Energy Efficient Bricks Production

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Abstract

The high quality bricks production requires a significant amount of heat energy especially for drying and kilning process. Therefore, the important request is the development and successful application of methods for reducing fuel consumption. One of the potentiality for energy conservation is reusing the hot air after kiln cooling for drying air heating. Another possibility is kiln stack heat recovery for combustion air preheating. Considering industrial process data such as production, amount and kind of fuel, relevant waste gases temperatures etc. the presented analysis is carried out. The obtained results show the fuel savings with hot air heat recovery of about 82% and with combustion preheating using stack of 6,5%.
The presented conservation methods are promising way for improving energy efficiency. Except that, using heat from waste has a smaller environmental impact in comparison with conventional sources producing the same quantity of energy.

Key words: hot air,stack, heat recovery, energy conservation, savings

1. Introduction

In the brick production the drying and kilning operations, as an integral part of the whole process, need a significant amount of heat energy produced using a high grade fossil fuel (Eastop, Croft, 1995; Budin et al., 1997). However, the temperatures of the hot air and stack from kiln present a significant potential for energy conservation. One of the opportunities for reducing fuel consumption is the kiln hot air recovery. This air could be used for drying air preheating. Reducing fuel requirements by air preheating as an energy conservation alternative may be applied in common practice.
Another possibility for effectively use the recoverable heat is combustion air preheating with kiln stack. This heat is added to raise the temperature of incoming combustion air what results in kiln heat consumption decreasing.
Considering industrial process data (Personal communication, 1998) the dryings without and with hot air recovery are compared. The last process, applicable to existing installations, provides the way of fuel savings i.e. reducing the costs of energy and environment pollution. Also, the savings using combustion air preheating with kiln stack is carried out.

2. Bricks Manufacturing

The production of bricks exists from several operations and the baseline process conditions are given in Figure 1.Raw materials in large lumps require crushing to produce small grains before grinding. To achieve proper grain sizing substances are fed to screens and after screening are

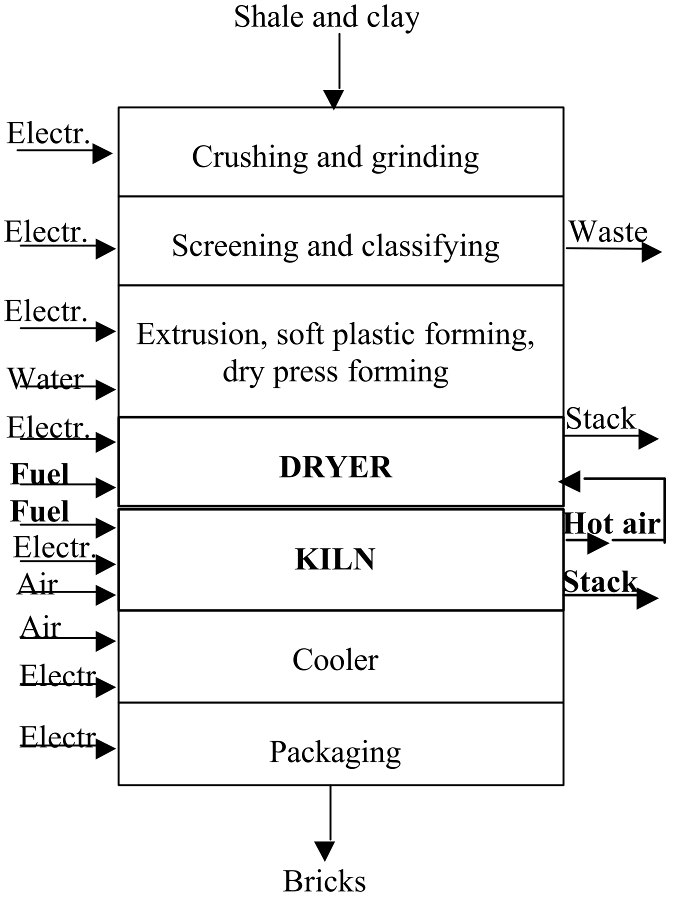

Figure 1. Brick production process flow

classified. Next operation is forming which employs extrusion, soft plastic and dry press forming. The bricks are then discharged into a dryer that has their own heat source or may be heated with waste heat from kiln cooling air. The next processing step is firing in kiln in order to obtain the necessary properties. The final products are then cooled and packaged (Othmer, 1968).

