Determination of pollutants in foundry during the manufacture of metal constructions for high buildings

Irina Ivanova [1,*] *Elena* Sushko[1], *Anna* Lyshnikova[2] and *Larisa* Prykina[3]

[1] Voronezh State Technical University, Moscow Avenue, 14, Voronezh, 394026, Russia
[2] Voronezh State Medical University named after N.N. Burdenko, Stydencheskaya st., 10, Voronezh, 394036, Russia
[3] Moscow State University of Civil Engineering, Yaroslavskoye shosse 26, Moscow, 129337, Russia

Abstract. Current developments are devoted to the environmental safety of the foundry. There is a significant amount of pollutants, according to dust, which is released in the working area, during the manufacture of metal structures for high buildings. From the point of dust extraction, the most unfavorable areas are shot blasting, sand-blasting chambers and knockout grills. The weight fraction of dust composition with diameters up to 20 μm reaches 43,8% by mass, according to experimental analysis. This kind of dust is the most dangerous to employees and also it creates problems for dust-cleaning in the air.

1 Introduction

Technological processes of manufacturing casting of metal constructions for high buildings are characterized with a huge amount of operations, in the performance of which dust, aerosols and gases are released. Dust is the main contaminant of work zone, it is formed practically on every site of the technological process of manufacturing foundry alloys:

- preparation of the molding mixture;
- molding;
- metal-smelting and metal-pouring;
- rod;
- knocking out lattices and rods, as well as cleaning castings.

A significant amount of carbon oxides, sulfur oxides, nitrogen oxides, phenol, formaldehyde, aromatic hydrocarbons, ammonia and cyanides are released into the environment in addition to dust, during the casting process. Pairs of zinc, cadmium, lead, beryllium, chlorine and chlorides, fluorides are also produced during non-ferrous metals melting. The use of organic binders in the manufacture of rods and molds leads to a significant release of toxic gases during the drying process, and especially when pouring the metal. Harmful substances such as ammonia, acetone, phenol, formaldehyde, furfural, etc. can be released into the atmosphere, depending on the class of the binder.

The most dangerous dust for employees health is that one which contains free silica - SiO_2. The poisonous of silica is not high, but with prolonged inhalation there are changes in

---

[*] Corresponding author: ivanova-eco@mail.ru

the lungs. There is a direct relationship between the weight concentration of dust in the air and the sickness rate of inhaling people. The danger of dust is also determined by its granulometric composition, i.e. the quantitative ratio of dust fractions of various sizes in it [1].

Large particles of dust linger on the mucosa of the upper respiratory tract, while particles with dimensions close to 1 μm can penetrate into the alveoli of the lungs, where the main part of them is persisted. The greatest amount of sulfur oxides is formed during the combustion of high sulfur fuel oil. Almost all sulfur is oxidized to sulfurous anhydrid $S0_2$ in emissions. Sulfuric anhydride refers to irritating gases.

At a concentration of 0.3 to 1 cm^3/m^3, it is noticed by a specific taste. At a concentration of 3 $cm^{3/}m^3$ and higher it is easily determined by its smell. At a concentration of 6 to 12 cm^3/m^3 it irritates the mucous membranes of the nose and throat, higher $20 cm^3/m^3$ it also affects eyes. Inhalation $S0_2$ causes painful phenomena in lungs and upper respiratory tract. Also sometimes it causes swelling of the lungs, pharynx, as well as respiratory paralysis.

If air contains more than 50 $\mu g/m^3$ of SO_2 it can cause obstructive changes in respiratory function and it might lead to the development of chronic obstructive pulmonary disease (COPD). Sulfuric anhydride SO_3 is also an irritating gas. It is capable of causing a sensation of suffocation at a concentration of about 1 cm^3/m^3.

Nitrogen oxides emitted into the atmosphere are basically consisted of $NO_{2,}$ because N0 will oxidize to $N0_2$ pretty fast. $N0_2$ has no color and smell, but it is very toxic.

Man breathing even with deadly concentration of dioxide of nitrogen, won't feel any indisposition during first hours. At the end of eight hour he will feel asphyxiation, nausea, abdominal pain, cough, fast heart rate, after which there is an violation of heart activity. Death will come in 8-48 hours. Concentrations of more than 50 cm^3/m^3, irritating the mucous membranes of the nose and eyes, should be considered as dangerous when exposed to short duration. Long exposure with nitrogen dioxide with concentrations from 25 to 100 cm^3/m^3 causes irritation of the lungs. Carbon oxides are formed in the incomplete combustion of substances containing carbon, including fuels of all types (fuel oil, coal, natural gas, etc.). It causes fast toxic effect of human's organism, if there is a huge concentration of it in the air. Some people are hypersensitive to the effects of this substance, the first symptoms of poisoning are headaches, nausea and a sense of weakness. It expels oxygen from blood's hemoglobin, which makes blood incapable of transferring oxygen from the lungs to the tissues. Due to the reduced oxygen concentration in the blood, suffocation occurs.

