Middle-East Journal of Scientific Research 15 (12): 1871-1876, 2013
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2013.15.12.7088

Management of Clinker Burning in the Rotary Kiln, Aimed to Improve the Quality of Cement and Fuel Economy

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Abstract: A definite relationship clinker quality from the rotary kiln operation modes and the combustion of fuel was established based on the tests that were carried out for optimization for more than 100 cement rotary kilns of wet method of production. The effect of the provisions of the sintering zone, controlled by the temperature maximum of the furnace body, the microstructure of clinker and the quality of the cement are shown.The optimal microstructure of clinker and the maximum strength of cement is provided in the middle position of the sintering zone where is the maximum temperature of the furnace body is in 12 ± 1 m from the hot furnace edge. It reduces the fuel consumption and increases the service life of the lining. Method for optimizing the conditions of burning of cement clinker and the intensity of fuel combustion by varying the speed of departure of fuel-air mix from the nozzle of primary air, secondary air temperature, excess air ratio, the position of the nozzle and swirl fuel-air streams in industrial conditions was proposed and implemented.

Key words: Position sintering zone % The strength of cement % Fuel combustion % Flame

INTRODUCTION

According to numerous studies the quality of cement clinker and heat rate for its production is largely determined by burning mode [1-8]. For 50 years, we have carried out tests and optimization of more than 100 cement rotary kilns of wet method production that helped us toreveal definite relationship of clinker quality from the mode of the rotary kiln [9]. Rational firing delivering a high quality of clinker at the same time leads to improvement of other technical and economic parameters of the furnace that is fuel economy and increase the life of the lining. In this regard, the aim of this work is to determine the optimal operation mode of the rotary kiln, the methods of identification and regulation of this indexes. As an example, results of industrial furnaces on the coal fuel 4,5×170 and 5×185 m of 1200 and 1800 tons/day research are shown.

MATERIALS AND METHODS

Major studies were carried out in industrial conditions for kilns of wet method of production by thermo technical tests.Clinker quality rated on the following parameters: hydration activity determined strength cement according to standard procedures at 28 days of hardening in water, the microstructure and the fractional composition that is characterized by containing dust fraction with a particle size less than 1 mm. Thermo technical tests were conducted by the conventional method [10]. In addition for studying the process of fuel combustion in an industrial furnace the tracer method was used [11]. As a radioactive tracer for determining the speed and structure of the gas flow in the rotary kiln 5×185 m La^{140} isotope in the compound of La_2O_3 was used. The essence of the experiment was the following. The powder with a radioactive substance in a paper bag was

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injected in the coal nozzle. On hit the bag in the flame paper burns, then the powder was picked up by gas stream and characterized the behavior of coal-gas mixture in the kiln. Passage of the labeled probe was registered by scintillation counters, established through the 7.5 m along the kiln which with high efficiency registered and continuously recorded signal of radiation.

This method allows measuring the velocity of the gas in the kiln, to calculate dispersion and thus turbulence of the gas stream. Knowing when this section of the furnace and the gas flow in normal cubic meters, one can estimate the temperature of the gas phase including flame. If the section of the kiln and gas flow rate in normal cubic meters are known then the temperature of the gas phase including flame can be estimated. The disturbances for fuel burning were produced by short-term changes in operating parameters in order not to disrupt the overall thermo technical condition of the unit. Paired experiments to change the same parameters were carried after 5-10 minutes. Simultaneously, the main technological parameters of the process were fixed and the composition of the exhaust gases was analyzed. Similar experiments under different conditions of combustion of coal fuel in the rotary kiln were made for the first time and allowed to get some relationship between the control parameters and the intensity of burning fuel.

Determination of the Optimal Position of the Sintering Zone of the Rotary Kiln: Position in the sintering zone of a cement rotary kiln can be determined by body temperature.

