CHEMICAL ENGINEERING TRANSACTIONS

VOL. 37, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Katharina Kohse- Höinghaus

ISBN 978-88-95608-28-0; **ISSN** 2283-9216

DOI: 10.3303/CET1437124

Energy Recovery in the Baking Line of the Cement Plant Djawad Taher of Algeria

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This study aims at the recovery of energy by using the tertiary air and the secondary air emerging from the cooler at the cement plant Djawad Taher of Algeria, in order to increase the production of clinker and to minimize the amount of hot air pumping out of the firing line to recover energy. There are several cements plants in the world that uses technology of tertiary air, however, in the cement plant Djawed Taher it is not used. In this context we conducted a study on the recovery of the tertiary air based on mass and heat balances in the firing line. We have developed a program in MATLAB that does all the calculations. The overall results led us to important suggestions by proposing two solutions: The first solution is the increased production of the clinker in the presence of the tertiary air by keeping constant the flow rate of natural gas. The second solution is to increase the production of the clinker in the presence of the tertiary air with changing the debit of natural gas. The results show a very significant reduction in the air pumping in the second solution, with an increase in production but with some more consumption of natural gas.

1. Introduction

It is well known that cement production is one of the most energy consuming industries in the world and comes after steel industry (19.7%). For this reason, energy saving and efficiency efforts target these industries in the first place. The method developed for cement industry, in which the ratio of energy costs with respect to total costs is very high (55%) that provides the optimum working ranges according to energy costs and efficiency for the units (Kolip, et al, 2010). The cement clinker manufacturing often employs a method of cooking said dry process, where the pre-comminuted raw materials were calcined in a rotary kiln. The hot gases are generally used for drying the raw materials used in the manufacture of clinker. A portion of the hot gases and unused energy is available (Bastier, 2001). Many plants worldwide, recover the lost heat to produce electricity. There are several plants that use technology tertiary air, however, in the cement plant Djawed Taher it is not used. The main objective of this work is to provide solutions to recover energy. On the other hand, to increase the production of clinker in the baking line of the cement Djawad Taher, which has a capacity of 3000 t/ day of clinker, it is intended primarily for the manufacture of three types of cement CPA400, CPA325 and CPA.Z (FLSmiDth, 2005). Recovering energy as possible is studied by establishing mass and heat balances in the baking line that is on the calculation of the amount of heat recovered from the hot air cooler exhaust.

2. Possible recovering of energy

2.1 Recovery of secondary air

Recovering an amount of mine drainage air of the cooler or appointed secondary air, injected into the furnace to do burning natural gas. The lime gas enters the preheater for the decarbonation of the material. An installation with a preheater and without precalciner, most of the decarbonation (80 to 90%) is in the rotary kiln (FLSmiDth, 2005).

Please cite this article as: Khatima K.D., Mokhtar K., Ghernoug S., Abdelber B., Salim B., 2014, Energy recovery in the baking line of the cement plant djawad taher of algeria, Chemical Engineering Transactions, 37, 739-744 DOI: 10.3303/CET1437124

2.2 Recovery of tertiary air

Recovering an amount of mine drainage air of the cooler or appointed tertiary air that is injected into the precalciner to the combustion of natural gas. The lime gas enters the preheater for the decarbonation of the material. The precalciner is to refer to the cyclone heat exchanger to increase the degree of decarbonation in the preheater (up to 95%) so long oven is gained, involves installation of a kiln of a reduction factor 2 to 2.3 (FLSmiDth, 2005).

3. Material and heat balances in the baking line

We fact a material and heat balance in both cases: with and without tertiary air for constant and varied flow rate of the natural gas.

3.1 Flows of material in the baking line

$$\sum \dot{M}_{inlet} = \sum \dot{M}_{outlet} \tag{1}$$

- The total material flow entering in kg/h is given by the following formula:

$$\dot{M}_{inlet} = \dot{M}_{GN} + \dot{M}_{F} + \dot{M}_{AR} + \dot{M}_{AF} + \dot{M}_{AP} + \dot{M}_{An} \tag{2}$$

$\dot{M}_{inlet}$: total mass flow of the inputs in kg/h; $\dot{M}_{GN}$: natural gas mass flow in kg/h; $\dot{M}_{F}$: mass flow of the raw meal in kg/h; $\dot{M}_{AR}$: mass flow of air from the cooler in kg/h; $\dot{M}_{AF}$: mass flow of faux air in kg/h; $\dot{M}_{AP}$: mass flow of primary air in kg/h; $\dot{M}_{An}$: mass flow of the nos-ring air in kg/h.