Phenol - possible poisoning with phenolic vapor, fine dust, formed when condensation in colder air vapors, as well as when it gets on the skin.

The lesion of 0.5-0.25 of the body surface is fatal, with the lesion of 0.25-0.17 of the surface, poisoning occurs with an increase in temperature, a violation of the functions of the nervous system, blood circulation and respiration. Formaldehyde - is a gas with a strong odor. Solutions give off formaldehyde gas even at room temperature and especially when heated. It forms explosive mixtures with air or oxygen. It is irritant gas, which also has a general toxic effect. It also has a huge influence of central nervous system. Benzopyrene – is a carcinogenic substance. It causes gene mutations and cancers. It is formed with incomplete combustion of fuel. Benzopyrene has huge chemical stability and it can easily dissolve in water. It spreads over long distances from pollution sources (sewage) and accumulates in bottom sediments.

Carbon monoxide, nitrogen dioxide, formaldehyde; sulfur dioxide and sulfuric acid aerosol; sulfur dioxide and nickel; sulfur dioxide and nitrogen dioxide; sulfur dioxide and carbon monoxide, phenol and converter dust; sulfur dioxide, carbon monoxide, nitrogen dioxide and phenol; sulfur dioxide and phenol; oxide and sulfur dioxide, ammonia and nitric oxide have a cumulative effect in the joint presence in the ambient air [2].

2 Materials and Methods

The search for highly efficient means for cleaning gas dust is largely dependent on the correct evaluation of the dispersed and chemical composition of the dust.

Experimental data shows, that dust emission in the zone of knockout lattices is 0-1% of the volume of emissions at dust concentrations from 2050 to 7850 mg/m^3.

The high requirements of regulatory documents for the purity of atmospheric air and the ambiguity of the methods for determining the scattering parameters pose the task of a complex solution in assessing the dispersion, fractional and chemical compositions of dust. The greatest dust emission is determined from the injection molding section of molds and shot blasting (Table 1).

Table 1. The concentration of dust in air removed by local exhaust systems (experimental data).

	Nature of the equipment or process	Concentration mg/m^3		Nature of dust
		Highest	Average	
1	Chipping lattices: a) bottom drainage of hopper b) full shelter grill with upper drainage	 7850 2050	 2600 650	 Humid Dry
2	Shot blasting and shot-shot cameras: a) from the camera b) from the head of the elevator	 6150 6000	 050 2200	 - -

The estimation of the true density of dust is necessary to determine the velocity of the particles of different sizes.

The estimation of the true density of dust was carried out on Le Chatelier's device. The error wasn't more then 5%. Results of the estimation are shown in table 2. The true density test was carried out by a pycnometric method.

Table 2. The true density of dust

No	Name of sample	Density, g/cm^3
Samples 1-10	Shot blasting devices	4,50
Samples 11- 20	Chipping grid of the steel casting site	2,95

Determination of the fractional composition of samples No. 1-10 and No. 11-20 was carried out on a sedimentometer by using a cathetometer with a total error of not more than 5.5%.

The results of the sedimentation analysis of the dust dispersion of the black casting shop, taken from cyclones, are showing that particles with diameters> 200 μm predominate (76% dust of shot blasting machines, and 76.7% dust from knockout gratings by mass).

The rest of the dust is represented by fractions of 200-0 μm, while the content of fine dust in the shot blasting apparatus is 2.3%.

Cyclones SK - CN of chipping grids have an IV class of a dust collector with an allowable input dust concentration of 1000 g / m3 with a hydraulic resistance of 4 kPa with a gas productivity from 2.54 to 92 thousand m^3/h with a 95% cleaning efficiency.

An evaluation of the actual efficiency of the PU established lower values of ~ 68-70%.

Table 3 shows the experimental data on the weight percent dust content of various fractions captured by a dry dust collector.

The analysis of the experimental data shows a significant presence of particles with a diameter of 15 to 125 μm coming from the fractured section and a diameter of 25 to 200 μm from knockout gratings.

