Ensuring safe working conditions during the operation of foundry equipment

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Abstract. Human activities in industrial production are subject to the risk of occupational diseases. This problem is of particular relevance in the working area of foundries. Prevention of occupational diseases and reduction of the concentration of pollutants in the atmospheric air of the working area is one of the many complex tasks associated with the assessment of the elemental and dispersed composition, as well as the density of distribution of particles of multicomponent dust. The aim of the study is to assess the elemental and dispersed composition of dust, which determines the hygienic state of the working area of the foundry.

Results of the research. In order to develop a mathematical model, the particle size was estimated. The elemental composition of the dust has also been determined. A significant amount of fine dust and iron (48%) was found, which is associated with the processing of casting with iron shot. Having carried out statistical processing of experimental data on dispersed dust analysis and using the known distribution laws: normal, normal truncated, gamma distribution, Weibull distribution, an empirical dependence of the distribution density of the number of particles depending on their size was obtained.

1. Introduction
In the foundry at the section of shot blasting of castings, a large amount of fine dust is released, which determines high dust concentrations in the working area [1]. The workshop infrastructure includes the following sections: knock-out grates, molding sections, shot blasting chambers, induction furnaces. Dust, aerosols and gases are emitted during the technological processes of manufacturing castings, which are characterized by a large number of operations. The aim of the study is to assess the elemental and dispersed composition of dust, which determines the hygienic state of the working area of the foundry.

In closed cast iron cupolas with a capacity of 5-10 t / h per 1 ton of smelted cast iron, 11-13 kg of dust, 190-200 kg of carbon monoxide, 0.4 kg of sulfur dioxide, 0.7 kg of hydrocarbons are emitted. The dust concentration in the exhaust gases is 5-20 g / m³, the median dust size is 35 μm. Specific emission of pollutants from electric arc furnaces depends on the capacity of the furnace and ranges from 6.6 to 9.9 kg / t [3].

In induction crucible furnaces, this figure ranges from 0.75 to 1.5 kg / ton of metal. When casting non-ferrous metals and alloys in furnaces, 1.2 to 2.8 kg / t is released. During crushing and grinding of charge materials in crushers, from 6 to 10 kg / t of dust is emitted, and during drying and mixing of molding materials from 0.5 to 4 kg / t is emitted. The maximum amount of dust is released when the castings are freed from spent molding sands, while dust, burnt earth and scale are emitted up to 30 kg / t [8].
From the areas of knockout of casting per 1 m$^2$ of the grating area, up to 45-60 k is emitted.

Dust emission during shot blasting with cast weights up to 80 kg ranges from 9 to 20 kg / t, depending on the capacity. The operation of sandblasting and shot blasting chambers, cleaning of drums and tables is accompanied by intensive dust emission with a median size of 20-60 microns. The dust concentration in the air removed from chambers and drums is 2-15 mg / m$^3$ [4].

When melting steel in induction furnaces, in comparison with electric arc furnaces, a small amount of gases is emitted and 5-6 times less dust, larger in size.

A significant amount of dust and gases is emitted into the atmosphere by the sections of foundries for the preparation, processing and use of charge and molding materials.

2. Formulation of the problem

Air pollution in the working area of a plant depends on the quality and consistency of maintenance and the condition of the dust collection equipment. In particular, the state of the supply and exhaust ventilation and its parameters determine the quality of atmospheric air in the foundry [13]. Calculations of exhaust and supply ventilation showed a significant supply ventilation deficit of 29595 m$^3$/h. The study of the sanitary state of the windy zone determined the value of the maximum surface concentration equal to 1.97 mg / m$^3$, which exceeds the permissible concentration of dust in the supply ventilation, which should be less than 30% of the occupational exposure limit (OEL) of the working area (occupational exposure limit (OEL) = 2 mg / m$^3$), then there is 0.6 mg / m$^3$ [10].