Figure 1 shows how the temperature of the furnace body ($t_{surface}$) and removal of high temperature (L_{max}) of the hot edge depending onposition of the sintering zone. Because of the position of the sintering zone greatly determines the mode of the clinker burning and cooling it naturally effects on its quality. In this regard, studies have been conducted to identify the relationship between the above qualitative indicators of clinker and the mode of burning, which was estimated by the position of the maximum temperature in the kiln body. The temperature maximum was shifted by for each mode determined by the change in combustion conditions and therefore flame shape for the quality of the clinker burning and thermal engineering performance rotary kiln (Table 1).

The test results show that the optimal burning mode is middle position of the sintering zone where the maximum temperature is located at a distance L_{max} = 12 ± 1 m from the hot edge of the kiln. In these circumstances, the maximum activity is provided of the clinker equal 48.4 MPa, which exceeds the value of 37.8 MPa at irrational mode by 22%. If the sintering zone is too close to a hot edge, then the activity of clinker is reduced again to 41.5 MPa – 14%.

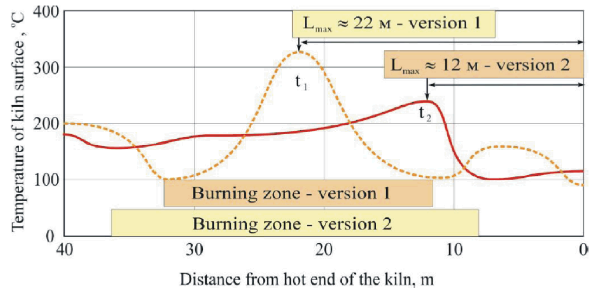

Fig. 1: Position sintering zone in kiln and the body temperature on irrational (1) and management (2) modes of clinker burning

Table 1: Characteristics of the kiln depending on the position of the high temperature

Parameter	Value				
Removal of high temperature – L_{max}, m	6±1	9±1	12±1	17±2	22±2
The content of dust fractions, %	10	5	2	25	50
Activity of clinker, MPa	41.5	44.0	48.4	42.1	37.8
Heat loss, kJ/kg of clinker,	980	910	840	1070	1250
including: – cooler	280	210	140	320	450
– to the environment by kiln	700	700	700	750	800

This dependence is explained by clinker microstructure (Fig. 2).

If the sintering zone is too close to the hot edge, then small, often elongated crystals of alite with well-defined edges are formed in clinker # 1. Cement clinker from such has greater strength (29.4 MPa) at an early stage of hardening, but does not provide high activity in 28-day age. If the sintering zone is too far (L_{max} = 22 ± 2 m) from the hot edge then due to prolonged extract of clinker at high temperature in flame space large crystals with broken edges of clinker phases are formed and the decomposition of aliteis observed. The micrograph of the sample # 5 this clearly shows it, that is the reason for reducing the activity of clinker by 22%. Furthermore, while in the clinker 50% of the dust is produced that results in heat deteriorating in clinker cooler with a significant increase in heat loss from 140 to 450 kJ/kg of clinker. In this burning mode furnace body temperature increases simultaneously from 220 to 330°C, what leads to an increase in heat loss to the environment and reducing the life of the lining (Fig. 1, Table 1).

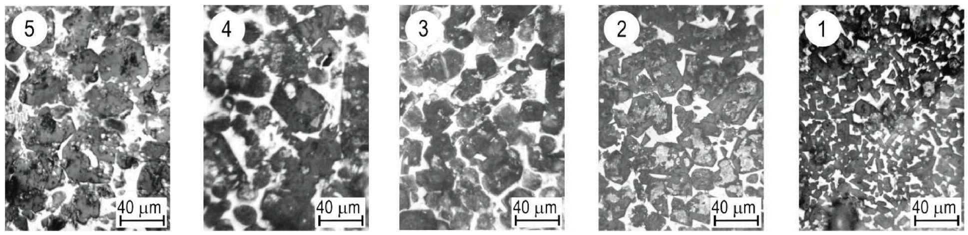

Fig. 2: Change of microstructure of clinker depending onthe position of the sintering zone in furnace