- The total material flow outgoing in kg/h is given by the following formula:

$$\dot{M}_{outlet} = \dot{M}_{kk} + \dot{M}_{GF} + \dot{M}_{Aé} + \dot{M}_{ND} + \dot{M}_{PS} \tag{3}$$

$\dot{M}_{outlet}$: total mass flow of the outputs in kg/h; $\dot{M}_{kk}$:mass flow of clinker in kg/h; $\dot{M}_{GF}$:mass flow of fumes gas in kg/h; $\dot{M}_{Aé}$:mass flow of the excess air kg/h; $\dot{M}_{ND}$:mass flow of the non-detected portion in kg/h; $\dot{M}_{PS}$: Mass flow of dust in kg/h. The material balance is summarized in the following two tables:

Table 1: Material flow in the inlet

$\dot{M}_{GN}$	$\dot{M}_{F}$	$\dot{M}_{AR}$	$\dot{M}_{AF}$	$\dot{M}_{AP}$	$\dot{M}_{An}$	$\dot{M}_{inlet}$
9924	191766	393873	126103	9577	15600	751413

Table 2: Material flow in the outlet

$\dot{M}_{kk}$	$\dot{M}_{GF}$	$\dot{M}_{Aé}$	$\dot{M}_{ND}$	$\dot{M}_{PS}$	$\dot{M}_{outlet}$
123900	363966	235318	20175,72	8054,17	731238,17

3.2 Heat flow in the baking line

The total heat flow to the input is given by the following formula:

$$\sum Q_{inlet} = \sum Q_{outlet} \tag{4}$$

$$Qinlet\ tot = Q_{c} + Q_{cf} + Q_{fc} + Q_{fa} + Q_{AF} + Q_{Ap} + Q_{Ang} \tag{5}$$

$Q_{inlet\ tot}$: total heat at the input in kcal/kg clinker (kcal/kg_{kk}).

- Q_c : the heat released during the combustion of natural gas in kcal/kg clinker is given by the following formula (FLSmiDth, 2001): $Q_c = PCI * B$ (6)

PCI : lower calorific value of natural gas in kcal/Nm^3; B : specific consumption of natural gas in Nm3/kg_{kk}.

- Q_{cf} Physical heat of the raw meal in kcal/kg clinker is as follows:

$$Q_{cf} = \frac{(G * Cp_f + W * Cp_{watL}) * (T_c - T_{ref})}{Qm_{kk}} \tag{7}$$

T_c :Temperature of the raw meal is 90°C; Cp_{watL} :Calorific value bound water to the flour is 0.4467kcal/kg_{kk}°C; Cp_f :Calorific value of of the raw flour at T_c is of 0.216kcal/kg°C; T_{ref} : Reference temperature which is 0 °C; G : flow of the raw meal in kg /h (FLSmiDth, 2001).

- Q_{fc} The physical heat of the gas in kcal / kg clinker, which is given by the following formula:

$$Q_{fc} = \frac{Qv_{GN} * Cp_{GN} * (T_{GN} - T_{ref})}{Qm_{kk}} \tag{8}$$

Qv_{GN} :Volume flow of natural gas in Nm^3/h; Cp_{GN} :Calorific power of natural gas is 0.402 kcal/$Nm^{3\circ}C$;

T_{GN} : Temperature of natural gas is 15 °C.

- Q_{fa} The sensible heat of the air of the cooler in kcal/kg clinker is given by the following formula:

$$Q_{Af} = \frac{Qv_{air} * Cp_{air} * (T_{air} - T_{ref})}{Qm_{kk}} \tag{9}$$

Qv_{air} : flow of cooling air in Nm^3/h; Cp_{air} : Calorific value of the air at Ta, is of 0.3093 kcal/Nm^{3}*°C.

