Theoretical and experimental studies of dust in jobs in concrete production

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Abstract. The article discusses and analyzes well-known scientific approaches to assessing the dust content of jobs at enterprises in the construction industry in the production of concrete. Boundaries are defined for the description of the log-normal distribution of particles and the probabilistic–stochastic approach to the description. The author presents the results of experimental studies at factories and enterprises for the production of ready-mixed concrete, reinforced concrete structures and products. The research direction is determined, recommendations are given.

Introduction

The issue of labor protection at construction industry enterprises, as well as throughout the country as a whole, is determined by combined factors: technical, economic and legal.

Chronic occupational diseases in workers at enterprises of various industries arise as a result of the following circumstances: imperfection of technological equipment and processes 45%; design flaws of labor means 30%; imperfection of the working place 5%; absence or non-use of personal protective equipment (PPE) approximately 5%.

It is considered to be harmful factors in the production of reinforced concrete products: noise, vibration, air pollution of the working area with dust of inert materials (sand, gravel, etc.), as well as harmful substances from electric arc welding. Dust of construction industry plants contains particles with sizes up to 5 microns, which is 70-97.5% of the total volume. Dust is emitted during technological processes, among them: crushing, sieving, transportation and loading of bulk materials. The influence of each factor individually on the body is well known and widely covered in scientific, technical and medical sources. However, in the manufacture of products and structures made of reinforced concrete, workers are exposed to the simultaneous effects of several harmful production factors.

Analysis

The predominant amount of work uses correlation and regression analysis, which allows to establish and evaluate the relationship between the determining factors and the output indicator and requiring a large amount of statistical data. [one].

The work considers the possibility of using probabilistic methods. A special case of the application of this method in order to calculate the probability of exposure to hazardous factors causing injuries is expression (1)

\[ P_{ofi} = \frac{t_{ofi}t_{pl}}{T_{cm}} \]  

(1)
Where $t_0$ is the duration of the $i$-th hazard during the shift, $h$; $t_p$ is the time spent working under the influence of the $i$-th hazard during the shift, $h$; $T_{cm}$ working shift, $h$.

If a worker is exposed to several factors at the same time ($i = 2, 3, 4... N$), then the expression takes the form (2)

$$ P_{of}(n) = P_{of_n} + P_{of}(n - 1) - P_{of_n}P_{of}(n - 1) $$

The term "exposure" is understood to mean the concentration of a harmful substance or the level of the physical factor of the working environment contained in workplaces and threatening an individual employee and / or professional group of employees. The term "dose" refers to the level of factor accumulated in the body of a person who has been exposed.

To date, this scientific direction is of interest to research and improve methods for assessing occupational risk and the choice of means of ensuring working conditions within the framework of standards based on the dose-effect relationship.

Such analysis of the features of the distribution of airborne dust masses in the workshops of the plants of concrete products and concrete products with dust emissions was carried out by such famous Russian scientists as: V.N. Azarov, V.I. Bespalov, E.I. Boguslavsky, V.P. Zhuravlev, P.A. Kouzov, V.A. Minko, N.A. Strakhova, E.A. Shtokman, and many others. The dust is knocked out of the production equipment at random, i.e. stochastically. This approach is used to analyze and determine the processes associated with diffusion, to describe and study the fluidized bed [2,3,4], and many others.

The diffusion equations obtained by G.I. Marchuk, helped in solving the problem of optimal design of the production scheme taking into account emissions into the environment from existing plants. In his works M.E. Berland investigated the issue of the movement of harmful substances in the atmosphere. Modeling of diffusion processes formed the basis of engineering methods for calculating atmospheric pollution by industrial sources. When considering the presence of a source of particle formation, the equation of diffusion in a dust stream has the form (3)

$$ \frac{\partial C_n}{\partial t} = D_m \nabla^2 C_n - W \nabla C_n + Q_n $$

where $Q_n$ is the volumetric source of particle formation in $1 \text{ m}^3$.

