burner does not drop below 125°C (Figure 13), despite programming a temperature of 100°C. Therefore, the temperature rise of the tiles in the intermediate zone is still considerable (22°C), although less so than at the beginning (40°C).

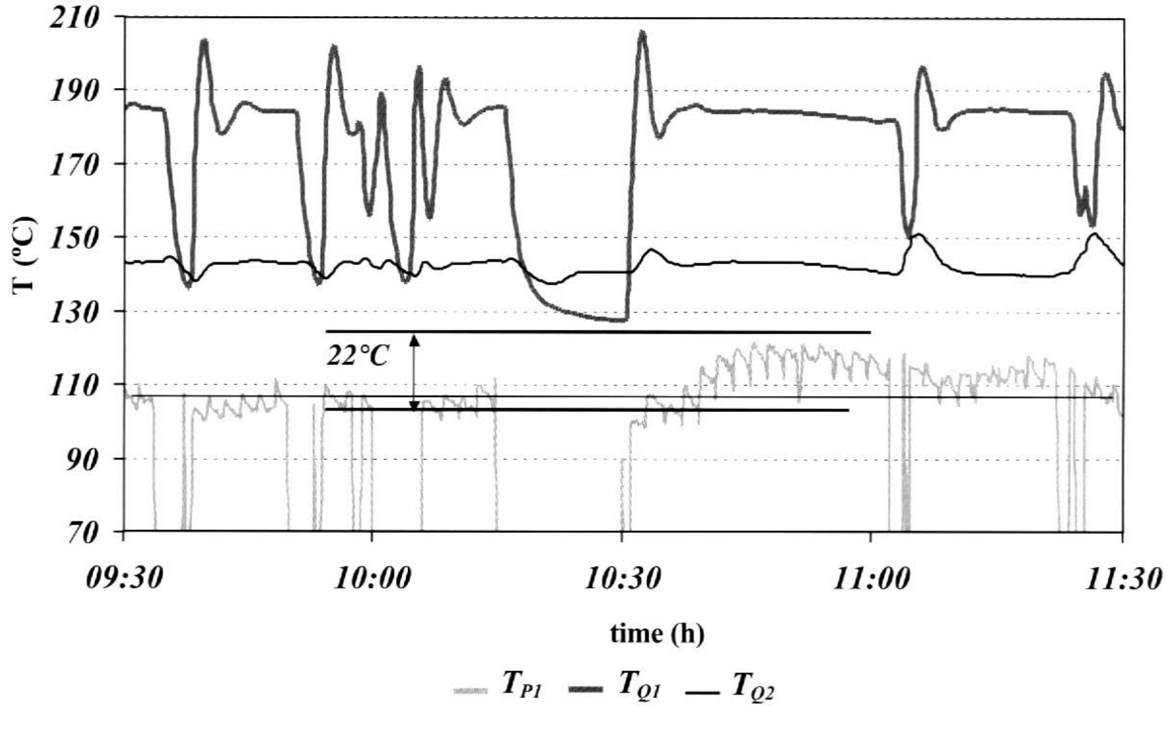

Figure 13. Dryer operation with new burner temperature settings in stoppages.

4.3.2 Reduction of gas flow in the stack

Figure 14 depicts the Sankey diagram for a vertical type dryer. These diagrams show the percentage each stream contributes to the total energy flow in a thermal process.

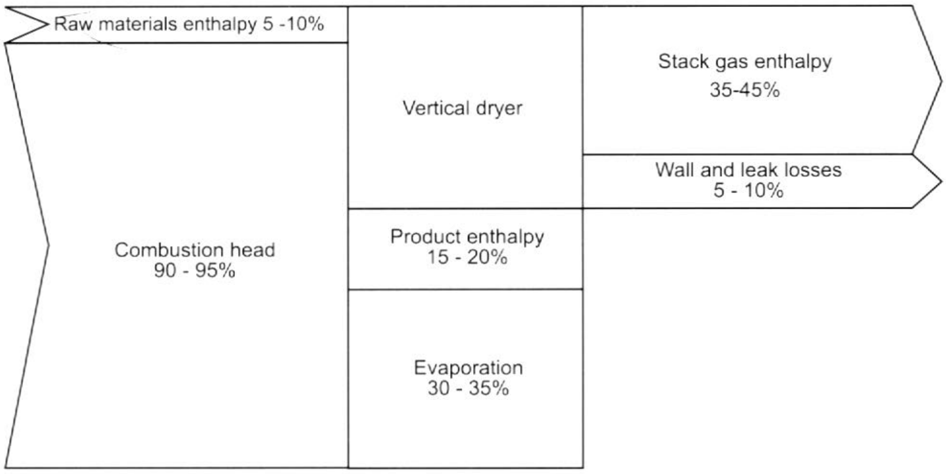

Figure 14. Sankey diagram for a vertical dryer.