T_a : Ambient air temperature is 25 °C; the flow rate of cooling air Qv_{air} was calculated from the flow velocity of air (Energy, Mines and Resources, 1980). So the flow of cooling air Qv_{air} is of 304 619 Nm^3/h.

- $Q_{ent\,tot}$ The sensible heat of the false air kcal/kg clinker is given as follows:

$$Q_{Af} = \frac{Qv_{Af} * Cp_{Af} * (T_a - T_{ref})}{Qm_{kk}} \tag{10}$$

Cp_{Af} : calorific power of the air at T_a is of 0.3093 kcal/Nm^{3}*°C; Qv_{Af} :flow rate of the faux air in Nm^3/h,

- $Q_{ent\,tot}$ The sensible heat of the primary air kcal/kg of clinker

$$Q_{Ap} = \frac{Qv_{Ap} * Cp_{Af} * (T_a - T_{ref})}{Qm_{kk}} \tag{11}$$

Qv_{Ap} :primary air flow which is of 7406.89 Nm^3/h; Q_{Ang} heat of the nos-ring air in kcal/kg of clinker.

$$Q_{Ang} = \frac{Qv_{Ang} * Cp_{Af} * (T_a - T_{ref})}{Qm_{kk}} \tag{12}$$

Qv_{Ang} : flow rate of the nos-ring air which is 15600 Nm^3/h;

- The total heat flow at the output in kcal/kg_{kk} is:

$$Q_{sort\,tot} = Q_{fkk} + Q_{ch} + Q_{kk} + Q_P + Q_{Ax} + Q_{As} + Q_F \tag{13}$$

- Q_{fkk} : heat of formation of clinker (Jutz, et. al, 2006)

$$Q_{fkk} = Q_{dis} + Q_{des} + Q_{pl} + Q_{exo} \tag{14}$$

Q_{dis} : quantity of heat of dissociation of $CaCO_3$; Q_{des} :amount of heat of dehydration of clay; Q_{pl} : amount of heat of formation of the liquid phase; Q_{exo} : amount of exothermic heat.

- Q_{ch} :sensible heat to evaporate moisture from vintage: If the water is evaporated inside the limits of the system, the heat of evaporation in kcal/kg_{kk} will be (Documentation cement, 2012):

$$Q_{ch} = \frac{S \times W}{4.18 \times Qm_{kk}} \tag{15}$$

W : linked water flow in kg /h; S : sensible heat to evaporate 1 kg of water is taken to 2500 KJ/kg water.

- Q_{kk} :physical heat of clinker, Physical or internal heat of clinker in kcal/kg_{kk} is given by:

$$Q_{kk} = \frac{Qm_{kk} * Cp_{kk} * (T_{kk} - T_{ref})}{Qm_{KK}} \tag{16}$$

Qm_{kk} : flow of Clinker in kg/h; T_{kk} :Clinker temperature at the outlet of the kiln is93^{0}C. Cp_{kk} : at T_{kk} is187kcal/kg ^{0}C.

- Q_P : Physical heat of dust: The physical heat of dust in kcal/kg_{kk} comes from the separator, which is:

$$Q_p = \frac{G_p * Cp_p * (T_p - T_{ref})}{Qm_{kk}} \tag{17}$$

G_p flow of dust in kg/h (Jutz, et. al, 2006).

- Q_{Ax} : The Physical heat of air exhaust from the cooler in kcal/kg_{KK} is given by the following formula:

$$Q_{Ax} = \frac{Qv_{Ax} * Cp_{Ax} * (T_{Ax} - T_{ref})}{Qm_{kk}} \quad (18)$$

Cp_{Ax} at T_{Ax} is 0.3106 kcal/Nm^{3}°C; T_{Ax} temperature of exhaust air from the cooler is 108°C; Qv_{Ax} :The volumetric flow of exhaust air from the cooler is calculated from a mass balance on this latter:
Total air of cooling = Secondary air + Air exhaust.
We have the volume flow of the total air of cooling which is 304 619 Nm^3/h and the volume flow of secondary air which is 122 625.28 Nm^3/h. Therefore, the exhaust air from cooler is: Qv_{Ax} = 181 993.94 Nm^3/h.

