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Peculiarities of fuel burning in dry and wet cement production kilns

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Abstract. The paper presents the findings of fuel efficiency in cement rotary kilns. It demonstrates the relevance of the aggregate of factors which provide obtaining a sustainable hot flame during fuels burning. The paper analyses the impact of alternative fuel and heat recuperation when cooling a cement clinker on the flame exergy as well.

1. Introduction

The energy efficiency of cement production depends on the heat-exchange conditions in the baking zone. These conditions are specified by the peculiarities of fuel burning in cement rotary kilns, burner units construction, alternative fuel characteristics and a clinker cooler operating efficiency.

The technological conditions of clinkering in the baking zone of cement rotary kilns impose specified requirements concerning the fuel burning mode. The length of the baking zone is frequently equal to the length of the fuel flame. The fuel burning temperature must provide the completeness of physico-chemical processes of generating clinker minerals determined by the properties of the raw cement mix being baked. The correspondence of fuel burning parameters with the parameters of the raw cement mix baking is the most significant condition for the burning mechanism in cement rotary kilns.

The fuel flame burns in a zone under the conditions of comparably low heat consumption but kiln lining and kiln charge have the temperature which is 150-400°C lower than the temperature of the flame. An average temperature of the flame in the combustion zone is from 1650 to 1850 °C depending on the production method.

The heat-balance calculations of the fuel combustion zone show that in the case of using a wet cement method of a clinker production with the heat rate equal to 5.4 – 6.5 mJ/kg, from 3.5 to 4.5% of heat is spent on heating material up to the clinkering temperature and about 6% – on the heat losses in the kiln body in the part of the baking zone [1]. Heating power in this part is not more than 10% of its total heat.
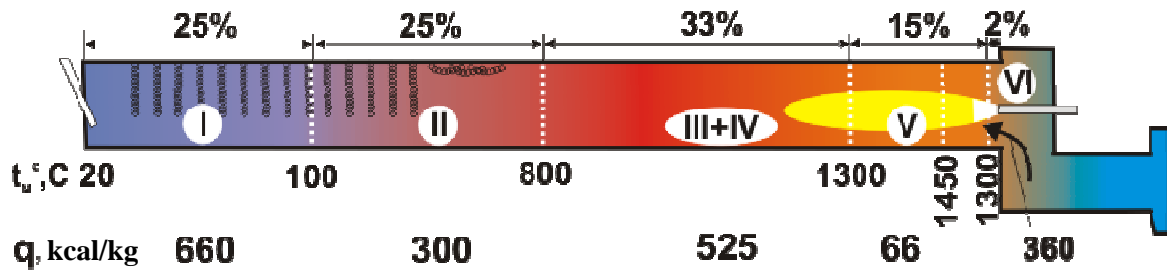
Figure 1. Operational areas in the kiln of wet cement production and heat consumption in zones.

Low heat emission to the material and high temperature provide burning stability.

Clinker burning is possible in different combustion zones either "long or short", or "far and close". Each mode has its positive and negative sides and defines the kiln construction features and the methods of their operation. Operation in the "short" part enables to raise clinker activity but increases burning rate by means of high temperatures concentration on a small section of the kiln length, which causes lining coating destruction and favours material rings generation. Operation in the "long" part decreases the heat effect on the lining but restricts kiln capacity. Flame elongation is practically impossible in the dry production kilns due to being restricted by material temperature parameters in external heat exchangers, constructions' heat-resistance and kiln length.

2. Main body

The requirements to the combustion zone position with regards to the temperature of the clinker coming from the kiln, which must not exceed 1200 – 1300°C, and to the case temperature, which must not be higher than 250 – 300 °C, are the peculiarities of fuel burning in rotary kilns.

Let us analyse the efficiency of fuel burning modes without going into particulars of the preparation of different types of fuel for burning and the influence of kiln working conditions on the quality indicators of the production being obtained. It must be admitted that the determinant of fuel burning efficiency is the temperature which determines the speed of chemical processes (which comply with the Arrhenius dependence) under the conditions of the portland cement clinker synthesis. One of the reasons why the productivity of dry cement production kilns increases under the conditions of the aggregates' small size is the temperature of the flame which is 100-200 °C higher than the temperature in wet cement production kilns.