Distribution of dust concentration for particles of fine fractions in mines, studied by V.P. Zhuravlev and B.F. Kirin is described by the following diffusion equation (4)

$$ \frac{\partial \bar{c}}{\partial t} = D_m \frac{\partial^2 \bar{c}_n}{\partial x^2} - (V_n \pm W_k) \frac{\partial \bar{c}_n}{\partial x} - \beta \bar{c}_n $$

where $\bar{C}_n$ is the average over the production cross section dustiness of air; $t$ is the process time;
$D_m$ — coefficient of turbulent gas diffusion;
$W_k$ - feed rate of the combine;
$V_n$- air velocity in the mine;
$\beta$ is the sedimentation coefficient of dust particles.

The specific process parameters were used to select the boundary conditions. In the works of R.I. Nigmatulin noted that to obtain practical results, rational generalizations are used, which are reduced to the equations being solved, due to the complexity of the interaction inside and between heterogeneous media. To compile mathematical models in the field of dust removal, stochastic methods can be used.

In the work of N.A. Fuchs is one of the first to use the theory of random processes in aerosols and the AN equation is presented Kolmogorov, in the form of (5)

$$ \frac{\partial \bar{p}}{\partial t} = -div(\bar{W} \bar{P}) + D_n \Delta \bar{P} $$

Baseline

$$ \bar{P}(\lambda, t_0) = \bar{P}_0(\lambda) $$

Border conditions:
Reflection  \[ \tilde{\mathcal{W}} \tilde{P} - 0.5 \frac{\partial (D_n \tilde{P})}{\partial \lambda} \]  
Absorption  \[ \tilde{P} = 0 \]  

It was found that under the found conditions the equation of A.N. Kolmogorov takes the form of a diffusion equation with the same boundary conditions. The objective function is the probability of particles in the range \((x, x + dx)\) at a certain point in time \(t\).

\[ \tilde{P} = (x, t) = n / n_0 \]  

where \(n_0\) is the calculated concentration of particles in the interval \((x, x + dx)\), at time \(t\), pcs / m\(^3\).

From a mathematical point of view, the term “probability of finding” can be applied to equation (9), although in reality we are talking about the probability density of finding. In view of this, in matters of dust removal, the probabilities of events are described by the last formula given, which is not scientifically substantiated in all cases.

**Objects of research**

Research on the assessment of real working conditions was carried out at construction industry enterprises: Rostov KSM No. 14 LLC (Rostov-on-Don), Volgodonsky Concrete Structures Plant CJSC manufactured products - foundation blocks, products for the construction of industrial and civil buildings, commercial concrete;

Measurements were carried out in accordance with regulatory requirements [5,6,7]. As an example, some sampling and measurement sites are shown in Figure 1.

**Figure 1. Plan of the molding area LLC "Rostov KSM No. 14".**
1 - vibrating table; 2 - workplace; 3 - control panel

**Analysis of the results of studies evaluating the dustiness of the air in industrial premises**

Studies of technological processes occurring in the manufacture of reinforced concrete products and reinforced concrete products allowed us to conclude that there is indeed a significant emission of dust into the working area of operators. Measurements of dustiness of the air in the working areas were carried out on the basis of the requirements of [76]. Part of the results are shown in table 1.
Table 1. The results of measurements of the concentration of aerosols in the air of the working area of operators

| Serviced equipment, workshop (site) | Workplace (position) | The concentration of aerosols of fibrogenic action, the proportion of MPC |
|------------------------------------|----------------------|-------------------------------------------------|
| LLC "Rostov KSM No. 14".          |                      |                                                 |
| Molding workshop                   | molder               | 2.54                                            |
| Vibrating table                    | vibrating table operator | 0.85                                         |
| Cement conveyor                    | line operator        | 4.5                                             |

As a result of the analysis of the studies, it was revealed that the numerous sources of dust emission into the working area are inert materials (sand, gravel, cement) loading units, belt conveyors and concrete mixing plants. When analyzing the quantitative and qualitative composition of dust contained in the air of the working area, microscopic examination was used [8,9].

Evaluation of the dispersed composition of dust as a random function was carried out using the “dissection” method [10]. Its essence is that the dispersed composition of small fractions is constant, and the integral distribution function depends on the content of large particles. We obtain the integral particle mass distribution functions separately for dust up to 20 μm and dust over 20 μm.