- Q_{As} : physical heat of secondary air, It comes from the clinker cooler. It penetrates into the kiln through the area of the cover of heating. $$Q_{As} = \frac{Qv_{As} * Cp_{As} * (T_{As} - T_{ref})}{Qm_{kk}} \quad (19)$$

T_{As} secondary air temperature is 1000°C; Cp_{As} T_{AS} is 0.3367 kcal/Nm^{3}.^{0}C; Qv_{As} secondary air volume flow rate. It is calculated as follows: Volume of secondary air = Volume of combustion air – Volume of Primary air
We have the primary air volume which is7406.89 Nm^3/h. In addition, the volume of combustion air (Jutz, et. al, 2006) that is 130 032.17 Nm^3/h is calculated by the following:

$$Qv_C = f * (1 + E/100) \quad (20)$$

f is the air flow with excess equal to 0 is 118168 Nm^3/h; E :Stoichiometry of the combustion reaction.

So: the secondary air volume is: Qv_{As} = 122625.28 Nm^3/h

- Q_F : Sensible heat of the fumes: The molecular specific heat of the fumes gas component varies depending on the temperature. These specific heats are given by the chatellier. We can quickly determine the waste heat of the kiln when we know the air and the flue gas temperature excess.This heat is given by the following equation (Documentation cement, 2012):

$$Q_F = Q_{co_2} + Q_{N_2} + Q_{H_2O_L} + Q_{Air} + Q_{co_2c} + Q_{H_2O_C} \quad (21)$$

Q_{co_2} physical heat of free CO_2 in kcal/kg$_{kk}$; Q_{N_2} physical heat of N_2 in kcal/kg$_{kk}$; $Q_{H_2O_L}$ physical heat of free H_2O in kcal/kg$_{kk}$; Q_{Air} physical heat of air in kcal/kg$_{kk}$; Q_{co_2c} physical heat of related CO_2 in kcal/kg$_{kk}$; $Q_{H_2O_C}$ physical heat of related H_2O in kcal/kg$_{kk}$.

4. Results and discussions

4.1 Heat flux without tertiary air

Figure.1 shows that the heat of combustion in the furnace is the most important comparing with the other heats. From Figure.2 it is noted that the secondary air has a great amount of heat that will be sent to the kiln to enhance cooking. Well as the high heat fumes this plays the role of the heating of the raw flour.

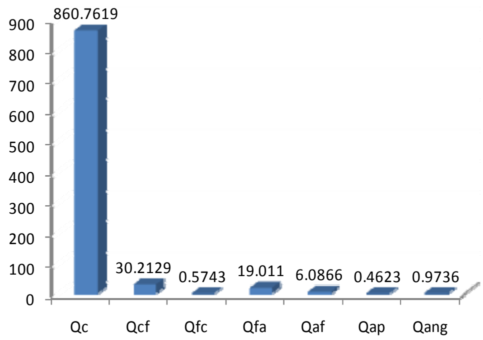


Figure 1: Heats at the input without tertiary air.

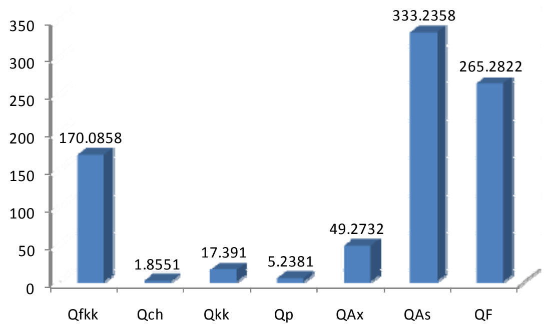
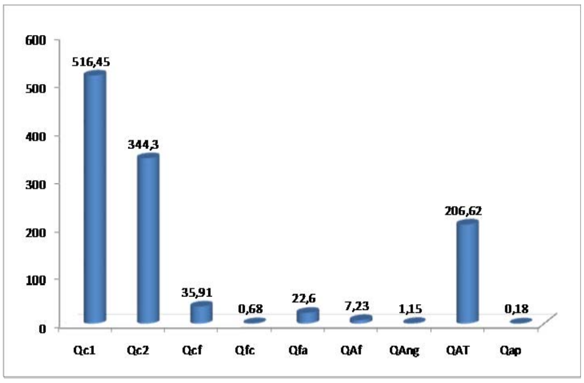


Figure 2: Heats at the output without tertiary air.