A lot of attention is paid to the augmentation of heat transfer between the material and gas streams in the kiln as well as to the fuel conservation. The long experience of the Cement processing department of "Belgorod State Technological University named after V.G.Shukhov" (BSTU) has given practical expression to the importance of heat economy in the hot part of a kiln [2].

Considering exergy (efficiency) of combustion products heat flow ($E_{n.c.}$), obtained by burning 1 kg of fuel can be written as follows:

$$E_{n.c.} = H_T \cdot \left(1 - \frac{T_0}{T_T}\right)$$

where $H_T = Q_н^p \cdot \eta_T + Q_в + Q_T$ is theoretical enthalpy, kJ/kg;

$$T_T = \left(\frac{H_T}{\Sigma V_i \cdot c_{n.c.i}}\right) + 273 \text{ is theoretical flame temperature, K;}$$

T_o is the environmental temperature and the combustion products temperature in the selected section of the rotary kiln; η_T is furnace efficiency; $Q_в$ and Q_T are the heats brought to the furnace by an airflow or fuel respectively, kJ/kg.

The given formulae demonstrate that the efficiency of heat flow rises with the increase of air and fuel heating and decrease of combustion fuels under the conditions of excess air coefficient α, while H_τ and T_τ increase as well. Measures increasing $E_{n.c.}$ will favour the decreses of exergy losses in the process of transmitting heat from the combustion products to the heated body under the conditions of other equal conditions. Thus, great attention should be paid not only to the decrease of heat losses in the process of recuperation of heat from the clinker but also to gaining maximum possible temperature in the fuel combustion zone, which can be achieved by burner units improvement and effective working conditions of the burning aggregate.

Heat loss reduction with a clinker and the increase of secondary air enthalpy are determined by the clinker cooler operation. The key indicator of a cooler operation is its heat efficiency. Only if heat efficiency of a clinker cooler is not less than 0.8, the wet cement production kilns achieve economical operation mode. Although heat losses related to clinker cooling are about 5% of the general heat flowrate, economy according to this heat balance is of primary importance. The essence of such heat economy eficiency under the conditions of clinker cooling lies in the fact that a part of fuel heat is exchanged with the heat of the secondary air. Herewith, the volume and speed of the furnace gases decrease and the heat exchange inside a kiln increases. Practically [3], it leads to the decrease of waste gas temperature, improvement of the conditions of lining coating generation in the baking zone and decrease of kiln body temperature and, consequently, to the decrease of heat losses into environment.

Considering the physical conditions of heat exchange in the baking zone, it should be noted that up to 80-90% of heat is transmitted by the flame radiation. Radiative heat transfer for the rotary kiln complies with the Stefan–Boltzmann law with the addition of A. Bloch [4] and is defined according to the formula:

$$Q_l = 5,67 \times \varepsilon_{m.} \left[\varepsilon_{g.} \left(\frac{T_f}{100} \right)^4 - \alpha_{g.m.} \times \left(\frac{T_{m.}}{100} \right)^4 \right]$$

Q_l is heat-flux density of radiation energy;
$\varepsilon_{m.}$ is material radiating power;
$\varepsilon_{g.}$ is flame radiating power;
$\alpha_{g.m.}$ is gas absorbing capacity at a temperature equal to material temperature;
T_f and Tm are flame and material temperatures.

Radiant heat exchange in the baking zone of cement rotary kiln increases up to 23% when the flame temperature increases by 100°C within the temperature range of 1650 – 1750°C. However, temperature rise in a kiln is restricted by firebrick lining performance and clinker synthesis conditions. It is possible to intensify a heat exchange process under the conditions of the flame reduced temperature, but herewith it is necessary to provide the conditions leading to the increase of ε_g being flame emissivity (ε_g can change from 0.25 to 0.7). Although it should be remembered that temperature is the moving force of clinker phases. Creating favourable conditions of fuel buring has a significant importance and depends largely on burner units structure.

The speed and completeness of burning is controlled by the speed and completeness of the air-fuel mixture, i.e. by the advance speed of the oxidant to the fuel and intensity of their mixture and is determined by Peclet number: **$P_e = P_r R_e = 0.7 R_e$**

Reynolds number: **$R_e = (w \cdot d)/\nu$**
where d is the determining diameter (kiln diameter);
w is gas flow speed;
ν is gas kinematic viscosity.

