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Way of Elimination of Dust Emission Through the Unloading End of the Furnace

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Abstract: Justification and the analysis of aerodynamic processes' features in a refrigerator mine. Movement of air dust mixture in the refrigerator of the rotating furnace. Definition of the valid picture of a field and use of mathematical planning of experiments. Way of dust removal from under consolidation. Conditions carrying out experiments for clarification of the valid reasons of carrying out of dust. Dust content on the hot end of the furnace. Design of the dustproof device with injector way of elimination of settling dust. Principle of the dustproof device operation. Jet device (injector) for removal of dust from the sealing device in refrigerator mine. The analysis of operation of the jet device for dust removal. Consolidation with an injector. Optimum conditions for return of dust-air weight from under consolidation back in the refrigerator. General efficiency of this device increases.

Key words: Large-size rotating roasting furnaces, consolidation, operation, dust emission, way, unloading end of the furnace, tightness, refrigerator of the cement furnace, air dust mixture

INTRODUCTION

Prompt growth of industrial and civil engineering in recent years in Russia causes an increasing demand for cement. The increase in cement production is connected with increasing consumption of energy carriers. In average from 170 up to 200 kg of conditional fuel is spent for production of one ton of clinker. Considering that the cement rotating furnace is the main consumer of fuel and is not the subject to replacement in the next years, therefore, reduction of fuel consumption can be reached by heat preservation at technological process (Mednikov, 1965). Owing to the design, the rotating furnace has big gaps on loading and unloading parts, through which the external air is sucked.

The air arriving on the hot end is necessary to warm up to the temperature of the gases arriving from the grid-iron refrigerator and the air arriving on the loading end is drained by the smoke exhauster, reducing the recharge. Therefore, it is necessary to install more powerful smoke exhausters. In another case, it is necessary to install reliable sealing devices preventing suction of air. Fight against dusting is one of burning issues in many industries. There are various ways and devices for fighting against dusting for example use of an irrigation of the raising dust weight by water, application of nozzles, creation of air veils, application of mechanical consolidations, labyrinth, aerodynamic and others (Lavrentev and Shabat, 1977). However, efficiency of these devices in fight against dusting is very low, especially at a dry way of cement production.

The existing dustproof devices on the hot and cold ends of cement furnaces do not possess sufficient efficiency for fighting against dusting and reliability. It leads to that through a furnace head a significant amount of dust gets into the environment and the devices should be often replaced because of their deterioration (Fedorenko, 2007a).

THE MAIN PART

The sealing device on the hot end of the furnace is intended not only for prevention of external air suction but also for prevention of emission of dust which gets from the refrigerator to the mine and through low-quality consolidations in the atmosphere. The greatest number of dust is emitted out at the process of cement production by dry way.

To check the aerodynamic hypothesis of carrying out of dust, concentration of dust, dispersion of parts, temperature and pressure of the air and dust stream were investigated. It was established that an excessive pressure occurs instead of the discharge in the head of the furnace.

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For optimization of the refrigerator of the cement furnace operation and decrease in energy consumption in the course of its operation, the idea of movement of dust air mixture is necessary. However, the problem of diagrams drawing of the movement speed of firm and gas phases is complicated by influence (Fig. 1) on the main stream (from the source 1 to the drain 2) of various collateral streams (in particular, convective ones) of borders existence of difficult configuration and also of the material stream 3. Compliance of areas at comfortable display is given in Fig. 2.

It is known that energy consumption on transport of dust ΔW is calculated on a formula (Povh, 1969):

$$\Delta W = \sum_{i=1}^{n} \int_{Li} (\Phi_{ki} dx + \Phi_{yi} dy + \Phi_{zi} dz) \quad (1)$$

Where:

$$\Phi_{xi} = m_i \frac{d^2x}{d\tau^2} = -F_i \cos\theta_i + \Pi_i \cos\theta_i$$
$$\Phi_{yi} = m_i \frac{d^2y}{d\tau^2} = -F_i \sin\theta_i + \Pi_i \cos\theta_i \quad (2)$$

$$\Phi_{zi} = m_i \frac{d^2z}{d\tau^2} = Q_i - t_i^2 m_i \left(u - \frac{dz}{dr}\right)^2 + \Pi_i z \quad (3)$$