Table 3. Experimental data

Dust extraction point	The weight percentage of fractions with an average particle diameter, μm						
	Less than 5	5-10	>10-20		>40-60	>60-100	More than 100
Shotcracker	8,8	9,2	30,5	18,8	12,3	12,5	7,9
Knockout gratings	6,2	8,3	30,0	18,2	11,1	12,0	14,2

Thus, the amount of fine dust reaches significant values in knockout grids - up to 44.5% (at d≤20 μm). The lack of it in the dust receptacle is confirmed by its presence of a discharge pipe and a flare discharge (H = 8 m) at the cutoff zone.

The selection of dust in the flare emission, on the contrary, shows a significant amount of fine dust, not settled in the PU. Its fractional composition is presented in Table. 4.

Table 4. Fractional composition

Dust extraction point	The weight percentage of fractions with an average particle diameter, μm				
	Less than 5	5-10	>10-15	>15-20	>25
Knockout gratings	12	16	30,2	30,5	11,3

Due to the low efficiency of dry method of dust collection, it is much more effective to carry out the preassembly of existing dust collection systems with equipment for collecting dust by wet method, for ex-ample, with a Venturi's scrubber.

Highly effective Venturi's scrubbers (class II) have higher hydraulic resistance (from 6 to 12 kPa), gas productivity from 1.7 to 84 thousand m^3/h and have the efficiency of purifying gases from dusts of any dispersed composition 96-98%.

In order to reduce dust and gas content in the working zone of the knockout grate, it is expedient to install a three-sided upper sidewall tent with two-sided drainage and compensating air [3].

The maximum allowable concentration of dust Cn, mg/m^3, in the technological and ventilation emissions that are diffused, is determined, depending on the volume of ejected air L, thousand m^3/h. With a volume of more than 15 thousand m3 / h Cn = 100R; at a volume of 15,000 m3 / h or less, Cn = K (160-4L), where K is the coefficient taken in accordance with the MPC of dust in the air of the working area of the premises in permanent workplaces:

MPC ppm, mg/m^3……………	≤ 2	$>2 \div 4$	$>4 \div 6$	$>6 \div 10$
К ……………..	0,3	0,6	0,8	1,0

Emissions of air with a concentration of dust exceeding Cn are not allowed to dissipate into the atmosphere without preliminary purification. For areas of black casting, where there is dust molding with metal, at MPC = 2 mg/m^3, Cp = 46.2 mg/m^3. The actual dust concentration at the pipe cut is 11.04 g/m^3.

The degree of risk of the technological process also depends on the purity of atmospheric air in various sections of the shop, since the technological process in all phases of production is accompanied by the release of a significant amount of dust and harmful gases.

The industrial safety of the foundry industry is associated with the risks of failures in the operation of devices and equipment, as well as the presence of causes that induce defect castings due to incompleteness of technological regimes. To a great extent, the latter is due to the strength and the clean surface of the molding mixture.

An important condition for obtaining a strong molding mixture is to ensure uniform coverage of the entire grain surface of the binder component mixture. The uniformity of its distribution is determined by the design of the mixer and the mixing time. As the agitation time increases, the compressive strength first increases, reaches a maximum (usually in 6-8 minutes), and then begins to decrease.

The resistance to the dislocation system shift in general form is expressed by the equality:

$$\frac{H}{F} = fP + C \tag{1}$$

where H - shearing force; P - specific vertical load; f is the coefficient of internal friction; C is the force of adhesion; F is the area of the cut.

The use of binders, which provide high strength of the molding mixture and new technological schemes of casting - on melted models, in thermosetting binder molds (actually plastic molds with sand filler), in forms made of liquid-glass mixtures, etc., - made it possible to obtain thin-walled nonmetallic shell shape with a high-purity surface.

The quality of castings also depends on the modes of filling the molds, the outflow of metals and their properties, external forces, cooling and hardening of the metal during casting.

In the process of filling the mold, liquid metal can destroy its walls and carry the products of destruction into different parts of the casting, forming clogs.

The number of clogs is halved in castings cast with a gating bowl, compared to castings cast with a sprue funnel, however the use of a sprue bowl causes inconvenience in a number of subsequent technological operations [4].

With prolonged exposure to a metal jet on the surface of the rod, there is burnout of organic additives, as a result of which the purity of the surface of the casting deteriorates significantly, although exfoliation does not occur.

The quality of atmospheric air in the working area of the foundry depends on the concentrations of harmful substances and their toxicity. The effectiveness of existing means of emission purification does not ensure compliance with the requirements of hygiene standards. Preliminary experimentals and calculated data show a multiple excess of the maximum surface concentrations above the maximum permissible - this excess reaches 20 times. It lasts not for long at piece production however during mass production the degree of environmental risk significantly increases.