Relevant Operating Parameters

- From the wet bricks entering the dryer in amount of D_{WB}=6,9t/h the 78% dry bricks is produced i.e. $D_{DB}=D_{WB}*0,78=6900*0,78=5400$ kg/h.
- The evaporated water is: $D_W= D_{WB}-D_{DB}=6900-5400=1500$ kg/h.
- The plant operation time τ = 8064 h/y or use factor β=92%.
- The drying air conditions are:
  - ambient temperature and relative humidity: $t_1=25^0$C, φ_1=40%
  - heater outlet (dryer inlet) temperature: $t_2=140^0$C
  - dryer outlet temperature and relative humidity: $t_3=40^0$C, φ_3=95%.
- The natural gas used for dryer and kiln has a composition (by volume): 0,85%CO_2; 0,56%N_2; 98,05%CH_4 ;0,36%C_2H_6 ;0,12%C_3H_8; 0,05%C_4H_{10};0,01C_5H_{12}, what gives heating value H_L=35507kJ/m^3 calculated from (Požar, 1991).

- The existing average gas consumption for firing in kiln with efficiency η_K=82% is V_{FK}=540 m^3/h. Natural gas is burned with excess air coefficient α=1,8. The temperature of kiln stack is t_{SK}=140^{0}C, while outlet hot air temperature t_{Ko}=170^{0}C.

3. Basic Drying Process

A scheme of elementary drying process is given in Figure 2.

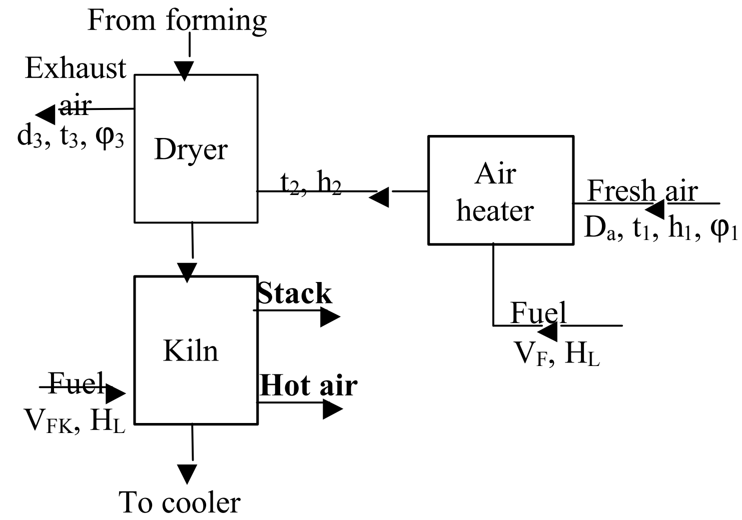

Figure 2. Block scheme without heat recovery

- The mass flow of drying air is calculated as:
  D_a=D_W/(d_3-d_1)=1500/(0,047-0,008)=38462 kg/h with the inlet (d_1) and outlet (d_3) moistures taken from psychrometric chart (Budin, Mihelic-Bogdanic, 2002).
- The heat input rate is: Q_H=(h_2-h_1) ∗ D_a= (163-46) ∗38462=3,81∗10^{6}kJ/h, where enthalpies h_1 and h_2 are taken from (Budin, Mihelic-Bogdanic, 2002).
- The yearly heat expressed in kJ and tCE :
  Q_{Hy}= Q_H∗τ=3,81∗10^6∗8064=30,7∗10^9 Kj or 30,7∗10^9/29,3∗10^6=1047,8 tCE
- The fuel consumption to give the heat for drying is:
  V_F = Q_H/H_L=3,81∗10^6/35507=107,3 m^3/h.
- The initial yearly gas consumption is: V_{Fy} = V_F∗τ=107,3∗8064=865∗10^3 m^3