Where:

- L = Trajectory of a separate particle movement
- Φ_x, Φ_y, Φ_z = Pojections on coordinates axes of the total force operating on a particle
- m_i = Particle mass
- τ = Time
- Q_i = Carrying-away force
- $t_i^2 m(u\text{-}dz/dr)^2$ = Resistance force
- θ = Corner between the direction of a speed vector concerning movement and the stream direction
- u = Flow speed
- Π_i = Carrying power (force of aerodynamic passing which occurs as a result of nonlinear profile of speeds and of uneven particle flow)
- h = Number of particles
- t_i = Coefficient

In some cases the system of the differential Eq. 2 is integrated and calculation of energy consumption for a Eq. 1 is possible if to include a trajectory of particles' movement L_i. It is necessary to notice that equally effective of all forces Π_i in the case is directed to the periphery (a lateral wall) of the refrigerator.

Besides, in the wall area 4 (Fig. 1) the speed of movement of gas is reduced and if to consider also forces of adhesion between the wall and the particles, the phenomenon of sticking of a firm phase on refrigerator walls becomes clear. On the other hand, the developed turbulence of a gas stream interferes with dust congestion on the walls. There is an optimum thickness of a layer of the wall dust, corresponding to dynamic balance at which

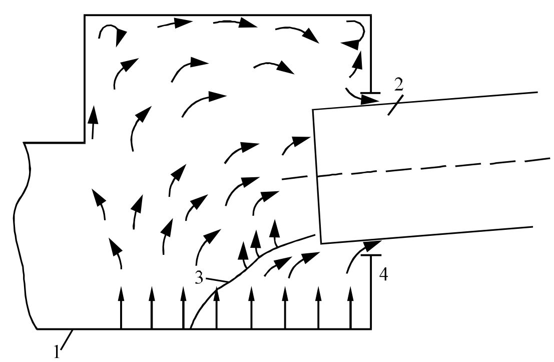

Fig. 1: The scheme of movement of air dust mixture in the refrigerator of the rotating furnace

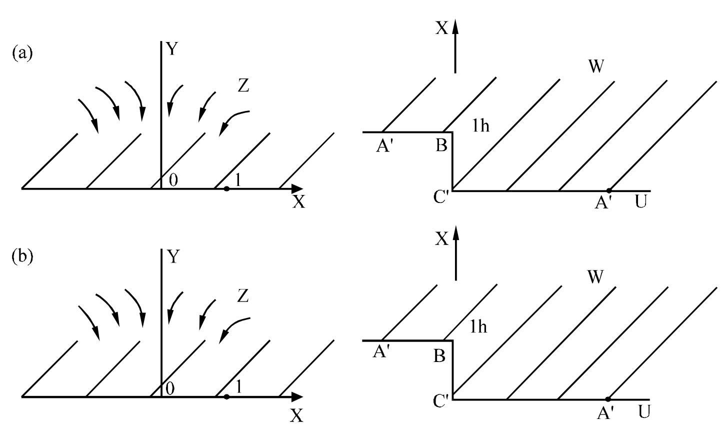

Fig. 2: Compliance of areas at comfortable display

the quantity of a dust carried away by a stream is equal to the quantity of the dust settling on a wall at a unit of time. This thickness is insignificant (by approximate calculations for lateral walls it doesn't exceed half of an inside logarithmic layer (Povh, 1969)).

Nevertheless because of the big area of the general surface of walls of the refrigerator, the quantity of the settled dust can be considerable and it should be considered. The developed turbulence and as a result, local pressure differences are one of the reasons of a slot-hole dust allocation. Elimination of dust sticking on machines of the refrigerator and the subsequent involvement of dust into the main stream will reduce losses of a material and will increase overall performance of the refrigerator. It is possible to reach it by surface vibration by means of sound or ultrasound. Ultrasonic and sound waves will promote also to coagulation of particles (Mednikov, 1965) and to removal them from refrigerator volume, thus the slot-hole dust reduce will decrease.

