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Neighborhood model for the ventilation system in the industrial premises

[1]Anatoliy Shmyrin, [2]Valeriya Semina and [3]Valery Kavygin

Department of Mathematics, Lipetsk State Technical University, Lipetsk, 398055, Russia.
[1,2,3]Orcid: 0000-0001-8454-6032, 0000-0001-8421-2569, 0000-0002-2814-428X

Abstract

The questions of the neighborhood modeling of the ventilation system in the premises of the cement production shop are considered. The proposed measures allow for purification of fresh air, remove excess heat, moisture, dust, harmful gases and vapors entering the air of workspaces and the atmosphere.

Keywords: neighborhood systems, ventilation system, complex systems.

INTRODUCTION

In the production of cement, there is a problem of exceeding the allowable concentration of dust in the shop and in the environment, associated with a non-optimal operation of the dust-free ventilation system in the clinker burning department.

The optimally organized ventilation system ensures the microclimate of the production premises, corresponding to the sanitary norms and rules, which contributes to the increase of the staff's efficiency.

The optimal operating modes of the industrial ventilation system associated with the technological process allow solving energy saving issues in the ventilation section and the maximum productivity of rotary cement kilns.

STRUCTURAL MODEL OF THE CLINKER BURNING DEPARTMENT.

Cement production is a system with a complex structure, which includes departments (nodes): "Primary processing of raw materials", "Grinding of raw materials", "Roasting and air purification system", "Clinker milling", "Cement shipment". Each node is also a complex system.

The dust extraction system is present at all stages of production, as dust is released during the processes of crushing, grinding lime and coal, when unloading the furnace, during subsequent transportation and crushing of cement, its shipment. The three main sources of dust emissions from the chimney are the kiln, clinker cooler and cement mills.

The technological block diagram of the air ventilation system in the roasting shop is shown in Fig. 1

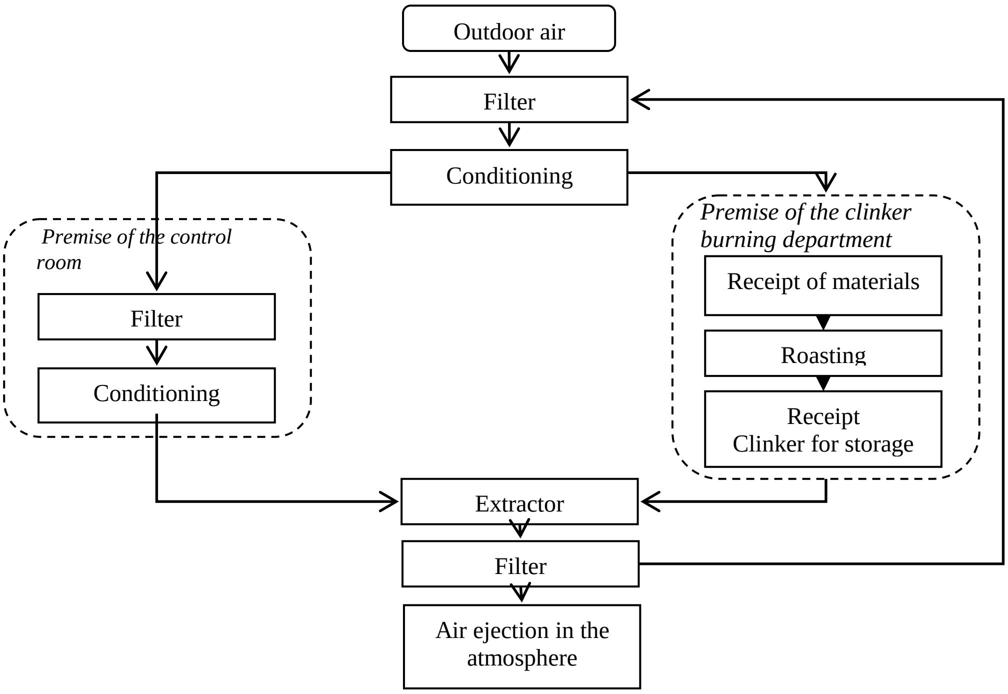

Figure 1: Block diagram of the air ventilation system in the firing department

We construct a neighborhood model [1-2, 7-8] of node 3, "Roasting and air purification system" consisting of subsystems 1 (Roasting) and 2 (Air purification system), shown in Fig. 2.