4. Drying with Kiln Hot Air Recovery

Energy conservation could be achieved by kiln hot air recovery. After kiln cooling the air with temperature t_{Ko}=170^{0}C is mixing with air from air heater in the ratio 2:1 (66,7%:33,3%). In this process air is drawn into heater from outside conditions and is heated by heat supplied from natural gas. This air stream enters mixing chamber where is mixing with kiln hot air. The mixture with drying temperature is delivered to the dryer. Described arrangement is shown in Figure 3.

Referring to denotations in Figure 3. the mass flux of air entering the mixing box is:
- from heater $D_i = D_o = D_a * 0,333 = 38462 * 0,333 = 12808$ kg/h, and
- from kiln $D_{Ko} = D_a * 0,667 = 38462 * 0,667 = 25654$ kg/h.

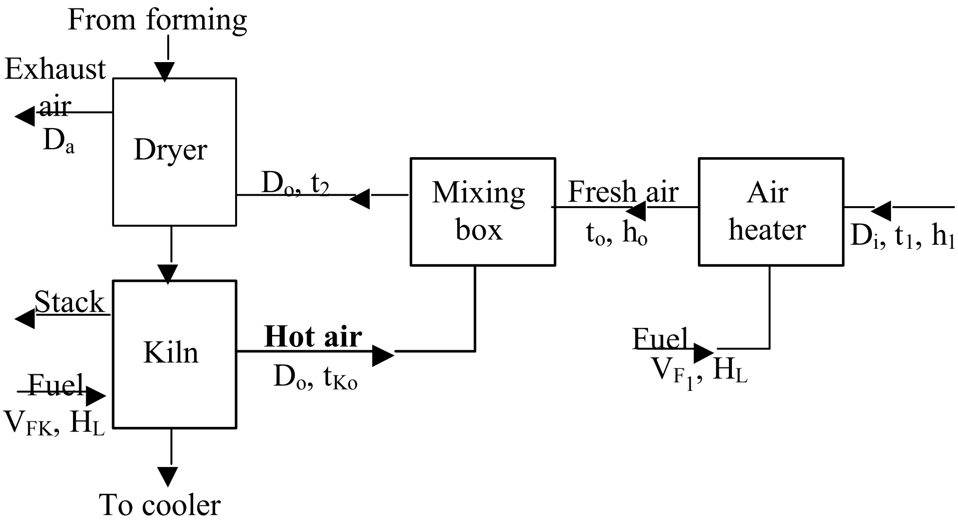

Figure 3. Kiln hot air recovery

- Assuming that the air streams are mixing adiabatically and using heat balance:
  $D_o * t_o + D_{Ko} * t_{Ko} = D_a * t_2$
- the heater outlet temperature is:
  $t_o = (D_a t_2 - D_{Ko} t_{Ko})/D_o = (38462*140-25645*170)/12808 = 80^0$C.
- Applying waste heat recovery, the air is heated from ambient temperature to temperature of 80^0C. Now the heat supply is:
  $Q_{H_1} = D_i * (h_o - h_1) = 12808 * (101-46) = 0,7*10^6$ kJ/h, where enthalpies h_o and h_1 are taken from (Budin, Mihelic-Bogdanic, 1991).
- The yearly heat expressed in kJ and tCE:
  $Q_{H_1 y} = Q_{H_1} * \tau = 0,7*10^6*8064 = 5,6*10^9$ kJ or $5,6*10^9/29,3*10^6 = 191$ tCE
- From the fuel viewpoint, the proposed option reduces natural gas consumption that is now:
  - $V_{F_1} = Q_{H_1}/H_L = 0,7*10^6/35507 = 19,7$ m^3/h, or yearly
  - $V_{F_1 y} = V_F * \tau = 19,7 * 8064 = 158,9*10^3$ m^3.