Corners (Mednikov, 1965) at which flow the swirled zones are created with increasing have essential impact on the structure of a stream of dust air mixture. The corner can be presented in the form of set of vertical and bottom walls. As a result of force of adhesion with a vertical wall and friction forces at the bottom wall, the swirled zone tends to pulling in horizontal direction. At achievement of some critical size the vortex zone breaks from a wall and is carried away by a stream.

After that near the vertex of the corner the new vortex zone is formed which grows to the critical size and breaks again, etc., (Lavrentev and Shabat, 1977). As a result there is dust accumulation in coal and its quantity has to have a cyclic character. Approximate calculations for formulas (Lavrentev and Shabat, 1977) confirmed the raised congestion of dust in corners (about 8% of all dust containing in the refrigerator are constantly in its corners). For fighting against this phenomenon it is necessary to smooth things over having formed the lines with equations which can be received from the source (Samul, 1982). If to take as current lines a circle arch with the central corner not less than $\pi/4$, it is possible to reach satisfactory decrease in the corner effect of dust accumulation.

The ledge of the furnace coming at an angle into the refrigerator and slanting jet blow of a material 3 (Fig. 1) at the platitude 4 have dominating impact on the structure of a stream of dust air mixture. For the simplest approximation of this influence it is possible to use the device of conformal displays (Korn and Korn, 1977). In the first case, we will make display of the top half-plane $j_m z>0$ (Fig. 2a) on the figure W presented in Fig. 2 where the corner CBA schematically represents a furnace ledge, BC is an aspiration opening in the platitude Z. Function of conformal display in this case (Korn and Korn, 1977) is:

$$W = \frac{h}{\pi}\left[(\Pi z^2\text{-}1)^{\frac{1}{2}} + A_c chZ\right]$$

The carried-out calculations (as a first approximation) showed that for normalization of structure of a stream, the furnace ledge has to be on >0.4 m from the refrigerator arch. Instead of the vertical refrigerator shift it is possible to truncate the furnace ledge and to reach the same effect.

At existence of a slanting jet blow of the material 3 (Fig. 1) at the platitude 4 there can be an intensive current of a firm phase which can approximately be described by means of classical model of the slanting blow presented in the literature (Lavrentev and Shabat, 1977). It is possible to show that the ascending dust-air stream is stratified and more heavy traffic of a dust happens in the direction specified in Fig. 1.

According to the offered hypothesis it is necessary to establish existence of an electrostatic field round trailer part of the case of the furnace. For confirmation of physical and mathematical calculations and establishment of the valid picture of a field, it is necessary to define characteristic points in which it is necessary to make potential measurement. According to predesigns, the size of potential of dust reaches the maximum size in the plane of an end face and decreases in the axial direction along the furnace case. Therefore, we take the first point of measurement of potential in the planes of an end face of the furnace at distance of 200 mm from a surface of the furnace (Fig. 3). The following measurements are made in the point lying on the same radius and in the same face plane but located on 20 mm closer to the furnace axis. The following measurements are made similarly but 20 mm

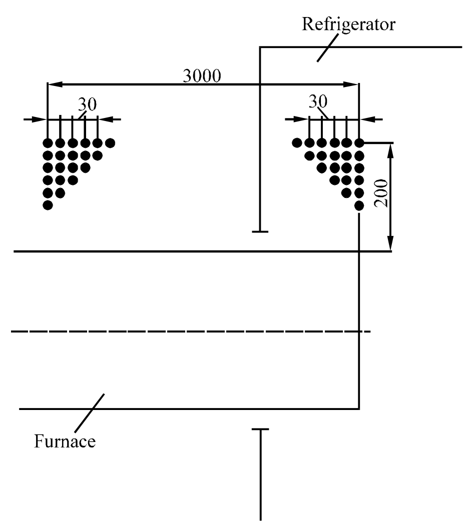

Fig. 3: Scheme of measurement of potentials of electrostatic field

closer to the furnace axis. And so on to the surface of the furnace case. The following radius on which the measured points will be placed has to be parallel to the previous one and to be remote from it on a furnace axis towards the other end at 30 mm. On this radius, the control points are settled down similar to the first radius; i.e., the first point of this radius is at distance 200 mm from the surface of the furnace case. Each following point of this radius has to lie 20 mm closer to the furnace case.