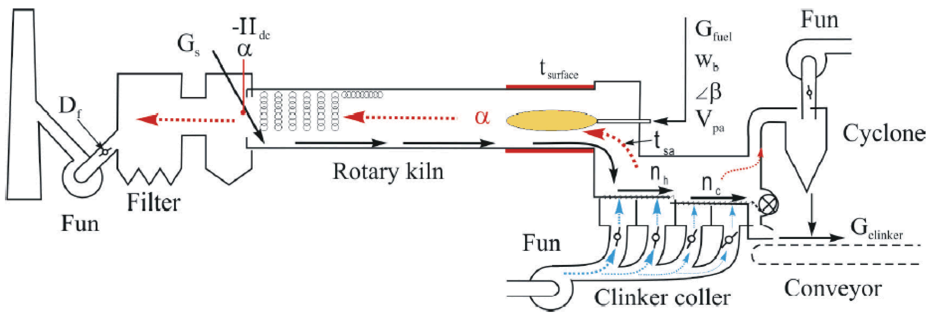

Fig. 3: The control circuit of a cement rotary kiln wet method.

The maximum activity of the clinker # 3 provides the middle position of the sintering zone, where the optimum microstructure is formed. At the same time the total heat losses are reduced almost 1.5 times from 1250 to 840 kJ/kg clinker and protective coating is created on lining in the sintering zone that protects the firebrick from deterioration.

Ways to Ensure Optimum Clinker Burning Mode: One of the tasks of the operator or automation system is to ensure the optimal position of the maximum temperature of the kiln body – L_{max} = 12 ± 1 m solution of this problem is a rational fuel combustion, which forms an optimal flame. This requires a control system of a cement rotary kiln of wet method, shown in Figure 3.

G_s, $G_{clinker}$, G_{fuel}, – the amount of sludge, clinker and fuel, t_{sa}, $t_{surface}$– temperature of secondary air and kiln body; $_c$ – rarefaction in a dusty chamber; D_f, – damper of exhauster; n_h, n_c – the number of oscillations of hot and cold grates of cooler.

The system includes controlled and controlling parameters. The former include the temperature of the secondary air (t_{sa}) in the furnace body and in the sintering zone ($t_{surface}$), rarefaction in a dusty chamber ($_c$) and associated air excess factor ([alpha]). The second – flow of sludge (G_s) and fuel (G_{fuel}), the position of slide exhauster (D_f), the amount of primary air (V_{pa}), the speed of the fuel at the outlet nozzle (w_b), nozzle angle to a material ([beta]), the number of oscillation hot and cold grates of cooler (n_h , n_c).

Regulation of the Process of Fuel Combustion: Influence of individual regulating parameters was studied using radioactive isotopes as here above described and the nature of the temperature distribution of the furnace body in the sintering zone. The results of using radioactive isotopes experiments indicate that the total gas phase residence time in the furnace is 14-16 seconds. The burning zone length 30 m, in which the main portion of the fuel burns, the gas passes for only 1.1-1.4 seconds, which is considerably faster than before. For example, in study [12] calculated time of the gas residence in the furnace with diameter 5 m at the same site was about 3 seconds. Average velocity in the combustion space were within 21-27 m/s. By the gas velocity could be estimated, in which cases the combustion temperature was higher. Higher velocity corresponds a higher flame temperature and combustion intensity.

The burning rate is shown more clearly by the parameter 1/Pe / (W. L), which is the reciprocal of the diffusion test Peclet – 1/Pe and characterizes the intensity of the longitudinal mixing of dust-gas phase (Fig. 4). Here D – diffusion coefficient, w – velocity, L – a longitudinal section of the kiln.