In comparison with conventional process without hot air heat recovery the yearly natural gas saving is: $\Delta V_{Fy} = V_{Fy} - V_{F_1 y} = (862-158,9)*10^3 = 703*10^3$ m^3 i.e. 81,6%.

Firing in the Kiln

After drying bricks are placing in a kiln that is the largest energy consumer in production. Fuel burned in kiln with efficiency $\eta_K = 82\%$ is natural gas with before shown volumetric analysis.
- The excess air coefficient is $\alpha = 1,8$.
- In presented case the amount of heat for firing is:
  $Q_K = V_{FK} * H_L * \eta_K = 540*35507*0,82 = 15,7*10^6$ kJ/h.
- The yearly absorbed heat expressed in kJ and tCE:

$Q_{KY}=Q_K*\tau=15,7*10^6*8064=127*10^9$ kJ or $127*10^9/29,3*10^6=4334$ tCE.

- The stoichiometric volume of combustion air is calculated as:
  - $V_a^s=0,0476[2CH_4+\Sigma(x+y/4)C_xH_y]$
  - $V_a^s=0,0476[2*98,05+(2+6/4)*0,36+(3+8/4)*0,12+(4+10/4)*0,05+(5+12/4)*0,01]$,
  what gives $V_a^s= 9,445\ m^3/m^3$.
- Actual combustion air flow expressed in m^3/m^3_F and m^3/h:
  - $V_a=V_a^s*\alpha=9,445*1,8=17m^3/m^3_F$
  - $V_{aK}= V_a*V_{FK}=17*540=9181\ m^3/h$.
- The stoichiometric volume of kiln stack is calculated from:
  - $V_S^s = V_{CO_2}+ V^s_{H_2O}+ V^s_{N_2}$
  - $V_S^s=0,01(CO_2+CH_4+\Sigma mC_mH_n)+0,01(\Sigma n/2C_mH_n+2CH_4)+0,0161+0,79V_a^s+N/100$
  - $V_S^s=0,01(0,85+98,05+2*0,36+3*0,12+4*0,05+5*0,01]+0,01[2*98,05+3*0,36$
    $+4*0,12+5*0,05+6*0,01]+0,0161*9,445+0,79*9,445*0,56/100=10,59\ m^3/m^3_F$
- The actual stack volume in m^3/m^3_F and m^3/h:
  -$V_S= V_S^s+1,0161(\alpha-1)\ V_a^s=10,59+1,0161(1,8-1)*9,445=18,3$,
  -$V_{SK}=V_S*V_{FK}=18,3*540=9882$, or yearly:
  -$V_{SKY}=V_{SK}*\tau= 9882*8065=79,7*10^6\ m^3$.

In an inefficient process this amount of stack with 140°C is withdrawn to the ambient.

5. Combustion Air Preheating with Stack

The air usually at ambient temperature, should be heated to the combustion temperature at the expense of fuel energy. It follows that if this air were preheated before its entry to the furnace a fuel saving would results.
In a case presented in Figure 4. the stack from kiln with temperature $t_{SK}=140^0C$ and volume $V_{SK}=9882\ m^3/h$ enters the air preheater with efficiency $\eta_{AP}=75\%$.