The passage functions for the set of small fractions $D_m(d_u)$ are described by expression (10) and for the set of large fractions $D_k(d_u)$ expression (11)

\[
D_m(d_u) = \begin{cases} 
\frac{100}{D(d_p)} D(d_u), & \text{if } d_u \leq d_p \\
0, & \text{if } d_u > d_p 
\end{cases} 
\]

\[
D_k(d_u) = \begin{cases} 
0, & \text{if } d_u \leq d_p \\
100 - \left[ \frac{100 - D(d_u)}{100 - D(d_p)} \right], & \text{if } d_u > d_p 
\end{cases} 
\]

Substituting the value of the dissection diameter into dependences (10) and (11), we obtain the passage functions (12) and (13) for the aggregate of small and large fractions, respectively

\[
D_M(d_u) = \begin{cases} 
\frac{100}{D(d_p)} D(d_u), & \text{if } d_u \leq 20 \\
0, & \text{if } d_u > 20 
\end{cases} 
\]

\[
D_K(d_u) = \begin{cases} 
0, & \text{if } d_u \leq 20 \\
100 - \left[ \frac{100 - D(d_u)}{100 - D(d_p)} \right], & \text{if } d_u > 20 
\end{cases} 
\]

It follows that when considering particles up to 20 microns, their number in the working area is unchanged, and are described by a log-normal distribution. The dispersed composition up to 20 μm is constant, and as a result, fine dust can be described by a deterministic curve.

The composition of large fractions ($d_u > 20 \mu m$) [10] it is desirable to describe using the probabilistic – stochastic approach, to consider the functions $D(d_u)$ as random (Figure 2).
During the experimental part, the sedimentation rate of dust particles was estimated. It was revealed that the median diameter of the settled particles is: after 3 s. - 52 microns, after 4 s. - 46 μm, after 6 s. - 34 microns, after 8 s. - 26 μm, after 10 s. - 15 microns, after 15 s. - 5 microns. Based on experimental data, digital models are constructed that describe the sedimentation rate of particles depending on the nominal diameter in a logarithmic grid.

Measurements carried out in real production conditions at the construction industry plants allowed us to conclude that when moving at 1 m / s the maximum particle size is 100 microns, the median diameter is 68 microns, and the minimum size is 18 microns.

When moving at 0.5 m / s, the maximum particle size is 63 microns, the median diameter is 44 microns, and the minimum size is 13 microns.

When moving at 0.3 m / s, the maximum particle size is 37 microns, the median diameter is 28 microns, and the minimum size is 10 microns.

It was found that during the first five seconds the maximum amount of dust particles of inert materials settles, both in number and in mass.

**Summary**

The generalized results of the studies of construction industry enterprises are shown in table 2.

**Table 2. Identification of hazardous and harmful production factors**

| Process operation, workplace | Name of production factor in excess of standard values | Production factor values |
|-----------------------------|-----------------------------------------------|-------------------------|
|                             |                                               | actual  | normative   |
| LLC "Rostov KSM No. 14".  |                                               |         |             |
| vibrating table operator    | increased dust in the air of the working area | 10 mg/m³ | 2 mg/m³     |
| compressor unit operator    | increased noise                               | 97 dB   | 80 dB       |
|                             | increased dust in the air of the working area | 10 mg/m³ | 2 mg/m³     |
|                             | insufficient lighting of the working area      | 185 lx  | 200 lx      |
|                             | increased noise                               | 92 dB   | 80 dB       |
In general, the content of hazardous and harmful production factors at the enterprises of reinforced concrete structures and products and the excess of the parameters over the normalized ones are observed by the dust content of inert materials in the air.

The noise level above the maximum permissible level, as well as the dust content above the maximum permissible concentration in the working area are typical for the considered factories for the production of reinforced concrete structures and the industry as a whole, exceeding the permissible values for which is most common.

Therefore, the solution of the problem, dust removal of air from the working areas of construction industry facilities, reduction and reduction to the standard content of harmful and hazardous substances in the air to a level below the maximum permissible concentrations, including in factories for the manufacture of reinforced concrete structures and products by developing methods to reduce the level air pollution and the introduction of new, more efficient and economical engineering methods and means, is an urgent problem in the field of ensuring standard working conditions.

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