The maximum permissible concentration of dust in the working area of MPC depends on the SiO_2 content, in particular, if $SiO_2 \leq 10\%$ MPC= 10 mg/m^3, and the actual content of SiO_2 varies in the range from SiO_2 = 35-50%, 28.2 - 46.51%, and practically all areas of the foundry have quartz. And MPC is necessary to be 2 mg/m^3. That is why the approach to assessing the health status of the work area and the effectiveness of engineering and technical measures to reduce air pollution is much harder.

The evaluation of the dispersion of dust and its true density is necessary for two reasons. First, it determines the degree of an impact on a person. In particular, the presence of dust of less than 10 microns, the so-called "pulmonary", indicates the possibility of obtaining a number of occupational diseases: dermatitis, conjunctivitisб cataract, pneumoconiosis and silicosis. Secondly, the size of suspended particles and density significantly determine the choice of dust collection devices and the optimal parameters for the emission of dusty air.

Therefore, the analysis and optimization of already operating dust-collecting complexes in combination with new promising developments and technologies for dust utilization is of particular importance. An important property of dust collecting devices is that the capture efficiency of a given particle size, known as fractional capture efficiency, increases with particle size [5]. If the capture efficiency for a given size is good (for example, 90% at 10 μm), then for particles of a larger size the efficiency will be even better. However, we have to note, that the fractional capture efficiency changes sharply with the particle size. This dependence is shown in the form of a hypothetical curve in Fig. 1, which is typical for some gas-cleaning devices. However, in the course of the experiment it was established that the system existing in the foundry shop has a low efficiency at particles less than 18 μm (Fig. 1).

In the region of small particle sizes the efficiency rapidly increases, reaching almost 100% with large dimensions it is shown on Fig. 2. The shape of this curve can vary for different types of devices and for circuit modifications within this type of device. In addition, the capture efficiency can be a function of the dust type, due to the different physical characteristics of the particles, for example, such as their shape. Figure 1 shows the dependence of the fractional efficiency of cyclones.

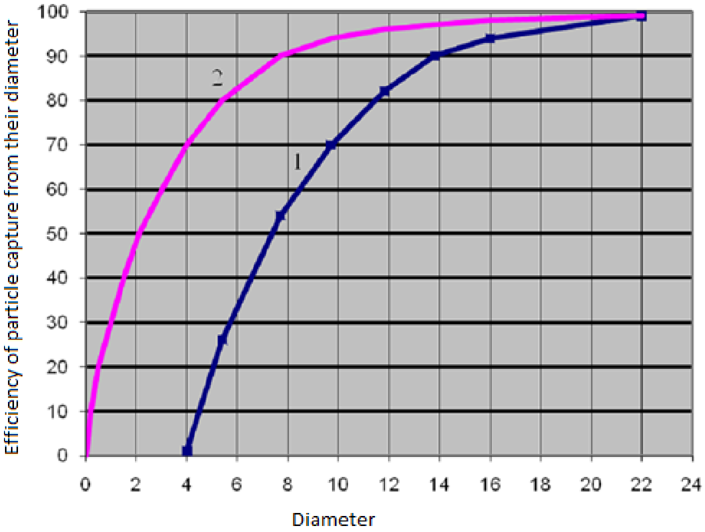

Fig.1. Experimental curve of the dependence of the efficiency of particle trapping on their diameter: 1 - experimental curve; 2 - hypothetical curve

With the joint operation of general exchange of supply and exhaust ventilation in the zone of the knockout grid, dust concentrations exceed the MAC by 7-16 times.

It is much more important to know the overall efficiency of capture than the efficiency of capturing particles of a given diameter. This means that for a particular type of dust and a certain gas cleaning device, it is necessary to have information about what percentage of the total amount of incoming dust will be removed from the stream of gas to be purified. To obtain this type of information, it is necessary to know the particle size distribution and capture efficiency as a function of the particle diameter d.

Experimental estimation of the foundry dust parameters of the working area showed that despite the piece production, there is an intense dust evolution in the areas of knockout of molds and shot blasting areas.

In the working area of shot blasting chambers, the dust content is 22-135 mg/m^3, and in knockout grates - 32-207 mg/m^3. The average values of the concentrations in the drainage, are from 650 to 2600 mg/m^3 and from 2200 to 2950 mg/m^3.

3 Results

The true density from the knockout lattices is 2.95 g/cm^3 and from the shot blasting chambers 4.5 g/m^3. This is determined by Le Chatelier's method. The dust size in the dust receptacles is 14-200 μm. Photographs of X-ray spectral microanalysis of dust captured from the shot-blasting sections of the casting and knockout gratings obtained by the scanning analyzer "Camscan S4" according to the international ASTM method, are shown on Figures 2,3.