The intensity of mixing and burning increases with the increase of the speed of gas flow out of the burner. The intensity of mixing and burning decreases with the increase of the secondary air temperature due to the significant increase of air viscosity.

Flame configuration is determined by the ignition point. Advance ignition in diffusion-flame burners deteriorates the advance speed of the oxidant to the fuel and slightly elongates the flame which must be optimally-configured.

Single or rarely double gas burners are applied in the process of burning gas of moderate pressure in rotary kilns. Intensive mixing of gas and air in such burners is achieved by a high degree of gas flow turbulization at high speeds of gas escape from a nozzle. They have a relatively small diameter and can operate without any swirlers. Installation of swirlers provides the improvement of the contact of gas mixture with air and the burning process intensity by means of mixing gas with air. Intensive burning and good contact with the kiln charge in the process of swirlers installation is stipulated by the fact that the maximum possible number of flashpoints is generated by means of the contact of the flame with the red-hot surfaces of both kiln lining and kiln charge. The analysis of burning natural gas in rotary kilns [5] under the conditions of moderate gas pressure from 0.4 bar and the speeds of gas escape equal to 300-400 m/s in single diffusion-flame burners of a small diameter has shown that gas burns intensively with a lack of incomplete combustion when the excess air coefficient values are $\alpha >$ 1.05.

However, the application of such burners has a significant drawback, which is the presence of flame axis of high fuel concentration. It determines the position of peak temperature load in the kiln body depending on the burner operating mode (gas pressure, swirlers position, coefficient of excess air in a kiln, etc.) in the "close, middle or far" baking zones and forces to use techniques to minimise the fuel combustion intensity (e.g. increase burner tilt with respect to the material, decrease the speed of fuel discharge from the burner nozzle, etc.), which, eventually, decreases heat-exchange efficiency.

To intensify burning of gas mixture, a developed and steady mixture burning should be provided by means of splitting the flow into small streams and creating stable ignition points. Stability of ignition is the ability of burner units to provide inflammation close to a burner port at a possible larger speed of burning mixture escape. The developed inflammation and the developed ignition surface decrease the inert flame volume and increase the heat stress of its volume. It is possible to consider the application of slot burners to be appropriate because the developed ignition occurs in this case with the help of enlarging the ignition perimeter. In these circumstances a flame takes the shape of a hollow conical pattern, in which ignition is generated both in a circumferential direction of a burner and along the flame inside surface due to intense recirculation. Combustion products are taken from the flame and ignite the incoming fuel. The inside recirculating zone can be achieved by means of the following:

- presence of a bluff body in a torch nozzle
- fuel swirl
- primary air swirl
- fuel and primary air swirl

High stabilityof a flame with natural gas is really difficult to provide due to its high ignition temperature, close limits of ignition and low speed of a flame propagation. The oil-fueled flame stabilisation requires the corresponding diffusion together with the consideration of a local recirculation. Stabilisation of a flame with powder fuel (e.g. coal/coke) influences the milling fineness, ash properties, volatile components proportion and the speed of coal and air stream.

The primary air swirl is a very effective solution to providing a flame stability but the account must be taken of the fact that herewith the percent of the secondary air decreases and, consequently, heat recuperation in the fridge decreases as well. Although the use of primary air in dry cement production kilns is stipulated by the necessity to intensify the fuel burning, this technique application is strongly objected with regards to wet cement production kilns. Furthermore, it should be noted that burning the gas even with a fuel stream high-impulse performance (8-9 N/MWth) in the burners of a large diameter with an annular ring leads to a rapid fuel stream damping. Consequently, a flame with a close inflammability point under the conditions of a relatively small involvement into a secondary air stream is being formed. The flame is slow and it can transfer to preparation zone when a low heated material comes into a baking zone. Account must be taken of a gas flow geometric parameters as well and in the case of multiflow nozzles, the appropriate impulse should be given to each.
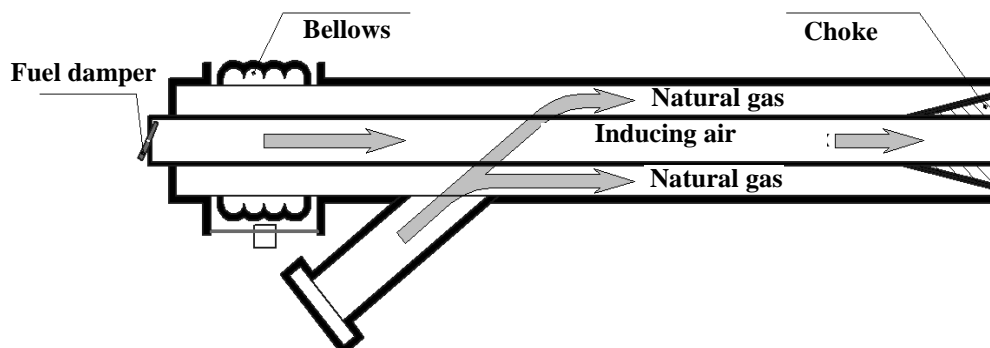
Figure 2. Functional diagram of burner GID

