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Development of Dedusting Technology in the Silicon Production

M S Leonova¹, S S Timofeeva²

¹Candidate of Engineering Sciences, Specialist of the Industrial Ecology and Life Safety Department of Irkutsk National Research Technical University, Lermontova str. 83, 664074 Irkutsk, Russia

²Doctor of Engineering Sciences, Head of the Industrial Ecology and Life Safety Department of Irkutsk National Research Technical University, Lermontova str. 83, 664074 Irkutsk, Russia

E-mail: leonova@istu.edu

Abstract. The aim of this paper was to identify processes forming the largest amounts of dust and to develop and test additional methods for suppressing dust emissions into the air of the working area for the main occupations, primarily at the stage of loading ore raw materials into the ore-smelting furnace for the silicon production. Using the method for determining the specific surface area of fine materials - the Brunauer-Emmett-Teller (BET) method - it was shown that gas cleaning dust of the silicon production has a developed surface and high wetting ability, which makes it possible to recommend dust suppression methods using irrigation systems. In assessing occupational risks, it has been found that the level of risk is high, working conditions are hazardous and it is necessary to take measures to reduce the dust content in the workplace through the introduction of effective dust suppression systems.

1. Introduction

It is known that the production of metallurgical silicon is accompanied by the formation of a significant amount of dust emissions. One ton of silicon accounts for 280 - 900 kg of dust waste [1,2] which has a negative impact on the health of working personnel (especially on the respiratory system) [3], the environment near existing enterprises, leading to premature wear of the equipment in operation and loss of valuable components due to dust loss.

Dust is a carry-over from the electric furnace forge. It can be of three product types: products of chemical reaction in the batch (Si and SiO₂ type); fine particles formed after the check screening and separation of fines and products of batch components grinding, particularly carbonaceous materials in the recovery and downsizing of the reacting particles during the batch top layer settling. The main source forming cyclone dust of the silicon production is the mechanical grinding of batch components in the process of transport, dosing, loading and melting, as well as chemical reactions of the process resulting in the formation of gaseous or dispersed industrial products [1,4].

Silicon production enterprises are most often equipped with a gas cleaning system - Venturi tubes - however, the dust collection rate of this system barely reaches 90%, which makes it possible to judge that a significant part of dust emissions remains in the air of the working area and causes pulmonary occupational diseases [5–7].



Dust from Venturi tubes contains the main mass of silicon lost with fumes and is the most finely dispersed product (up to 60% of particles are less than 1 μm). This material is composed of more than 80% of silicon dioxide, which due to the large labor costs required for the processing of sludge is currently dumped and irretrievably lost with production waste. Moreover, the very capture of fine dust using soda solutions requires a significant consumption of reagents, continuous expansion of sludge storage area, and ultimately fails to protect the environment (due to the formation of alkaline aerosols and alkaline drains) [1,8].

From practice it is known that Venturi tubes capture up to 700 kg of dust in the production of 1 ton of silicon by irrigation with soda solutions. This dust contains 630 kg of SiO_2 , 20 kg of C_{fr} , 15 kg of SiC and 35 kg of other components [9].

Currently, silicon enterprises face two major problems:

1. Complex use of raw materials and organization of waste-free production with the utilization of dust as a commercial product
2. Creation of optimal working conditions at workplaces in terms of the dust factor, reduction of the hazard class of the main occupations engaged in the silicon production.

While the first problem can be solved using the technology proposed by the author through pelletizing of carry-over dust and returning it to the main production [1,10], the problem of reducing dust formation and dust suppression directly at workplaces requires the study and implementation of effective technologies

The aim of this research was to identify processes forming the largest amounts of dust and to develop and test additional methods for suppressing dust emissions into the air of the working area for the main occupations, primarily at the stage of loading ore raw materials into the ore-smelting furnace for the silicon production.