As can be deduced from the Sankey diagram, most of the energy losses occur via the dryer stack (between 35 and 45% of the total contributed energy). About 10% of the energy supplied to the system is lost through the dryer walls and uncontrolled leaks. Therefore in order to increase the energy efficiency of the dryer, it would be convenient to reduce the enthalpy of the gases in the stack, besides carrying out correct maintenance of the facility to improve thermal insulation and avoid uncontrolled heat leaks.

To reduce the enthalpy of the gas stream in the stack the gas flow rate was reduced, closing off the stack by 50%. Under the new conditions the dryer operated correctly and the tiles could be processed without any problems in the glazing line. Table 3 shows the principal parameters of the new operating conditions.

Parameter	Initial situation	Action
Gas flow rate (Nm^3/h)	4900	3000
Gas humidity (g water/kg dry air)	75	85
Gas temperature (°C)	130	125
Natural gas consumption (Nm^3/h)	60	52
Average tile temperature (°C)	112	105
ΔPeak T of tiles in the deck (°C)	10	7
Tile residual moisture content (%)	0.1– 0.2	0.2 – 0.4

Table 3. Evolution of certain dryer operating parameters on decreasing the stack flow rate.

The reduction of the gas flow rate in the stack causes its temperature to decrease (5°C) and raises its moisture content. On decreasing flue gas temperature and flow rate, energy losses are reduced, and hence natural gas consumption at the burners. In the studied case, fuel consumption was reduced by 13 %.

The characteristics of the tiles leaving the dryer altered on reducing gas flow in the stack. The average temperature of the exiting tiles fell (5°C), probably as a result of the rise in moisture and lower temperature of the recirculating gases. This led to an increase in tile residual moisture on leaving the dryer, which if the rise does not exceed certain limits (around 0.5%) could even be beneficial for tile behaviour during glazing. The maximum temperature difference between tiles in the same deck is reduced by 3°C, possible owing to the rise in pressure inside the dryer caused by closing off the stack.

Partial closing of the stack valve did not produce significant variations, but greater reductions in the hot gas flow in the stack could be expected to produce exiting tiles that were too wet and cold, with the resulting danger of breakage, inadequate suction, etc., during tile decoration. Therefore, it is convenient to achieve a balance between all the factors.

4.3.3. Decrease of recirculating gas flow rate

The fuel used in natural gas combustion in the burners is mainly made up of drying gases which recirculate in the dryer (Figure 2). The action proposed involves reducing the flow rate of such gases, using a frequency modulator in the fan driving the gases. Specifically the recirculating gas flow rate was reduced gradually until reaching 80% of the initial flow. The burner temperature settings were held at the usual values.

Table 4 shows the values of the most important dryer operating parameters during the actions performed and the most important results obtained. In view of the values in Table 4 it can be observed that, on reducing the recirculating gas flow rate, while tile residual moisture increased, temperature and natural gas consumption of the dryer decreased. That is to say, reducing the recirculating flow decreased dryer consumption by reducing exiting tile temperature and increasing tile residual moisture. On decreasing the recirculating gas flow rate, the amount of heat entering the dryer and the gas velocity was reduced, which lowered the drying rate.

Flow of recirculating gases relative to initial flow (%)		**100**	**90**	**80**
Tiles	T_P (°C)	90	82	75
	H_p (%)	0.20	0.36	0.50
Fuel	Q_C (kcal/kg dry tile)	52	47	42
	Saving (%)	-	5.6	19.2

Table 4. Effect of recirculating gas flow rate reduction.

The temperature and residual moisture content required by the tiles leaving the dryer depend on the sequence of applications in the glazing line. Optimum temperature of the exiting bodies depends fundamentally on the model being produced. Usually the temperature variation range is found between 75 and 125°C. The optimum value of exiting tile residual moisture is difficult to determine, as it depends on each composition. Generally residual moistures between 0.2 and 0.5% give good results.