As the test results shows burning, escape velocity from nozzle coal-air mixture and the amount of primary air are intensified most strongly (experiment I-1). With increasing rarefaction therefore the excess air ratioburning is also accelerated and the flame moves away from the head of the kiln. The same effect has reducing of the temperature of the secondary air. All experiments were carried out by blowing from the hot end dust into a fiery space of about 20 t/h electrostatic precipitators. It is natural that it decreased the temperature of the flame. Therefore, an experiment IV-7 was conducted with disconnection of dust-back and showed a significant increase temperature and the approach of the flame to the head of the kiln.

At other plants, as already mentioned, the intensity of the combustion and the flame position are evaluated by the distribution of the temperature of the kiln body. Summarized results of our experiments conducted by the burning of various fuels by 8 factories of the countryare presented below.

Type, composition and parameters of fuel preparation. The highest speed and combustion temperature are set on burning coal fuel, the lowest – in the application of gas. A significant effect on the combustion of solid fuels is supported by: the volatile V_d, ash A_d, moisture and fineness of grinding. The increase of volatile V_d occurs earlier ignition of the fuel, increases the length of the flame and the degree of blackness [epsilon] $_{flame}$, the flame temperature is reduced. Lean coal ignites at a considerable distance from the nozzle and burns with concentrated high-temperature flame with low degree of blackness [epsilon]$_{flame}$. Acceleration of ignition lean coals can be provided by finer grinding, so depending on the ratio of V_d it is recommended to adhere to $R_{008} = 0,5 \cdot V_d$, i.e. to grind coal powder to a residue of 10-15% on a sieve with mesh 80 microns. With the increase in fuel ash content A_d for more than 20% it is recommended to increase fineness of grinding. Sometimes at the plants the grinding coal is roughened in order to lengthen the flame, but it doesn’t lead to desired result because it occurs late ignition of fuel with temperature concentrationat a remote site from the nozzle of burning zone, what leads to lower resistance of the lining and clinker dusting. Drying fuel in all cases is necessary to hygroscopic moisture, i.e. before W_{coal} = 1-2%.

On combustion of fuel oil the viscosity of nozzle fuel is essential, that depends on the brand and the preheating temperature of fuel oil. Optimal conditions of combustion of fuel oil reached at viscosity equal 1-2°VU. Thus it is necessary to provide the intensive spraying using appropriate burners and to raise the temperature of preheat up to 100-140°C and the proportion of primary air can be reduced to 5-15%.

Efficient combustion of gaseous fuel is provided by reducing the rate emission of gas fromthe burner to 200-280 m / s with a partial twist flow.

Primary Air: The amount of primary air is one of the main factors that determine the intensity of burning of fuel. With the increase in primary velocity V_{pa} and velocity of emission of coal-air mixture from the nozzle w_b (experiment I-1) happens more distant fuel ignition, flow turbulence increases and the flame shortens.

General Air: Excess air ratio depends on the work of behind-kiln traction devices.With increasing rarefaction of edged kiln the amount of air sucked through the furnace and the air ratio – [alpha] is increased. Due to the fact that the flame moves away from the orifice of the nozzle (experiment 3 and 4), most operators had the idea, that flame lengthens. In fact, with increasing [alpha] flame temperature and heat transfer in the furnace are reduced and therefore the fuel consumption increases sharply.

At the same time increasing [alpha] from 1.03 to 1.25 results in a concentration of temperature on 20-30 m from hot edge of kiln and rapid burn-through of lining in this area. Rational flame is obtained by reduction of [alpha] to 1,10-1,05. In this case, the fuel is ignited closer to the nozzle, rate of combustion is slightly reduced, increases the degree of blackness and the average temperature of the flame, which provides intense heat and high resistance of lining.