2. Materials and methods

As known, dust is the smallest particles of solid matter that can be suspended in the air for a long time. Dust suspended in the air is called aerosol [11], unlike dust in a settled state called aerogel. Depending on the way of formation, there are disintegration aerosols (formed during mechanical crushing, grinding, processing of materials, etc.) and condensation aerosols (formed as a result of condensation of highly heated vapors during their cooling). In terms of safety, physical and chemical properties of dust, dispersity, form of dust particles, their concentration, presence of electric charge, solubility, and degree of toxicity are of great importance for human health.

In this work, we measured the concentration of dust in the air of the working area by a direct weight (gravimetric) method consisting in the sampling of all the dust in the breathing zone [12, 13], as well as the physical and chemical properties of dust, its dispersity, and studied dedusting technologies. The chemical composition of dust was studied by the atomic adsorption method, the fractional composition - by the granulometric method, and the phase composition was determined using X-ray phase analysis and electron microscopy [1].

The object of the study is silicon dust produced as a result of electric smelting and present suspended in the air of the electrothermal workshop working area.

As a result of studying the properties of dust, it was found that it is represented by spheroidized SiO_2 particles by 85% [1]. The average dust composition of Kremny JSC is given in Table 1.

Table 1. Chemical composition of silicon production dust.

Chem. com.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	C_{fr}	Na_2O	SO_3	P_2O_5	K_2O	TiO_2	SiC
Content, %	85.41	0.46	0.3	1.5	1.24	6.09	0.08	0.16	0.12	0.31	0.02	5.03

The results of the sedimentation analysis are shown in Table 2.

Table 2. Chemical composition of silicon production dust.

Particle size, μm	Mass fraction, %	
	1 sample	2 sample
More than 100	29.66	28.8
100-50	21.1	21.2
50-20	35.4	36
1-20	12.84	13
0.1-1	1	1

The dust content directly at the workplace ranges from 100 to 50 μm . Dust of this size easily penetrates the lungs when inhaled, significantly affecting the lung tissue of operating personnel [14,15].

The total error in measuring the dispersion composition of dust does not exceed 4%. The assessment of the reproducibility of experimental data corresponds to a confidence level of 95% by Student's t-test.

Table 3. Actual and guideline values of the measured parameters.

Substance (working area)	Actual value	Guideline value	Hazard class	Class of working conditions	Exposure time, %
Silicon dioxide, amorphous, in the form of condensation aerosol with a content of 10 - 60%, mg/m ³	8.51	6/2	3	3.1	39
Shift-average concentration values:					100
Silicon dioxide, amorphous, in the form of condensation aerosol with a content of 10 - 60%, mg/m ³	8.5196	2		3.3	

According to the specified tabular data, the actual level of the hazardous factor does not meet hygienic standards, and the class of working conditions is 3.3 [16].

3. Results of the study and their analysis

There are certain methods for lowering the dust content in the working premises of a silicon enterprise:

1. *Moistening* dry bulk materials using sprayers and special vehicles. For uniform moistening of fine suspended particles, it is necessary to properly select nozzles, height and spray pressure [17,18].

2. *Using surface-active agents (surfactants)* in the form of air-mechanical foam which is produced in special foam generators using 2–3% water surfactant solutions [1]. For example, this foam is fed into the bunker for loading bulk materials, and as the material is filled up it forms a so-called foam "lid" which, in turn, is a hindrance significantly reducing dust emission into the working area and atmosphere [19].

3. *Pneumatic hydro-irrigation* is used in the form of an air curtain created with a mixture of compressed air and water. Effective dust suppression using this method is reached by means of conical and cylindrical ejectors directed to the dust source [20].

4. *Dust exhaustion* is used to control dust which is most often formed as a result of overturning when overloading ore raw materials. These dust exhaustion systems are equipped with fabric filters or electrostatic precipitators which are mounted in special chambers [21].

However, the best of the above methods is irrigation. The effectiveness of this dust suppression method is enhanced by the use of ionized liquid, since dust particles are electrically charged. To reduce the dust load in the shops, it is possible to use various methods of irrigation: hydromine, mechanical, aerial (when using aircraft), etc. Water consumption during irrigation reaches 12 l/min [22]. This method is more effective when the surface of dust particles involved in adhesion processes is developed, for better wetting with water and aqueous solutions. Therefore, we have conducted studies to determine the specific surface area of gas cleaning dust from the silicon production (Figure 1) [1].