In the case studied, a temperature reduction of the exiting tiles of 15°C (from 90 to 75°C) and an increase in residual moisture of 0.3 %, did not give rise to any problems in tile decoration. Under the new operating conditions fuel consumption was approximately 20% less. This indicates that dryer operation was not optimum for the model being produced, as the tiles were heated to a higher temperature than necessary, thus increasing energy consumption.

On some occasions tile temperature is adjusted for different applications, which makes it impossible to reduce recirculating gas flow rate without modifying dryer running conditions. In order to simulate this situation, another series of actions was carried out, reducing recirculating gas flow rate but maintaining exiting tile temperature, by conveniently modifying the temperature setting of the second dryer burner. Table 5 shows the values of the most relevant operating parameters of the dryer during the actions performed and the most important results obtained.

In view of the values in Table 5 it can be appreciated that, in the actions performed, exiting tile temperature was kept constant and residual moisture was increased. In this situation, the energy saving was 11.3%, lower than that obtained in the previous situation (20%). Therefore, reducing the recirculating gas flow rate leads to a decrease in natural gas consumption, which is higher or lower depending on the conditions of the exiting tile.

The possibility of modifying the recirculating gas flow rate allows controlling tile residual moisture and temperature separately within certain limits. This is impossible at present since, on modifying tile temperature by means of the burner settings, tile residual moisture also change.

Recirculating gas flow rate relative to initial flow (%)		**100**	**90**	**80**
Burners	T_{PQ} (°C)	120	120	120
	T_{Q1} (°C)	150	150	150
	T_{Q2} (°C)	215	225	235
Tiles	T_P (°C)	113	113	112
	H_p (%)	0.20	0.37	0.49
Fuel	Q_C (kcal/kg dry tile)	71	67	63
	Saving (%)	-	5.6	11.3

Table 5. Effect of reducing the recirculating gas flow rate, keeping tile temperature constant.

This fact is especially interesting when, as a result of the applications in the glazing line, the exiting tiles need to have a high temperature. As the flow volume of the recirculating gases is constant, under these conditions tile residual moisture is very low, or at times zero, thus increasing tile brittleness. If the recirculation flow is reduced and temperature decrease is compensated by increasing the second burner setting (as already described in this section), it is possible to hold tile temperature while increasing residual moisture content and therefore tile resistance to fracture.

5. OPTIMISING EFFICIENCY IN THE USE OF CO-GENERATION SYSTEM OUTPUT IN VERTICAL DRYERS

Some tile body drying facilities use co-generation systems with internal combustion motors. These systems provide thermal energy for drying (in the form of hot gases) and electric energy, increasing the overall energy efficiency of the drying operation.

The stream of hot gases from a co-generation system is fed into the dryer in the recirculation duct, thus increasing the temperature of the recirculating gases and reducing the thermal leap that the burners need to provide. The manner in which these gases are fed into the dryer could optimise the efficiency of co-generation facility use. In this section a series of actions is described directed towards optimising the efficiency in the use of the energy output of the co-generation facilities.

5.1. CURRENT SITUATION

The present situation in most dryers that use co-generation systems is reflected in the diagram in Figure 15. A single fan set in the recirculation duct, before the dryer stack and behind the co-generation gas entrance, drives the mixture of co-generation and recirculating gases. Under these conditions, part of the energy provided by the co-generation gases is lost directly through the dryer stack. Therefore one of the first improvements would consist of feeding in the co-generation gases after the dryer stack.

Subsequently the recirculating gases are fed as fuel to the burners (Q_1 and Q_2), which are responsible for increasing the gas temperature until the set temperature is reached in each case (T_{Q1} and T_{Q2}). The flow rate of the co-generation gases is determined by the temperature of the gases before being fed to the burners (T_{PQ}). This temperature should be slightly lower than the burner temperature setting, for the burners to actually control the temperature inside the dryer. As there is a common entrance for the preheated gases to the burners, their temperature must be less than the lowest burner temperature setting, which causes inefficient use of the co-generation system.