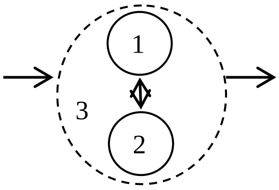

Figure 2: Enlarged diagram of the node "Roasting and air purification system"

In compartment 1 there are three rotary cement kilns, a clinker warehouse, as well as a control panel for a rotary kiln, on which the operator-type works are carried out. At the same time, the greatest amount of cement dust is released from the drying zones, calcination and exothermic reactions. Clinker dust is also formed at the end of the sintering and cooling zones.

The air ventilation system should also address the issues of reducing heat losses from the rotary cement kiln head and normalizing the air humidity.

Let's imagine a ventilation system in the form of a neighborhood system, including nodes (Figure 3): "4-Input", "5-Filter1", "6-Conditioning1", "7- Filter2", "8-Conditioning2", "9- Control panel premise"," 10-Extractor "," 11-Filter3 "," 12-Ejection".

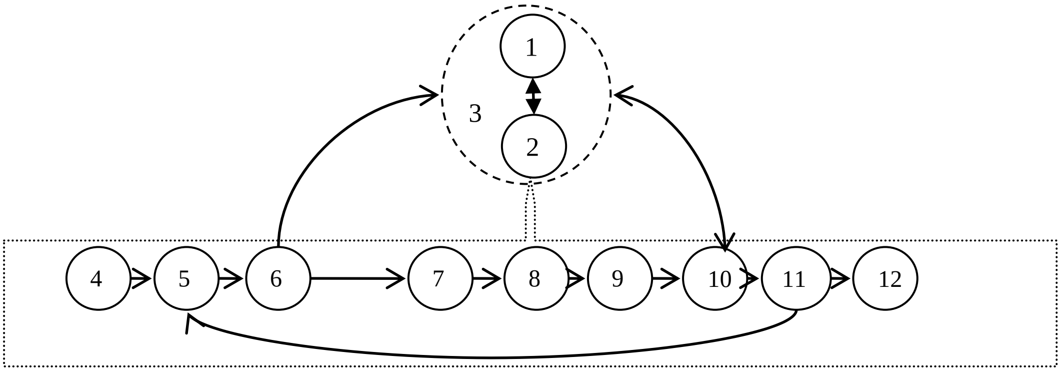

Figure 3: Detailed scheme of the node "Roasting and air purification system"

Figure 3 shows a ventilation system as a hierarchically subordinate subsystem, located in the enlarged schema node 2.

The node 4 supplies external air to the room, then the air is cleared of dust in the node 5, brought to the desired temperature and humidity in the node 6. Since the requirements for the air environment in the control room are more stringent than in the workshop room, the air must be further processed (node 7, 8) to achieve the necessary parameters of the microclimate. Then the prepared air enters the room of the control panel (node 9) and in the workshop (node 3), from which it is removed by exhaust ventilation node 10. Then it passes filtration (node 11) and is recycled to the atmosphere (node 12). In order to save energy, air recirculation is carried out - the transfer of part of the air flow after the filters to the node 5. In addition, one must take into account the dust and heat entering the shop from the rotary kiln.