The following radius and the point in it are settled down similarly to the previous one only at 30 mm farther on a furnace axis towards the other end. Extreme or last radius on which it will be necessary to make measurements of size of potential in extreme points has to be at distance of 3000 mm from a furnace end.

Definition of the valid picture of a field and use of mathematical planning of experiments allows choosing the number and conditions carrying out experiments for clarification of the valid reasons of carrying out of dust.

For confirmation of partial or full justice of this hypothesis a number of measurements is carried out. These measurements gave a full and real picture of the aerodynamic processes which are taking place in the furnace. It forms a basis for mathematical planning of the experiment. According to the made hypothesis the following physical characteristics of air-dust stream have been measured in several characteristic points: concentration of dust, dispersion of parts of stream, temperature and pressure. The arrangement of characteristic points is given in Fig. 4.

Using the obtained data, the real mathematical model of occurring aerodynamic process was created and mathematical planning of experiment and research was carried out.

It is established that generally carrying out of dust happens in a gap between the head of the furnace and the feedwell. As a result of researches of the dust stream leaving the gap on the hot end of the furnace, its following features have been noted:

- Uniform distribution on the forming furnace
- Lack of sticking or subsidence on the furnace feedwell, i.e., existence of a constant gap with a furnace surface
- Constant speed
- Various concentration of dust on thickness (in the direction normal to a furnace axis), i.e., stream consists of several dust layers of various concentration and the greatest concentration in the first layer from the furnace

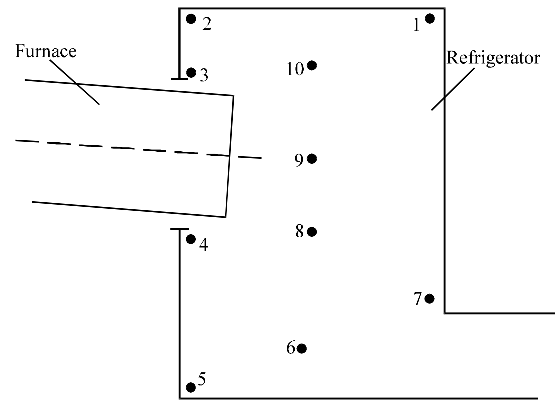

Fig. 4: Scheme of arrangement of control points of aerodynamic process

Excessive pressure appears owing to ”locking” of the section of the furnace. This effect is shown at loss of ability of smoke exhausters to release oven gases in necessary quantity into the atmosphere because of arising pressure differences on all gas channel the refrigerator pipe, connected with various phenomena in the units which are settled on a way of the gas stream. In this case the part of gases with dust jumps out through a gap of the furnace case (refrigerator mine) (Fedorenko, 2007a).

In Fig. 5 two furnaces of Pervomaysky plant are shown. On the furnace 1 there is no sealing device. Ttherefore, there is emission of dust which settles in surrounding space 2. On the second furnace 3 (Fig. 5) consolidation is established, it doesn't prevent dust hit in the atmosphere. In this case, the dust remains in the sealing device and is poured down. Therefore at a large number of the settled dust consolidation is deformed (Fedorenko, 2012).

A large number of dust settles under the furnace (Fig. 6) and it is usually taken out weekly by motor transport in order not to stir operation of the furnace.

The sealing device is developed for elimination of such phenomenon with injector way of elimination of settling dust (Fig. 7).

Preliminary researches and the analysis showed that for removal of brick dust it is possible to use the principle of injection (Fedorenko *et al.*, 2013). As the dust bulk leaves the head of the furnace through a gap between a forward wall of the refrigerator mine and the furnace case, we can receive a certain volume of space where the greatest concentration of dust is observed under the consolidation. Applying the principle of injection, we return all this dusty weight into the refrigerator by means of air stream of sharp blasting.