Secondary Air: Significant fuel economy can be obtained by increasing the efficiency of the cooler, when a substantial portion of the heat from clinker passes to the secondary air and back into the kiln. At the same time a temperature of the secondary air – t_{sa} is essential to the process of burning fuel and resistance of the lining (experiment 5, 6). Some researchers based on the concept of molecular diffusion of combustion find the wrong conclusion that with the increase in air temperature the flame shortens. In fact, the rate of combustion in the furnace is determined by turbulent diffusion and therefore the authors [12, 13], taking into account that an increase of t_{sa} – decreases its density and increases viscosity fairly admit the possibility of lengthening the flame.

According to our data, the most important influence on the burning rate has pre-mixing of fuel and air prior to its ignition. Because of increasing of t_{sa} the flame comes to the nozzle, but this reduces the concentration of oxygen logged in to the fuel-air mixture before the ignite, so the flame lengthens. It provides efficient fuel combustion, along with substantial savings in heat.

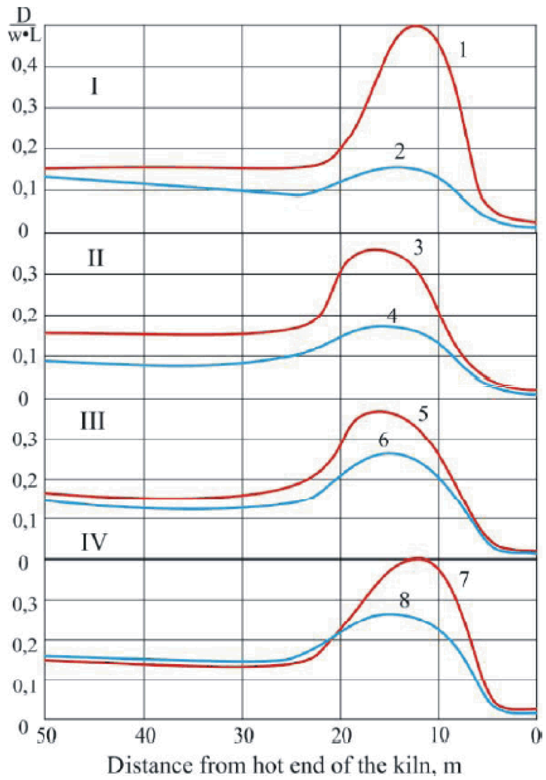

Fig. 4: Intensity of axial mixing fuel gas flow rate when the emission angle of the coal-air mixture (I), rarefaction at the cold end of the kiln (II), the temperature change of the secondary air (III) and disabling dust-back and the optimum mode.1 – 80 m/s; 2 – 50 m/s; 3 – 1,3 kPa; [alpha] = 1,3; 4 – 0,75 kPa; [alpha] = 1,03; 5 – 450°C; 6 – 660°C; 7 – dust-back disable; 8 – close ignition

The Nozzle Position and Direction of the Flame: Adjusting the length of the flame can alsobe provided by changing the nozzle position. The nozzle is recommended to install below the axis of the furnace, to shift it to the side of the material by 0.05-0.1 diameter of the furnace and be sure to tilt downward at an angle of 1-3%. The closer to the clinker is flame, the more difficult the access of oxygen to fuel and the longer the flame is.

The Cumulative Effect of Individual Factors on the Combustion of Fuel: It is natural that all of the above factors are interrelated and can not be considered in isolation from each other. The most important influence on the burning rate has pre-mixing of fuel and air prior to its ignition, which is greatly determined by the removal from the flame nozzle. The farther into the furnace fuel comes, the more it is premixed with air prior to ignition and consequently, the combustion zone is shorter. The amount that is supplied to the nozzle should be taken as the primary air as well as a share of the secondary air which has entered into the fuel-air mixture before ignite. Thus, in the kiln 5 m in diameter by removing the flame from the nozzle 6-7 m coal sprayed to the kiln walls and, consequently, all of the secondary air switches into the primary. Under such conditions, the flame for flash point becomes transparent blue with low emissivity and high temperature. In this case local overheating and low resistance of lining are observed. By decreasing the quantity and velocity of the primary air, rarefaction for kilnedgesor increasing of fineness of grinding, temperature of the secondary air and the volatile content in the nozzle coal closes to the flame, it becomes yellow and opaque. Visibility in the furnace is deteriorating, that indicates a high degree of blackness of flame. This creates the rational conditions for fuel combustion, providing high quality of clinker, long service lining and low fuel consumption.