3. Materials and methods

In the air environment of foundries, in addition to dust, a large amount of carbon monoxide, carbon dioxide and sulfur dioxide, nitrogen and its oxides, hydrogen, etc. are emitted [2].

The foundry of mechanical engineering is usually located in urban areas. The state of the working zone of the foundry is determined by the microclimate in the room and in the interbody zone of the plant [7, 9].

To study dust, the method of particle size analysis was used, which is based on the relationship between the size and speed of movement of a body in a viscous medium under the action of gravitational or centrifugal forces. According to the results of the analysis, the granulometric composition of the presented samples was determined. Analysis of the structure of the dust showed that particles with a size of 100 microns and more account for less than 10%. The sample contains the maximum amount of fine and medium-dispersed dust. Results are shown in Figure 1.

![Figure 1. Graphical results of measurement of dispersion analysis of the dust particles.](image-url)
For the purpose of a more accurate assessment of dust parameters: dispersion and elemental composition, the method of X-ray phase analysis was used, in which the following equipment was used: X-ray diffractometer “DRON”; X-ray diffractometer “Radian DR-02”; wave X-ray fluorescence spectrometer “Bruker S8 Tiger”. Spectrometers are attachments to a scanning electron microscope. Quantitative analysis is based on comparing the intensity of X-ray radiation from the sample under study and standards of usual samples of a known composition [6].

4. Results of the research
The study of the structure of the dust formed in the areas of shot blasting and removal of shapes in the process of X-ray spectral microanalysis showed that it, as a rule, has a predominantly shape that allows it to be conventionally considered spherical. When falling, dust particles always tend to take a position corresponding to the greatest resistance in the air, this form contributes to their settling in the atmosphere and in inertial dust collectors. However, the presence of particles less than 10 microns in size shows a significant settling time and, consequently, the need for the use of highly efficient systems for additional purification of air from the dust [5]. The appearance of a large number of reflections indicates the presence of several phases in the sample. To determine them, we used the PDF-2012 database of diffraction measurements to reduce the possible variants of the sample phases.

Due to the large number of possible elements and phases, X-ray spectral analysis was used. The survey was carried out for several times on a Radian DR-02 diffractometer with the function of X-ray fluorescence analysis (Figure 2, 3).

X-ray spectral analysis on a wave X-ray fluorescence spectrometer "Bruker S8 Tiger" in the Center for Collective Use of the Voronezh State University made it possible to obtain a more accurate percentage of elements in the sample. The iron (Fe) phase predominates (48.535%) (Table 1).

| Sample                        | Dust composition, % |
|-------------------------------|---------------------|
| Dust from shot blasting        |                     |
| Na                            | 0.141               |
| Al                            | 21.295              |
| Si                            | 27.94               |
| S                             | 0.04                |
| Cl                            | 0.056               |
| K                             | 0.183               |
| Ca                            | 0.143               |
| Ti                            | 0.095               |
| Cr                            | 0.511               |
| Mn                            | 0.712               |
| Fe                            | 48.535              |
| Ni                            | 0.05                |
| Cu                            | 0.0509              |
| Zn                            | 0.072               |
| Ga                            | 0.014               |
| Zr                            | 0.072               |
| Mo                            | 0.088               |

Having carried out statistical processing of experimental data on dispersed dust analysis and using the known distribution laws: normal, normal truncated, gamma distribution, Weibull distribution, it was possible to obtain an empirical dependence of the distribution density of the number of particles depending on their size. Formula (1) has the smallest value of the Pearson criterion [11].
5. Discussion and conclusion

For the purpose of additional treatment of the emission to standard concentrations equal to occupational exposure limit (OEL), it is proposed to supplement the existing dust collection system with a "wet" stage, patented by the authors - E.I. Golovina, T.V. Shchukina, Yu.V. Sychev, V. Ya. Manokhin, S.A. Sazonov (patent No. 2702554 Russian Federation, IPC B01D 47/06 (2006.01) / Device for wet gas cleaning) [14-16], Figure 4.