Gas burners of a GID type (injection diffusion) [6] developed on the basis of BSTU in cooperation with LLC PF "Ayan", Tula, Russia were practically tested at Public Companies "Mordovcement", "Schurovcement", "Kharadah cement", "Sebryakovcement". The mentioned gas burners provide positive heat exchange in a flame zone with a high heat stress of a flame volume. A distinguishing characteristic of such burners enhancement (Fig. 2) is the presence of a central channel through which primary air is injected by means of rarefaction created by gas flow behind the bluff body. The latter is represented by a flow-control valve made in the shape of an inverted cone. The burner has a broad range of control and highly stable ignition. A free central channel enables to burn other types of fuel in a kiln. Currently, the structure of a flow-control valve is being optimised for implementing a co-combustion of gas and various types of solid and liquid fuel in their predetermined combinations, which is a rather sophisticated task with account of different temperatures of ignition, heat capacity and speed of the combined fuel conponents.

Burner GID was tested at a Public Company "Mordovcement" with regards to the possibility of co-combustion of gas and wood chops and proved to be effective. Burning alternate fuel stipulates the determination of maximum possible amount of this fuel supply instead of gas, a traditional energy source.

To assess the efficiency of alternate fuel being a timber sleeper processed into chips we need to calculate heat capacity and flame maximum temperature under the conditions of different levels of humidity (Table 1).

According to All-Russia Thermal Engineering Institute the wood makeup is $C^r = 51\%$, $H^r = 6.1\%$, $O^r = 42.3\%$, $N^r = 0.6\%$, $A^c \sim 1\%$, $Q_H^r = 4530$ kcal/kg, $t_r = 2010°C$

Calculations have shown that when burning oven dry wood the flame maximum temperature is consistent with the temperature of a gas flame. If the humidity of wood chips being applied grows, combustion temperature decreases dramatically. If the humidity is equal to 50%, the flame's temperature will be consistent with the temperature required for obtaining a clinker, namely, 1450°C.

Thus, the humidity of chips influences their proportion under the conditions of being burnt together with gas causing them to limit significantly. The heat capacity of wood does not exceed 1980 kcal/kg in case of 50% humidity and 3510 kcal/kg if the humidity is equal to 20%. It is worth noting that wood gets 20% humidity under the conditions of natural storage during 2 years. Wood with 32.1 – 35% humidity was used during the research.

Table 1. Potential composition of wood chips with different humidity

Element	Wood chips humidity,%			
	20	30	40	50
Wood chips composition to the found basis, %				
C^p	40.8	35.7	30.6	25.5
H^p	4.9	4.3	3.7	3.1
O^p	33.8	29.6	25.4	21.1
N^p	0.5	0.4	0.3	0.3
Σ	80	70	60	50
$Q_н^r$, kJ/kcal	14698/3510	12558/2999	10418/2488	8290/1980
Air to the burning, m^3/kg	3.800	3.328	2.855	2.386
Volume of combustion products, m^3/kg				
V_{CO_2}	0.759	0.664	0.569	0.474
V_{H_2O}	0.797	0.854	0.910	0.967
V_{N_2}	3.006	2.632	2.258	1.887
Σ	4.562	4.15	3.737	3.328
Heat capacity, °C	1884	1773	1641	1489

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For normal heat-exchange conditions the temperature of a flame in a combustion space of a kiln must range within 1750°C. Decrease of flame temperature by 30°C will diminish radiant heat exchange by 17%, which will ultimately require the extend of the time spent by the material in baking zone and the loss of kiln efficiency. It is normal when the fuel with low heat capacity is applied, otherwise, the heat total consumption must be increased.