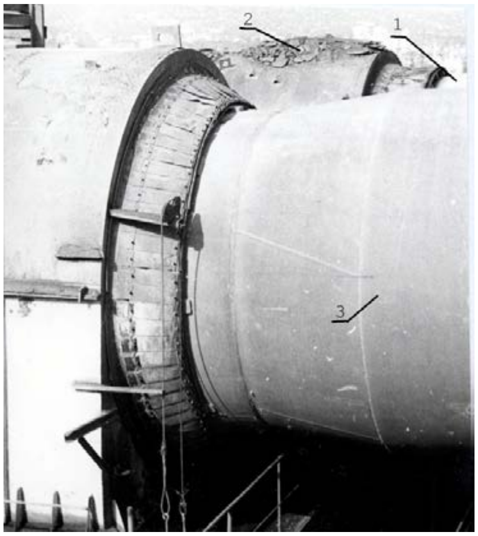

Fig. 5: Furnace of the plant "Pervomaysky"

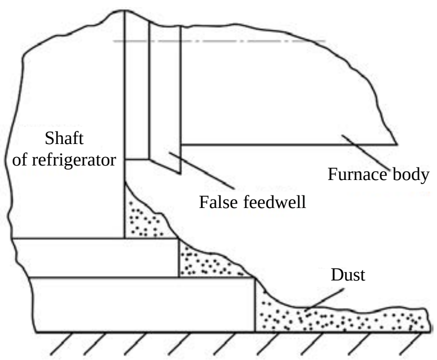

Fig. 6: Dust content on the hot end of the furnace

The design of the dustproof device represents the truncated cone collected from separate elements (Fedorenko and Bondarenko, 2008). The bigger basis of this cone 1 fastens not movably by means of welding to the wall of refrigerator mine and the smaller basis lies on the case of the furnace (Fig. 7).

As the main part of the dustproof device is the basic element 2 consisting of a bead, a combined lobe and a compensating plate 9 which are fixed among themselves by means of special bolts.

The combined lobe consists of a lobe and a slip connected by contact welding. At connection of an element with another one, the lobe of one of them enters the groove formed by a lobe and an overlay of another one. That provides tightness of the device. The basic element 2 of the compensating plate 9 is fixed to the big basis of a cone 1 by means of welding. The basic element contacts to the furnace case by means of the bead 7

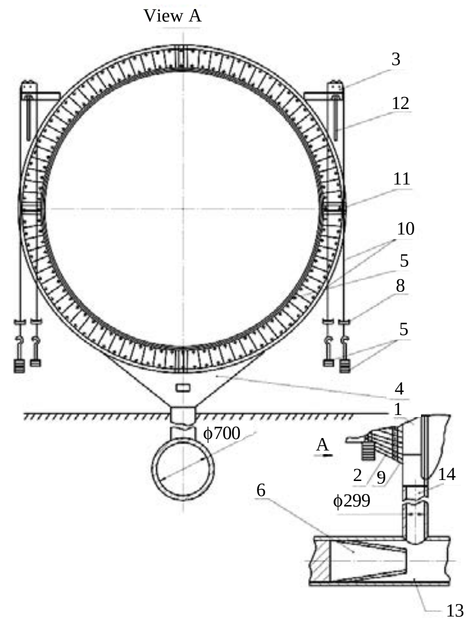

Fig. 7: Design of dustproof device

having wearproof self-greased inserts which increase service term of beads. All beads are pulled together with a cable 10 with diameter 11 mm, passing through a special groove of a bead.

The cable covers all the length of a circle of the furnace and consists of two parts. The top part of beads is pulled together by the top cable in length of 13 m; the bottom part is pulled by the bottom cable in length of 26 m. The tension of cables is made by means of freights 5. The optimum force of tension allows eliminating gaps between the case of the furnace and the ring of the beads. In order to escape turning of the beads' ring on a course of rotation of the furnace and not to deform the lobes it is possible to use stabilizers 11. One end of the stabilizer is connected to the bead by means of bolt and another one is connected to the cone by means of welding. Such stabilizers are established in three places: in the highest point of consolidation and from two lateral faces where there is a joining of the top and the bottom cables. As in the gap between the case of the furnace and a wall of the refrigerator there is a high temperature, the lobe was made of the zinced iron which is capable to keep the properties at temperatures of 5000°C and more.