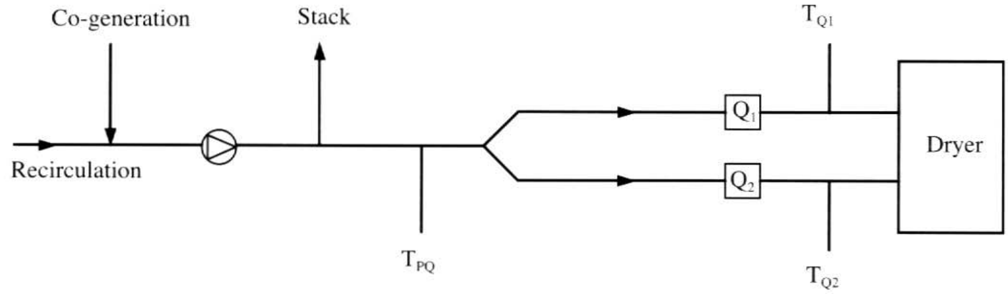

Figure 15. Single entrance of the co-generation gases into the system.

5.2. PROPOSED MODIFICATIONS

After analysing the present situation, with a view to optimising the use of the co-generation facility, it is proposed to feed in the co-generation gases after the stack, and do so separately to each burner. These modifications are set out in the diagram in Figure 16.

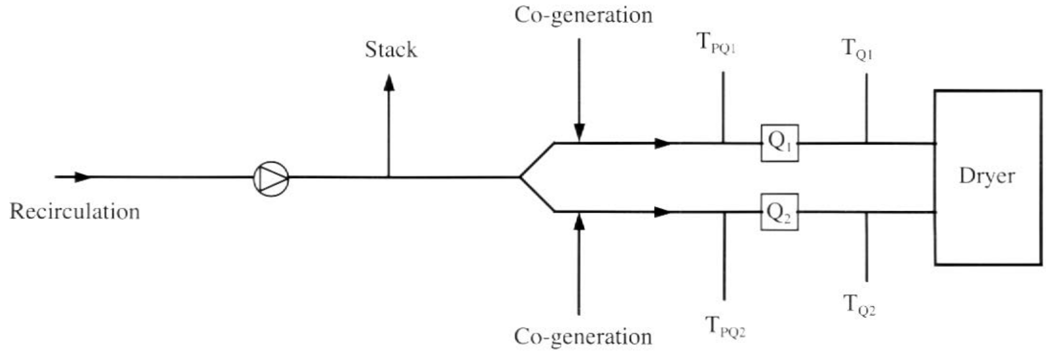

Figure 16. Separate entrance of the co-generation gases to each burner.

In this diagram, the stack remains before the co-generation gas feed and the flow of the these gases can be adapted to the needs of each burner to achieve the appropriate temperature. In this way the enthalpy of the gas stream in the stack is reduced and consumption of co-generation gases is increased, because part of the fuel can be heated beforehand to a higher temperature.

However, with present dryer design this arrangement presents some engineering problems. To incorporate the co-generation gases into the recirculating gases, the pressure in the co-generation duct must be higher than that found in the recirculating gas duct. This can only be achieved by additional fans driving the co-generation gases towards the recirculation duct of the dryer. This new situation involves an additional investment and in most cases, not enough space is available in factory plants to implement this.

These problems can be solved with the latest generation of dryers. In these dryers, the recirculating gas ducts to the burners are independent for each burner and each is fitted with a fan. Furthermore, the stack extracts gases directly from inside the dryer, and not from recirculation. With this design, co-generation gases can be fed as fuel separately to each burner without needing to install additional fans, feeding in the gases in each recirculation duct before the fan. Figure 17 shows the scheme of this situation, with two independent recirculations in the same dryer.

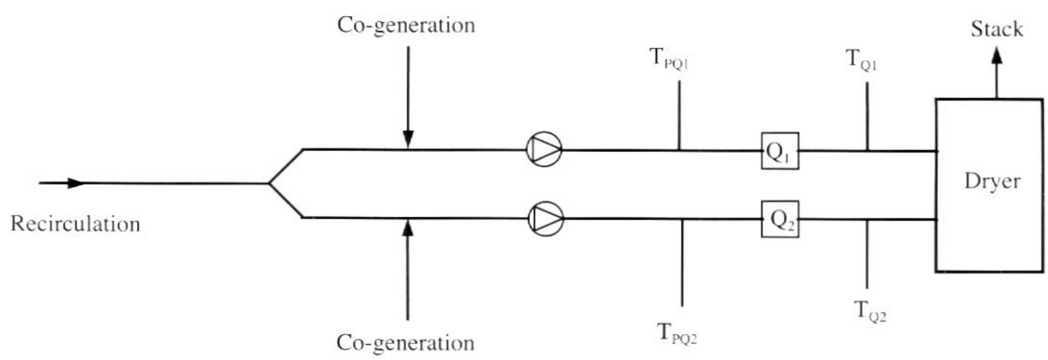

Figure 17. Separate distribution of the co-generation gases in a dryer with two recirculation ducts.