MATHEMATICAL MODEL OF VENTILATION SYSTEM

The neighborhood system of the node "Roasting and air purification system" has the form:

$$X(1) = F_1(X(1), X(2)),$$
$$X(2) = F_2(X(1), X(2)),$$

where the second (vector) equation describing the hierarchically subordinated ventilation system in the detailed record has the form:

$$\begin{aligned}
&X(3) = F_3(X(3), X(10), U(3), U(10)),\\
&X(4) = F_4(X(1), X(2)),\\
&X(5) = F_5(X(5), X(6)),\\
&X(6) = F_6(X(3), X(6), X(7), U(3)),\\
&X(7) = F_7(X(7), X(8)),\\
&X(8) = F_8(X(7), X(8)),\\
&X(9) = F_9(X(9), X(10), U(9)),\\
&X(10) = F_{10}(X(3), X(10), X(11), U(10), U(11)),\\
&X(11) = F_{11}(X(5), X(11), X(12), U(11)),\\
&X(12) = F_{12}(X(12)).
\end{aligned}$$

We describe the state and control in the nodes of the ventilation system:

$X_1(1)$ – surface temperature of the rotary kiln, $^\circ C$; $X_2(1)$ – concentration of dust from the furnace in the air of the working area, mg/m^3;

$X_1(3)$ – air temperature in the working area, $^\circ C$; $X_2(3)$ – temperature gradient over the height of the room, $^\circ C$/m; $X_3(3)$ – air mobility, m/s; $X_4(3)$ – moisture content of air in the working area, g/kg; $U_1(3)$ – current consumption of supply air, m/s^2; $U_2(3)$ – current speed of the electric drive of the fan, rpm;

$X_1(4)$ – outdoor temperature, $^\circ C$; $X_2(4)$ – density of fresh air supply, kg/m^3; $X_3(4)$ – dust concentration in outside air, mg/m^3;

$X(5)$ – concentration of dust in the incoming air, mg/m^3;

$X_1(6)$ – supply air temperature, $^\circ C$; $X_2(6)$ – moisture content of supply air, g/kg;

$X(7)$ – dust concentration in the incoming air, mg/m^3;

$X_1(8)$ – supply air temperature, $^\circ C$; $X_2(8)$ – moisture content of supply air, g/kg;

$X_1(9)$ – the number of people, pieces; $X_2(9)$ – temperature in the working area, $^\circ C$; $X_3(9)$ – moisture content of air in the working area, g/kg; $X_4(9)$ – temperature gradient over the height of the room, $^\circ C$/m; $X_5(9)$ – air mobility, m/s; $U_1(9)$ – current consumption of supply air, m/s^2; $U_2(9)$ – current speed of the electric drive of the fan, rpm;

$X_1(10)$ – concentration of dust in the removed air, mg/m^3; $X_2(10)$ – moisture content of the extracted air, g/kg; $X_3(10)$ – temperature of the extracted air, $^\circ C$; $U_1(10)$ – current consumption of the removed air, m/s^2; $U_2(10)$ – current speed of the electric drive of the fan, rpm;

$X(11)$ – concentration of dust in the removed air, mg / m^3; $U(11)$ – current speed of the electric drive of the fan, rpm;

$X(12)$ – concentration of dust in the recycled air, mg / m^3.

The volume of supply air to the room, in particular, is regulated by a smooth change in the speed of the electric drives of the fans by means of frequency regulation, which helps to save the energy spent on the preparation and distribution of air.

To identify the model, we use regression methods of parametric identification and, in addition, the following regulatory relationships.

It is known that the required speed of the electric drive, depending on the required amount of supply air [4]:

$$U_2(i) = \frac{U_1(i) \cdot \omega_i}{L_i},\ i = 3, 9,$$

where L_i – nominal flow of supply air, m / s^2; ω_i – rated speed of the electric drive of the fan, rpm. The nominal characteristics of the fan are indicated in its passport.

As in the production room heat and harmful substances are released simultaneously, for the amount of supply air to the control panel $U_1(9)$, in the shop $U_1(3)$, it is necessary to take the larger of the production emissions calculated for each type:

$$U_1 = \max\left(U_1^1,\ U_1^2, U_1^3\right),$$

where U_1^1 - the required supply air flow for removal of the heat excess, U_1^2 - the required supply air flow for dust removal, U_1^3 - the air flow, determined by the standardized air exchange rate.