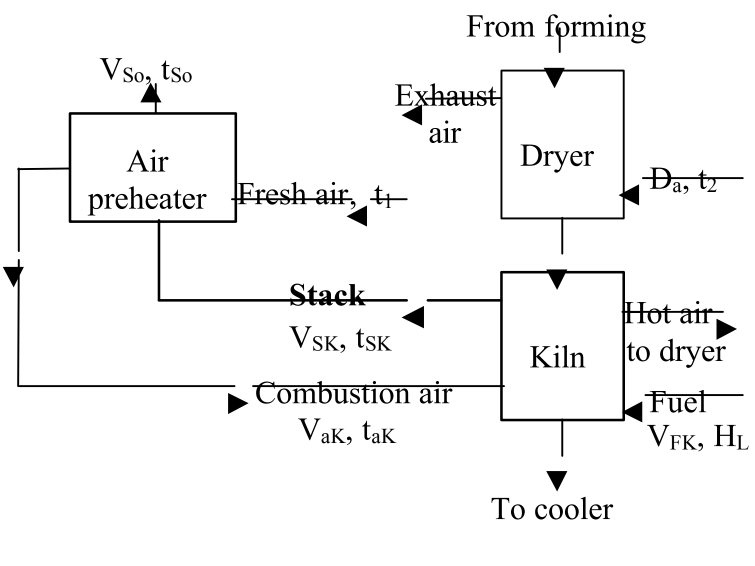

Figure 4. Combustion air preheating with stack

The heat is transferred to the combustion air with temperature $t_1=25^0C$ on its way to the furnace. The following calculation is based on air preheater balance:

$$Q_{AP}=V_{SK}*c_{pSK}*(t_{SK}-t_1)= V_{aK}*c_{pa}*(t_{aK}-t_1)= V_{aK}*c_{pa}*(t_{SK}-t_1)*\eta_{AP}$$

Now, heat exchange is:

$$Q_{AP}=V_{aK}*c_{pa}*(t_{SK}-t_1)*\eta_{AP}=9181*1,29(140-25)*0,75=1,02*10^6 kJ/h$$

The air leaves preheater and enters the kiln with temperature:

$$t_{aK}=Q_{AP}/(V_{aK}*c_{pa})+t_1=1,02*10^6/(9181*1,29)+25=111,1^0C.$$

The stack outlet temperature calculated from balance is:

$$t_{So}=t_{SK}-Q_{AP}/(V_{SK}*c_{pS})=140-1,02*10^6/(9882*1,36)=64,1^0C.$$

The heat rejected to the ambient and the corresponding amounts of fuel are calculated for process without (Q_S,V_{FS}) combustion air preheating:

- $Q_S=V_{SK}*c_{pSK}*(t_{SK}-t_1)=9882*1,36(140-25)=1,55*10^6$ kJ/h or yearly
- $Q_{Sy}=Q_S*\tau=1,55*10^6*8064=12,5*10^9 kJ/29,3*10^6=426,6$ tCE.
- $V_{FS}=Q_S/H_L=1,55*10^6/35507=43,7\ m^3/h$, or yearly
- $V_{FSy}=V_{SF}*\tau=43,7*8064=352,4*10^3 m^3$.

The values for combustion air preheating (Q_{SAP},V_{FAP}) are:

- $Q_{SAP}=V_{SK}*c_{pSK}*(t_{So}-t_1)=9882*1,36(64,1-25)=0,53*10^6$ kJ/h or yearly
- $Q_{SAPy}=Q_{SAP}*\tau=0,53*10^6*8064=4,3*10^9\ kJ/29,3*10^6=146,8$ tCE.
- $V_{FAP}=Q_{SAP}/H_L=0,53*10^6/35507=14,9\ m^3/h$, or yearly
- $V_{FAPy}=V_{FAP}*\tau=14,9*8064=120,2*10^3 m^3$.

6. Conclusion

In presented article two possibilities directed on increasing energy efficiency in bricks production are proposed. The first option is the hot air recovery after kiln cooling. This heat is used for drying air preheating. From previously calculation follows the savings:

$$S=(Q_H-Q_{H_1})/Q_H=(3,81-0,7)*10^6/3,81*10^6=0,816, \text{ i.e. } 81,6\%.$$

The second process concerned above is the kiln stack applying for combustion air preheating what results with savings:

$$S_S=(Q_S-Q_{SAP})/Q_K=(1,55-0,53)*10^6/15,7*10^6=0,065, \text{ i.e. } 6,5\%$$

It should be pointed out that the analyzed heat recovery results with increasing energy efficiency, money savings as well as smaller environment pollution what makes proposed options desirable.

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