Figure 4. Device for "wet" gas cleaning: a) general view; b) section A-A: 1 - case; 2 - conical bottom; 3 - cylindrical partition; 4 - shaft; 5 - coagulation plates; 6 - crosspiece; 7 - bearing; 8 - cover; 9 - bearing; 10 - spray nozzles; 11 - inlet pipe; 12 - drop catcher; 13 - lever; 14 - finger; 15 - non-motorized cylinder piston; 16 - outlet branch pipe; 17 - branch pipe for sludge removal.

The device shown in the diagram is highly efficient due to the fact that it has two zones for collecting coarse and fine dust.

After the introduction of an additional stage of purification, the economic damage to the atmosphere is determined in accordance with the formula (3)

\[
D = \gamma \sigma f m_{pr}
\]

where \( \gamma \) – constant, numerical value, rubles / conv. t;
\( \sigma \) – indicator of the relative hazard of air pollution;
\( f \) – correction that takes into account the nature of the scattering of impurities in the atmosphere;
\( m_{pr} \) – reduced mass of annual emission of pollution from the source, conv. t / year.

The estimation of the reduced mass of the annual emission from the source was made according to the formula (4):

\[
I_g(d) = \frac{0.048}{(3.1)^{1.14}} d^{1.14} \exp(-0.048 \cdot d)
\]

Functional relation (1) fairly accurately represents the particle distribution according to the size for a given category of dust, technical conditions, type of technological equipment.

For function (2) Pearson's criterion will be \( \chi^2_{10} = 0.257 \), For function (1) \( \chi^2_{11} = 0.097 \), which is much less than the theoretical value of Pearson which equals 24.7 [12]. Consequently, the proposed functions for describing the particle distribution according to the size are reliable.
\[ \text{m}_{pr} = \sum A_i^* M_i \] (4)\[\text{where } A_i \text{ – aggressiveness coefficient; } M_i \text{ – volume ratio, } \%.

| Suspended substances | Al   | Si   | Ca  | Fe  | Cu |
|----------------------|------|------|-----|-----|----|
| /proportion of       |      |      |     |     |    |
| substances           |      |      |     |     |    |
| volume ratio, %      | 21.296 | 27.94 | 0.143 | 48.535 | 0.05 |
| Weight ratio, t/year | 1240 | 1436 | 4.4 | 8311 | 8.8 |

Avoided damage for the proposed 2-stage installation is determined

\[ D_{sup} = \varepsilon*D \] (5)

The economic assessment of the prevented damage is determined by the dependence (6):

\[ \Delta D = D - D_{sup} \] (6)

The economic effect from the sale of dust is obtained by the dependence (7):

\[ E_{d.s.} = \sum c_i^* m_i \] (7)

where \( C_i \) – the cost of recycled metal per 1 kg, rub.;

Determining annual efficiency (8):

\[ E = \Delta U + E_{rp} - K (C_{eq} + C_{in} + C_{ps}) - (C_r + S_{st}) \] (8)

where \( K \) – depreciation rate, 1/5;

\( C_{eq} \) – equipment cost, rub.;

\( C_{in} \) – installation cost, rub.;

\( C_{ps} \) – cost of equipment for phase separation, rub.;

\( C_r \) – repair cost, rub.;

\( S_{st} \) – staff costs, rub.

An economic effect was obtained from reducing damage due to the captured dust and its utilization, equal to 1,778,722.4 rubles.

6. Conclusions
1. A significant amount of fine and medium-dispersed dust with a particle size of less than 100 microns (86.2%), as well as a significant amount of iron (48%), was found during processing of experimental data, which is associated with the processing of casting with iron shot.

2. The dependence for the analytical estimation of the density of the distribution of particles by dispersion is obtained when using the gamma function having the minimum standard deviation.

3. A social and economic effect was obtained, consisting in improving working conditions for those working at the shot-blasting section of the foundry, in connection with a decrease in the concentration of dust to the level of occupational exposure limit (OEL) in the working area.

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