In order to define the number of the input chips taking into account the flame temperature decrease, it is necessary to do the following manupulations on the basis of the graph (Fig. 3): draw a horizontal line, say, from the temperature 1720°C and find the recommended amount of alternate fuel calculated as t/h (with 30% humidity the amount is 4 t/h) at the intersection with a slant line showing the defenite humidity down the scale "The number of input of wood chips".

Additionally, much attention should be given to the clinker cooler operation, while it influences the temperature developed during fuel burning. The calculated dependences of wood chips number on the cooler heat efficiency show that wood chips expenditure can be doubled with the change of coller efficiency from 70% to 90% even under the conditions of similar humidity.
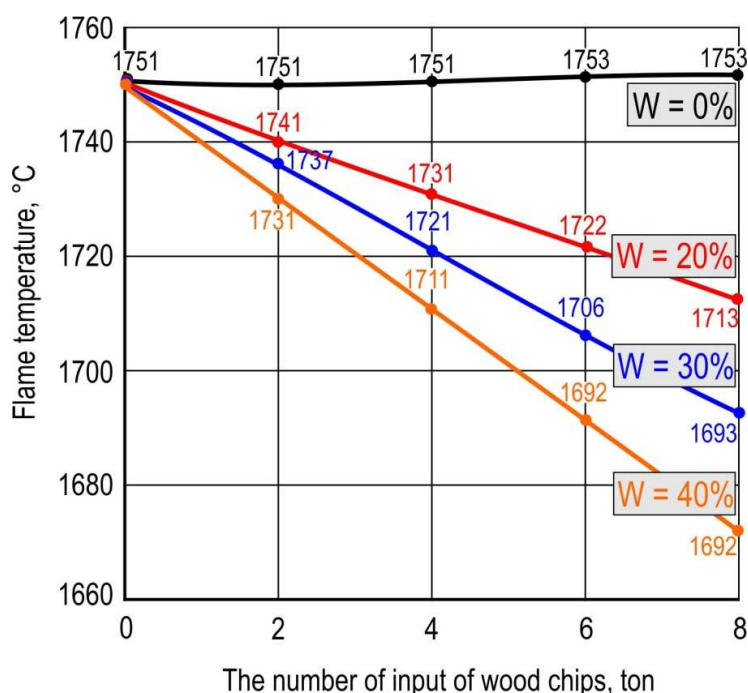
Figure 3. Influence of the number of the input chips on the flame temperature with account of its humidity

The tests run on the kiln №6 showcased that in the case of increasing the number of the input chips to more than 6 t/h the temperature of exhaust gases in the kiln increases (i.e. baking zone does not provide the proper heat exchange and the heat is transmitted into preparation zones). This temperature increase indicates the necessity to increase gas consumption in the combined fuel.

3. Conclusion

1. The flame combustion of fuel in industrial kilns of cement production requires the consideration of several factors with the purpose to achieve effective heat exchange. The mentioned factors include: the production method, burner units construction, techniques to enhance various fuel types' combustion.

2. Taking into account fuel exergy efficiency we should aim to create hot flame in a kiln without the prominent heat extremum, which accelerates physico-chemical processes of clinker synthesis without sacrificing kiln lining and raises the aggregate efficiency.

3. Application of alternate fuels with low heat capacity is limited by the recuperating ability of a clinker cooler.

4. Acknowledgments

References

[1]   Klassen W 2012 *Technology and optimization of cement production* (Belgorod: BSTU Publishing House)
[2]   Novoselov A G, Klassen V K, Novoselova I N 2016 *Bulletin of the Belgorod State Technological University. V.G. Shukhov* **3** 142-147
[3]   Klassen W 1994 *Baking of cement clinker* (Stroyizdat, Krasnoyarsk department)
[4]   Mazurov D Ya 1975 *Thermotechnical equipment of binder materials plants*. (Moscow: Stroyizdat)

[5]   Ponomarev V B, Pereskok S A 1993 *Cement* **2** 41-42
[6]   Konovalov B M, Litovchenko A V, Mishin D A, Strepetov I P, Shevchenko V N 2006 *Patent No. 2319073 Russian Federation, IPC F 23D 14/24. Diffusion Injection Burner; applicant and patent holder of BSTU. V.G. Shuhova,* LLC PF "AYAN" №2006122053