The received value U_1 must be checked for compliance with the sanitary and hygienic norms for supplying outdoor air to the room.

Calculation of the required flow rate of fresh air for removal of heat is made according to the formula [5]:

$$U_1^1 = \frac{\sum Q_{изб} \cdot 3{,}6}{X_1(4)(X_3(10) - X_2(4))c},\ \text{m}^3/\text{h},$$

where $X_3(10)$ – the temperature of the extracted air, $^\circ C$; $X_1(4)$ – supply air temperature, $^\circ C$; $X_2(4)$ – density of fresh air supply, kg / m^3; c – specific heat of air kJ /(m$^3\,^\circ C$).

The temperature of the exhaust air is calculated by the formula:

$$X_3(10) = X_2(3) + X_4(3) \cdot (h - h_{p.з.}),$$

where $X_2(3)$ – the temperature in the working area, $^\circ C$; $X_4(3)$ – temperature gradient over the height of the room, $^\circ C$/m; h – distance from the floor to the center of the exhaust openings, м; $h_{р.з.}$ – working area height, m.

Excess heat is calculated as follows [6]:

$$\sum Q_{изб} = Q_1 + Q_2 + Q_3 .$$

Heat input from lighting:

$$Q_1 = F \cdot E \cdot q \cdot \eta ,$$

where F – the floor area of the room, м^2; E – specific illumination, lx; q – coefficient of specific heat dissipation W/(m^{2}lux); η – the proportion of heat delivered to the room.

Heat input from people indoors:

$$Q_2 = q_я \cdot X_1(9) ,$$

where $q_я$ – the amount of heat released by a person, W; $X_1(9)$- the number of people.

Heat input from cement kiln:

$$Q_3 = \alpha \cdot F(X_1(2) - X_2(3)) ,$$

where α – heat transfer coefficient, W/(m^2 $^\circ C$); F – surface area of the furnace, м^2; $X_1(2)$ – the temperature of the furnace surface, $^\circ C$.

Air exchange with the allocation of cement dust in the room is calculated as follows:

$$U_1^2 = \frac{G}{z - X(7)} \text{ , m}^3\text{/h,}$$

where G – the mass flow rate of dust, g / h, z – the permissible volume concentration of dust in the room air, g / m^3.

The air flow, determined from the normalized air exchange rate, is expressed by the formula:

$$U_1^3 = K \cdot V \text{ , m}^3\text{/h,}$$

where K – coefficient of air exchange rate, h^{-1}; V – the volume of the room, m^3.

As a result of the neighborhood modeling, we obtain a complex system consisting of two components.

Due to the hierarchical structure of the aggregated model, the output values of higher-level models are used as parameters of lower-level models. The output of node 1 is the arrival of clinker dust and heat input from the rotary kiln. In this consideration of the system, the task is to identify the models of a complex system under the conditions of parametric coupling of models.

Based on the proposed model, it is planned to create an automatic climate control system, which operates using a programmable logic controller (PLC) [3]. The parameters of the air environment outside and inside the room are measured with the help of sensors, they act as input signals to a mathematical model implemented in the PLC programming language, then data analysis is performed, and an optimal automatic control algorithm is implemented [3].

To assess the effectiveness of the joint work of offices 1 and 2 (Figure 2), you can apply the criterion:

$$K = \frac{1}{K_1} + K_2 + K_3 \to \min ,$$

where $K_1 = \frac{K_1^p}{K_1^f}$ - the capacity of the furnace, $K_2 = \frac{K_2^f}{K_2^p}$ - the amount of energy consumed by the ventilation system, $K_3 = \frac{K_3^f}{K_3^p}$ - the volume of cement dust emissions, K^f и K^p - the actual and planned value of the indicator.

CONCLUSION

A system for minimizing energy costs and reducing dust emission in the clinker burning shop is proposed, which allows increasing the environmental safety of production.

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