For elimination of the settled dust in the lower part of the dustproof device there is an injector 4. The main function of the injector is creation of exhaustion in the zone under the lobes to make the dust extended into the injector and com into the refrigerator through the system of sharp blasting. The main part of the injector is the nozzle 6 which is built in a pipe of sharp blasting.

The stream of air accelerated by the nozzle creates depression in the volume of the pipe surrounding the nozzle (compartment 13). The pipe 14 is built in the compartment. The pipe is connected to the bunker by the other end.

The bunker serves as a transitional zone from the lower part of consolidation in the pipeline of sharp blasting. The dust under the influence of the created exhaustion from under consolidation gets to system of sharp blasting and further into the refrigerator. It partially settles there, partially coagulates and partially arrives again into the consolidation zone. Thus, the part of air-dust weight participates in the closed circulation, preventing dust emissions outside.

For the purpose of cooling of the furnace hot end at Pervomaysky plant it is possible to apply false feedwells 8 (Fig. 8) which are fixed on the hot end of the furnace with a gap to the furnace case. The air cooling the hot end of the furnace case gets to this gap from the system of sharp blasting. Taking into account the positive effect of cooling of the hot end, the dustproof device is mounted on the false feedwell which should be extended. Under the injector nozzle in the reception camera there is a hatch for removal of dust during the stop of the furnace work.

The first dustproof device is mounted at Pervomaysky plant PO ''Novorostsemen''. As a result of dusting of the hot end of the furnace, productivity of the furnace increased (Fig. 9).

By production of a clinker in dry and wet ways, a large number of dust comes into the furnace from the refrigerator. The dust is formed at clinker cooling and the dust arrives in the refrigerator together with the clinker from the furnace. Then the dust comes back to the furnace due to the sharp blasting and the exhausting in the furnace.

Through, the gap between the furnace case and the refrigerator mine, under adverse conditions of technological process, the dust is released into the atmosphere. If there is consolidation, it settles in it and deforms the consolidation.

For prevention of this phenomenon between the consolidation and the refrigerator there can be the jet device (injector) for removal of dust from the sealing device in refrigerator mine.

The dust which is placed in a suspension, gets under the sealing device and settles in its lower part, then it gets to te bunker and later on a soaking-up branch pipe in the reception camera of the jet device (injector) in which the compressed air is moved. The air stream creates exhausting in the reception camera, takes the dust and via the mixing camera it returns the dust into the refrigerator mine. The settled dust in the reception camera is removed via a special hatch.

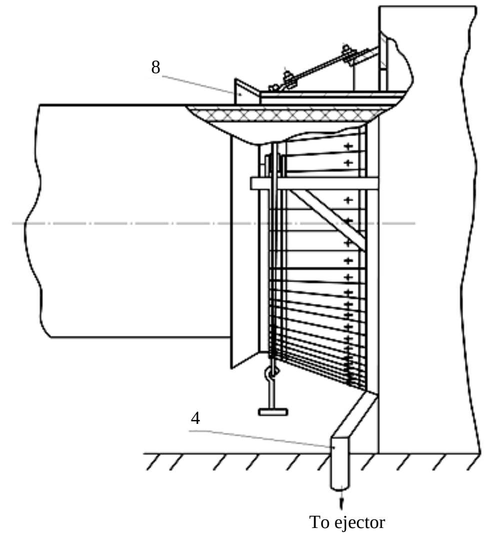

Fig. 8: Dustproof device

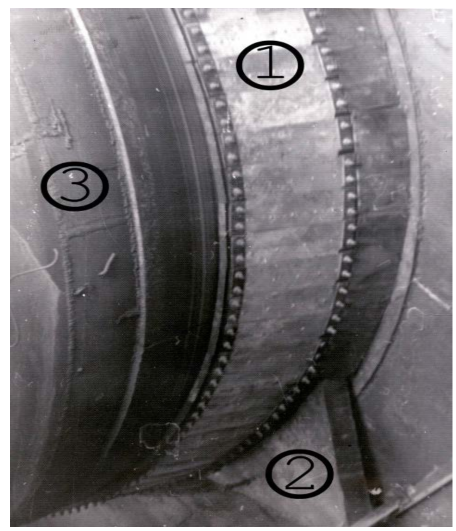

Fig. 9: Consolidation with injector; 1: consolidation; 2: injector bunker; 3: furnace

Calculation of the jet device needs to be made in each case of its application, considering features of dusting, design of the furnace, features of the refrigerator, sharp blasting, etc.