To evaluate the effect of the proposed modifications on the energy consumption of the dryer, energy consumption distribution in the dryers was calculated in each case, distinguishing whether the thermal energy is provided by the burners or the co-generation gases (Table 6).

Situation	Energy consumption (kcal/kg dried tile)			Variation of consumption (%)	
	Co-generation	Burners	Total	Co-generation	Burners
Initial (Figure 15)	61	52	113	-	-
Co-generation gas distribution (Figure 17)	72	40	112	+18	-24

Table 6. Analysis of thermal energy consumption by the dryer in the two situations studied.

In the first place it should be noted that total dryer consumption is kept approximately constant. However, on separately distributing the co-generation gases, burner consumption drops by 24%, increasing the consumption of the co-generation system output.

This situation should be taken into account on designing a new co-generation facility, as this can raise its efficiency. In the dryer facilities where a co-generation system already exists, it is interesting to establish if there is excess energy from that system. If this is the case, the modification proposed is highly recommendable with a view to making better use of the co-generation system, while reducing natural gas consumption at the burners.

6. CONCLUSIONS

In view of the results obtained in this study the following conclusions can be drawn:

Standard operating conditions.

- With the sensor elements installed in the dryer it is possible to monitor dryer operation continuously and in real time.

- The temperature measuring system of the tiles exiting the dryer is sufficiently fast and accurate to monitor this variable with time. The software used allows monitoring the evolution of tile temperature with time, according to its position in the dryer.

- In the dryer studied, temperature of the tiles exiting after stoppages was only significantly modified when the stops lasted longer than 1 minute. The duration of the disturbance depends on the length of the stop, at worst, lasting as long as a drying cycle.

Actions carried out

- The burner temperature setting during the stops influences the temperature of the tiles exiting the dyer. The changes made in these temperatures in this study have allowed reducing the effect of long stops by nearly 50%.

- The decrease of the stack flow rate produces a reduction of energy consumption in the dryer. This decrease is accompanied by a rise in tile residual moisture and decrease in surface temperature, so that the gas flow in the stack cannot be reduced without taking these effects into account.

- On reducing gas flow rate in the stack, by partly closing off the stack, pressure rises inside the dryer, thus smoothing temperature differences in the tiles.

- At present, it is not possible to independently modify temperature and residual moisture of the tiles exiting the dryer. The possibility of modifying the recirculating gas flow rate allows independent control of both variables within certain limits, increasing dryer flexibility.

- The decrease in recirculation gas flow rate in the dryers, keeping the remaining variables constant, reduces dryer energy consumption, increases tile residual moisture and decreases its temperature. Temperature reduction can be compensated by raising the burner temperature setting, which reduces the energy saving, though the final energy consumption of the dryer was still less than in the initial situation.

Co-generation system

- The most efficient thermal use of the co-generation facility is achieved by feeding in the co-generation gases after the stack and separately feeding these to each burner in the dryer. With this system, the use of the co-generation facility output rises by between 20 and 25% with regard to the arrangement used at present.

7. RECOMMENDATIONS

In view of the results obtained in the present study, the following recommendations can be suggested as regards the operating of the dryers and co-generation systems employed in the dryers:

- Address automatic control of the drying operation by taking as a variable control of tile surface temperature.

- Study the feasibility of reducing gas flow rate in the dryer stack, since its effect on dryer energy consumption is very high.

- Use frequency modulators to reduce recirculating gas flow rates, and thus dryer energy consumption, particularly in dryers where exiting tile residual moisture is very low.

- In dryer facilities fitted with co-generation systems having excess co-generated thermal energy, analyse the possibility of separating the feed of co-generation gases to each burner. This action enables reducing between 20 and 25% of burner energy consumption, thus optimising the use of the co-generation facility.

- Design new co-generation facilities in dryers with separate gas feed to each burner. In this way it is possible to use a greater quantity of co-generated thermal energy, increasing the efficiency of the co-generation facilities.

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