4. 2 Heat flux with tertiary air

- *First solution: no change in natural gas consumption*

Figure 3 shows that the heat of combustion in the preheater is the largest in comparison with the other heats. This heat is used in order to improve the heat transfer with mass and fumed gas, which involves an increase in the rate of decarbonation in the preheater. Figure 4 shows that the heat of fume is the most important comparing with the other heats. This heat is used in order to increase the rate of decarbonation in the preheater.



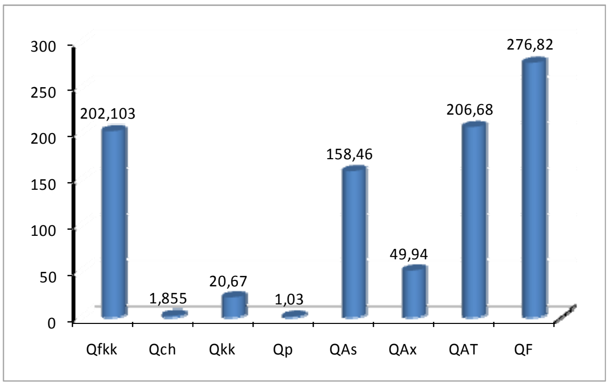
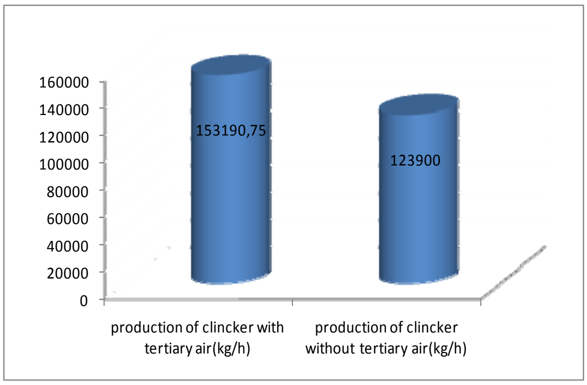


Figure 3: Heats at the inlet with tertiary air.

Figure 4: Heats at the output with tertiary air.

4.3 Estimating cost of the first solution

For an amount of heat of 918,08 kcal/kg_{kk}, the clinker product is 123900 kg_{kk}/h (Jutz, et. al, 2006). So if we provide an amount of 1135,12kcal/kg_{kk} we will produce 153190,75 kg_{kk}/h of clinker.The clinker production with and without tertiary air are presented by the following histogram:



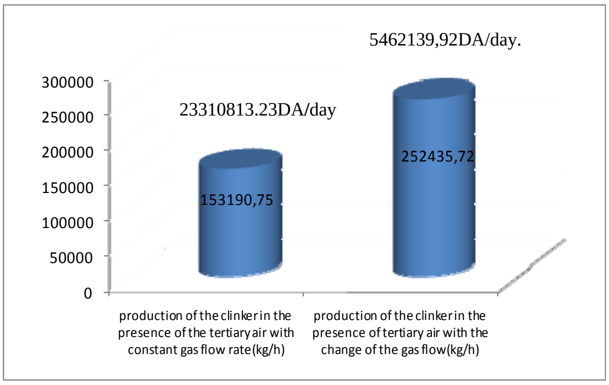


Figure 5: Comparison of production with and without tertiary air

Figure 6: Comparison of production and profit in both solutions.

From the Figure 5 above, we can clearly see that there's an increase of production in the presence of tertiary air, which is the main objective of this study.
To transform this increase in cost, at first we calculate the amount of clinker gained.
The amount of clinker obtained = the amount of outgoing clinker in the presence of tertiary air – the quantity of clinker exiting without tertiary air. The amount earned is of 29,290.75kg/h = 70, 2978.11 kg/day.
As the cost of 1 kg of cement is 7.777 DA (Documentation cement, 2012), we will have a profit of 546,2139.92 DA by day. From this result, we see an increase in production, which gives a very important benefit when using the solution that we have proposed keeping the same consumption of natural gas.