In the device there is a transportation of firm particles in a suspension and therefore, the speed of the gas stream has to exceed the speed of these particles wandering in 1.5-3.0. In each case, depending on the number of Re and the Fedorov's criterion it is possible to calculate the trajectory of particles and the duration of their condition in suspension (Povh, 1969).

Knowing the speed, temperature of the counter flow and the initial speed of the dust and also the diameters of the particles it is possible to determine the range of the flight. It is necessary for determination of length of the mixing camera. Calculation of the camera is made by Starovertov's technique. At calculation it is necessary to consider the volume of the dusty air which is between the mine of the refrigerator and the consolidation. It is necessary for calculation of the air volume, deleted from the mixture of dust in the unit of time L_B. Speed of air stream V_B in the soaking-up network is accepted from requirements to aspiration systems from the condition of sticking prevention. Diameter of a soaking-up branch pipe d_B is determined by the formula of cross section:

$$S_B = \frac{L_B}{v_B}$$

So:

$$d_B = \sqrt{\frac{4S_B}{\pi}}$$

Aerodynamic resistance of soaking-up network ΔP_B is determined by the following formula:

$$\Delta P_B = \sum (R_B l + z)$$

Where:

R_B = Losses of pressure upon friction on one meter in round air ducts
z = Losses of pressure upon local resistance
l_B = Total length of soaking-up branch pipe

$$R = \frac{\lambda v_B^2 \gamma_B}{d_B 2g}$$

Where:

v_B = Stream speed
γ = Volume mass of air
d_B = Biameter of the pipeline
g = Acceleration of gravity
λ = Coefficient of resistance determined by the formula of Alshul:

$$\lambda = 0.11\left(\frac{\kappa_э}{d_B} + \frac{68}{Re}\right) \cdot 0.25$$

Where:

$\kappa_э$ = Absolute equivalent roughness of the surface of air duct from the sheet steel
d_B = Biameter of air duct
Re = Reynolds's value for air

Let's discover coefficient of resistance and further loss on friction. Further, we define pressure losses in local resistance:

$$z_B = \sum \zeta \left(\frac{v_B^2 \gamma}{2g}\right)$$

where, $\Sigma\xi = \xi_1+\xi_2+\xi_3$ the sum of resistance coefficients on the site settlement of air duct.

According to the air duct scheme, there are three sites where pressure in the stream will decrease. Further, we can define resistance of a soaking-up chain:

$$\Delta P_B = (R_B + l_B + z_B)$$

Then it is possible to make calculation of pressure head part of the jet device. A fan of sharp blasting serves as pressure head part of the jet device. The working volume of the given air is accepted at the fan productivity.

We determine the area of cross section of an exhaust outlet, speed of the air stream, resistance of pressure head part of the jet device and loss of pressure upon local resistance. Having substituted the values of sizes, we will receive resistance of pressure head part.

We accept density of air as a constant and determine the mass of the deleted air, the mass of air of the jet device and the further mass of the displaced air deleted by the jet device.

We define the relation of cross section areas of a mixing site and a nozzle, dynamic pressure of a stream of the jet device, pressure of the jet device of air before a nozzle, the speed of the expiration of air from a nozzle of the jet device, the area and diameter of output section of a nozzle of the jet device, the area of section and diameter of a cylindrical mixing site, air speed at the end of a mixing site, distance from a nozzle cut to a place of contact of the stream with a wall of cylindrical part, length of a mixing site from a place of the stream entrance in mine of the refrigerator and distance from a nozzle cut prior to the beginning of the mixing camera.

This calculation will allow creating optimum conditions for return of dust-air weight from under consolidation back in the refrigerator. As the jet device is built in the gas flue of sharp blasting, the dust-air weight sucked away by the jet device can increase the air temperature of sharp blasting. On the basis of calculation it is possible to draw a conclusion that temperature increase of sharp blasting is insignificant and it can be neglected.