Table 5. shows the elemental composition of dust from shot blasting machines [6].

Table 5. Elemental composition

Element	**Weight, %**	**Atomic, %**
O K	42,04	61,98
Al K	7,38	6,45
Si K	24,38	20,48
Ti K	0,29	0,14
Mn K	0,48	0,21
Fe K	25,43	10,74

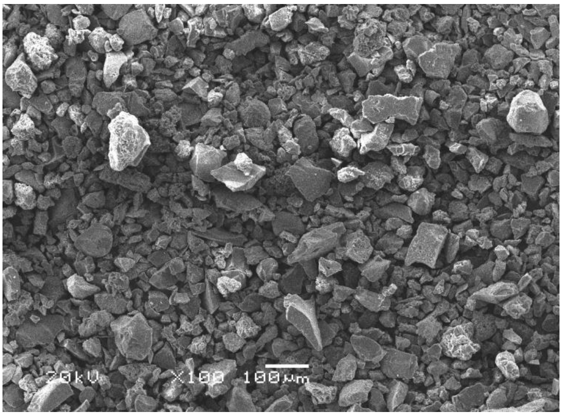

Fig. 2. Photo of captured dust from shot blasting machines

Fig. 3. Photo of dust caught from the knockout gratings

The sedimentation rate of the particles is determined by the Stokes equation for particles up to 50 μm in size, since this is a laminar flow regime:

$$V_t = \frac{g \cdot d_p^2 \cdot \rho_p}{18 \cdot \mu}, \tag{2}$$

g is the acceleration due to gravity; dp is the particle diameter; ρp is the particle density; μ is the viscosity coefficient. For particle sizes not deposited in the dust receptacle, it was determined that the settling velocity of the particles is V = 3.3 cm/s (at d = 20 μm, ρ = 2.95

g/m^3) and Vt = 0.06 cm/s (at d = 1 µm, ρ = 2.95 g/m^3). The settling time of particles at a flare discharge to a height of 10 m is 303 s for d = 20 µm and 16667 s for d = 1 µm.

Table 6. Shows elemental composition of dust from knockout gratings.

Element	Weight, %	Atomic, %
O K	33,29	55,42
Na K	1,41	1,63
Mg K	0,45	0,49
Al K	15,54	15,34
Si K	4,00	3,80
S K	4,43	3,68
Ca K	0,86	0,57
Ti K	0,66	0,37
Cr K	0,43	0,22
Mn K	0,56	0,27
Fe K	37,16	17,72
Zn K	1,20	0,49

4 Discussions

The obtained data on dustiness at the industrial site and the cutoff of the flare pipe allow us to conclude that the dust cleaning system is inadequate and that more efficient removal of fine dust is required, since this dust is the most dangerous and it creates concentrations in the working zone exceeding the maximum permissible concentration.

The greatest dust content is typical for sections of shot blasting and molding out of mold. The analysis of the experimental data allows us to conclude that the flow is laminar (Re = 10-4 - 5.0). The presence in the ejection of a significant mass of dust particles of less than 20 µm was found, which determines the inadequate efficiency of its capture by the existing dust-cleaning system, as a result of which there is an excess of MPC.

5 Conclusion

Disperse dust analysis shows that particles with diameters> 200 µm predominate (76% dust of sandblasting machines, 76.7% dust from knocked out gratings). The rest of the dust is represented by fractions of 200-0 µm, while the fine dust content in the sandblasting apparatus is 2.3%, fine dust is absent from the molding portion of the mold. On the site of knocking out castings of their shape, we proposed the installation of local drainage pumps.

References

1. I.V. Ilin, O. Kalinina, O. Iliashenko, A. Levina, Procedia Engineering, **165**, pp 1683-1692 (2016) DOi- 10.1016/j.proeng.2016.11.910
2. E.C. Gini *Technology of foundry. Special types of casting* (Academy, Moscow, 2005)
3. S.V. Belov *Environmental protection* (Higher School, Moscow,1991)
4. I.A. Ivanova High technologies in ecology: materials of the 13th interregional scientific and practical conference Voronezh, pp. 23-28 (2010)
5. V.P. Novikov *The automation of foundry production. In 2 parts Part 1. Management of foundry processes*. (MGIU, Moscow, 2006)
6. O. Kalinina, O. Valebnikova, Advances in Intelligent Systems and Computing, **692**, 1315-1322 (2018) DOi - 10.1007/978-3-319-70987-1_139