- Second solution: with change in the natural gas consumption.

The flow of natural gas consumed by the oven is (GAYE, 2006), (Documentation cement, 2012): Q_{GN1} = 11800 Nm^3/h. The flow of natural gas of precalciner is 60% of total natural gas. So: Q_{GN2} = 17700 Nm^3/ h.

- The flow of tertiary air into the precalciner Q_{AT}

For 1 Nm^3/h of natural gas, we have a flow of 10.04 Nm^3/h of air (S. GAYE, 2006), (Documentation cement, 2012), and 17,700 Nm^3/h of natural gas, so we need a flow of 177,708 Nm^3/h of air.

- The primary air flow Qv_{Ap} :A flow of 7,406.89 Nm^3/h of primary air is injected in the oven with a natural gas consumption of 11,800 Nm^3/h.

Airflow excess Qv_{Ax} :The volumetric flow of exhaust air from cooler Qv_{Ax} is calculated is as follows: $Qv_{Ax} = Qv_{air}$ - ($Q_{AT} + Qv_{As}$); Qv_{air} air flow rate of the cooling of 304, 619 Nm^3/h; Q_{AT} tertiary air flow rate; Qv_{As} secondary air flow rate; The debit of exhaust air from cooler is: Qv_{Ax} = 4,285.72 Nm^3/h. The calculations of Heats are summarized in the following table:

Table 3: Quantity of heat at the input

Inputs	Q_{c1}	Q_{c2}	Q_p	Q_{fc}	Q_{fa}	$Q_{ent\,tot}$	Q_{Ang}	Q_{AT}	$Q_{ent\,tot}$	Total heat input
Heat($kcal/kg_{kk}$)	1044.27	696.18	86.56	1.16	19.0110	6.0866	0.9736	34.71	0.3739	1870.51

The total heat at input is of 1,870.51 $kcal/kg_{kk}$. It provides an amount of heat of 918.08 $kcal/kg_{kk}$ to produce 123,900 kg/h of clinker. For an amount of heat of 1,870.51$kcal/kg_{kk}$ an amount of 252,435.72 kg/h of clinker will be produced.

4. 4 Estimated cost of the second solution

Chapter 2 The natural gas consumption is to 17,700 Nm^3/h, and the cost of 1 Nm^3 of natural gas is to 1.60104 DA (0.02 USD), so 28,338.41 DA/h (362.08 USD/h) or 680,121.84 (8689.95 USD/day) is spent. Clinker production has increased of 128535.72 kg/h or 3084857.28 kg/day, and the cost of 1 kg of clinker is to 7.777 DA (0.1 USD). A cost of sales 23990935.07 DA/day (306533.41 USD/Day) is obtained. To have a net profit, the difference between the selling price of the increased production of clinker and natural gas costs results a benefit of 23,310,813.23 DA/day (297,843.45 USD/Day). From the previous Figure 6 we see that the production of clinker in the presence of tertiary air is greatest in the case where the consumption of natural gas has changed (second solution) and increased earnings.

4. 5 Recovery rate of energy

To have the recovery of energy, we must compare the flow rates of the air exhaust in both solutions.

The flow rate of air exhaust from cooler is: First solution: Qv_{Ax} = 184,485.68 Nm^3/h, which is 60,56% of the cooling air. Second solution: Qv_{Ax} = 4,285.72 Nm^3/h, which is 1.41% of the cooling air. From these two values, it is clear that there is a very important reduction of the exhaust air in the second solution, with an increase in production.

5. Conclusions

The set of results obtained led us to important suggestions by proposing two solutions: the first solution is to increase the production of the clinker by using the tertiary air and keeping constant the debit of natural gas. The second is to increase the production of the clinker by using the tertiary air and changing the natural gas debit. The results show a very important reduction in the exhaust air in the second solution, with an increase in production but with some more consumption of natural gas, which is considered as a non-renewable energy.The choice of solution is for environmentalists of the cement plant that they consider our modest study.

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