Operation of lobe consolidation and the carried-out measurements show that air temperature under the lobes is +650°C. The average temperature of sharp blasting in a year is +200C.

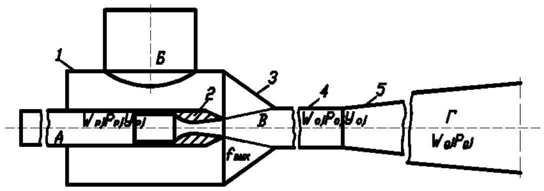

Fig. 10: Scheme of the jet device; 1: reception camera; 2: working nozzle; 3: entrance site of the camera; 4: mixture camera; 5: diffuser; a: working environment; b: the induced environment; B: free stream; Г: mixed stream

Using the equations of thermal balance, it is possible to determine the air temperature of the sharp blasting arriving into the head of the furnace. Amount of heat in the air stream is:

$$Q = L \cdot c \cdot t$$

Where:

L = Consumption of air
c = Specific heat of air
t = Air temperature

Taking into account that:

$$Q_3 = Q_1 + Q_2$$

Where:

Q_3 = Amount of heat of mixed stream
Q_1 = Amount of heat of the induced air
Q_2 = Amount of heat of the induced air

Then:

$$L_3 \cdot c \cdot t_3 = L_1 \cdot c \cdot t_1 + L_2 \cdot c \cdot t_2$$

Then the temperature of the mixed air is:

$$t_3 = \frac{L_1 t_1 + L_2 t_2}{L_3}$$

Where:

L_1 = Expenditure of induced air
L_2 = Expenditure of induced air
L_3 = Expenditure of mixed air
t_1 = Temperature of induced air
t_2 = Temperature of induced air

For increase in productivity of the jet device it is possible to install the diffuser at the exit of the displaced stream (Fig. 10) in this case the general efficiency of this device increases.

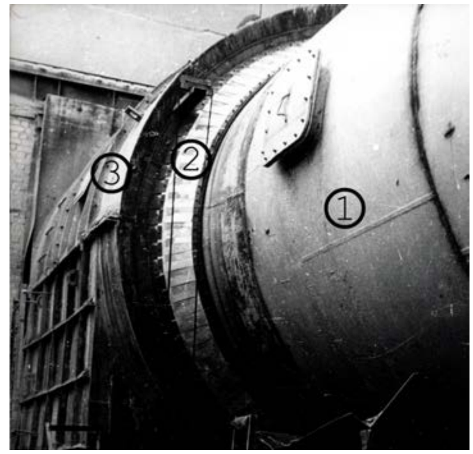

Fig. 11: Sealing (consolidation) of furnace; 1: furnace; 2: sealing; 3: refregirator

Diffuser installation at the exit of the mixed stream sharply increases the general efficiency of the jet device.

In Fig. 11 you can see the furnace of cement works of Bryansk with the new sealing device.

FINDINGS

For the purpose of prevention of air suction and dust emission on the hot and cold ends of the furnace, on the basis of the researches of these processes, we have developed and introduced the sealing devices of lobe type at a number of enterprises (Fedorenko, 2007b, c).

Features of such design of the lobe consolidations allow it to keep working capacity for a long time, to prevent suction of air and dust emissions (Aulov *et al*., 2011; Fedorenko *et al*., 2012; Sanina, 2011).

CONCLUSION

The new design corresponds to the requirements imposed to it and possesses the following features distinguishing it from the existing consolidations:

- The contact surface of consolidation with the case of the furnace has small weight and consists of sectors which are easily replaced if necessary
- The case of consolidation consists their separate independent elements which are easily replaced in use
- Elements of the case provide flexibility and mobility of consolidation at longitudinal and cross movements of the furnace
- Connections of elements of consolidation provide prevention of suction of air and dust emission

- The contact surface of consolidation is drawn in to the furnace case by means of suspended freights and the effort of contraction can be regulated
- At emergence of big excessive pressure, consolidation occurs under the influence of this pressure
- Dust, settling in conic part of consolidation is removed by means of injector installation back in the refrigerator

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