Based on the studies, the following principle of the rotary kiln control is suggested, shown in Figure 5. The arrows in the figure shows the effect on the control parameters for shortening or lengthening the flame. Rational flame is determined by the temperature of the kiln body, which is shown on the graph. The main parameter is the location of the maximum temperature, that must be at a distance L_{max} = 12 ± 1 m.

If it is necessary to bring the maximum temperature of the body to a hot edge and reduce the temperature of clinker in the sintering zone, the length of the flame should be increased by reducing speed of the departure of the fuel injector w_b due to changes in the output section of the burner and reduce the share of the primary air.Furthermore, to increase the length of the flame can also by greater tilting of the burner [beta] to a material, decreasing the air excess factor [alpha] and the temperature of the secondary air increases t_{sa} by reducing the number of oscillations n_h, n_c grates of cooler and increasing the clinker layer on them. In those cases when the temperature in sintering zone is lower clinker burning fuel must be intensified by increasing the temperature and reducing the length of the flame. To do this the opposite action should be done, i.e. increasing w_b and [alpha], moving away the flame from the material.

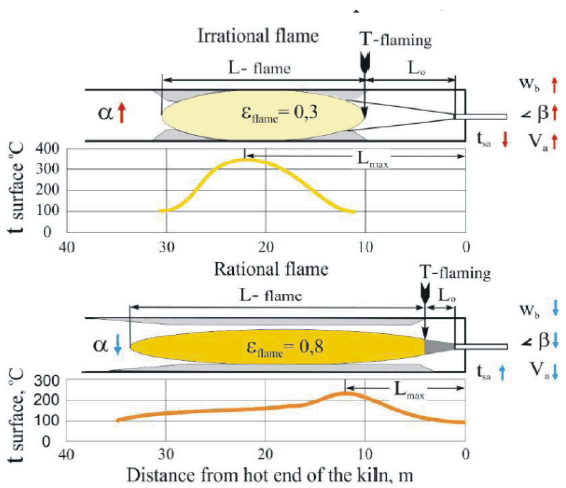

Fig. 5: The principle of the rotary kiln control

CONCLUSION

The system of control rotary cement kiln, based on the use of the location of the maximum temperature at the furnace body and the remoteness of from the point of ignition of the spray nozzles. The optimal settings of these parameters to ensure high quality clinker, fuel economy and increased lining life in the sintering zone.

Findings:

- A method for estimating the intensity of combustion in an industrial rotary kiln with the use of radioactive isotopes, based on the determination of the rate of gas flow and the intensity of the process of diffusion of carbon in the air mixture, characterized by a parameter, which is the reciprocal of the diffusion Peclet number – 1/Pe is developed and implemented.
- Set an important parameter – the position of the maximum temperature of the furnace body in the sintering zone, which for the rotary kilns of more than 120 m at the optimum process of burning of cement clinker shall be at a distance of 12 ± 1 m from the hot edge. Under these conditions of burning high quality clinker, long lining life and reduced fuel consumptionare provided.
- A way to optimize industrial setting cement clinker burning process by controlling the combustion of fuel based on the formation of a rational the flame, as measured by the remoteness offlash point from the nozzle is proposed and implemented in the further ignite the fuel, the combustion rate and the shorter the flame is.
- A method of adjusting the amount of fuel combustion by changing the speed of the departure of fuel-air mixture from the nozzle, the number of primary air, secondary air temperature, air ratio, the position of the nozzle and twist the fuel and air flows is proposed.

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