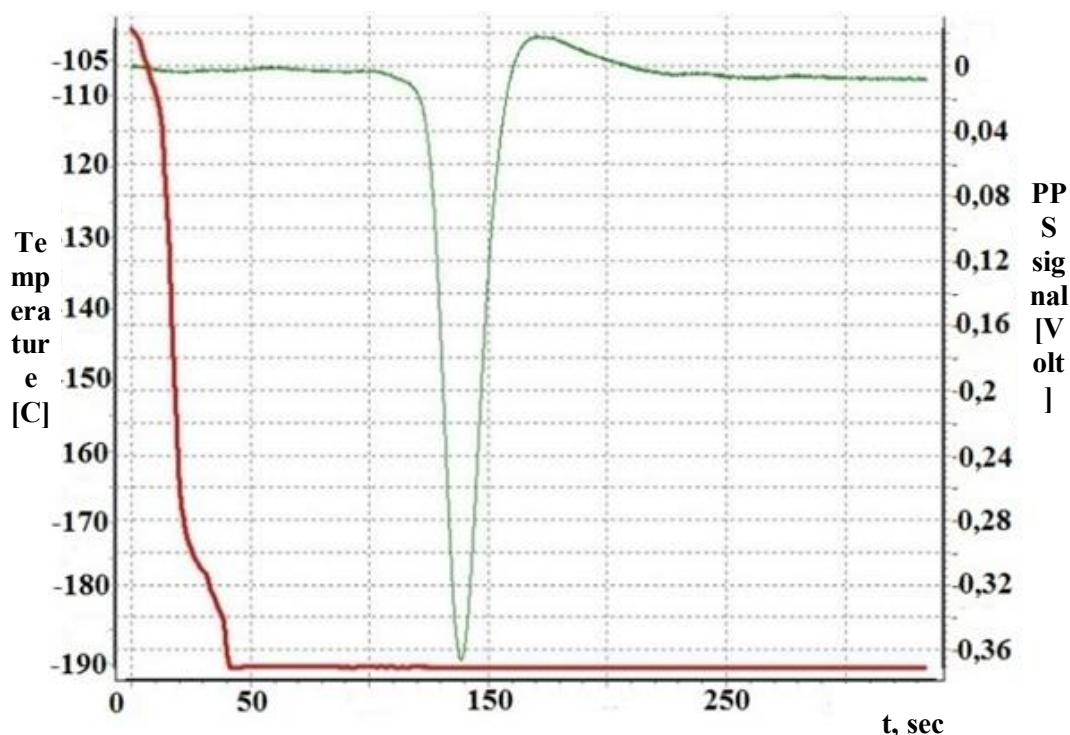


Figure 1. Specific surface area of gas cleaning dust particles from the silicon production.

Given the nature of the curves, it can be concluded that the dust studied has a good adsorption capacity, which is an obligatory basis for using the dust suppression method with aqueous solutions. This analysis was performed using the Brunauer-Emmett-Teller (BET) method on a SORBI-M sorptometer (Russia) [1].

This method is quite popular and widely used, because it allows to measure the surface of particles in the range from 0.1 - 2000 m²/g to a precision of 2 - 6%. Devices based on the BET principle of calculating the specific surface area, work using gases (nitrogen, argon as an adsorbate, helium as a carrier, and liquid nitrogen for cooling the measured samples). However, when using the described method, the physical process in the devices is quite slow, which increases the measurement time [23,24].

According to production data, the silicon enterprise uses the fog irrigation system. Water consumption when using this method is 3 l/h. To increase the effectiveness of this method, it is necessary to produce fog in a large area of dust generation with the following parameters: water consumption - up to 1 l, vapor pressure - from 0.5 - 0.6 MPa, volume-surface size of droplets in the fog - from 0.015 to 0.02 mm, the minimum size of captured dust - from 5 to 10 μm [25]. With given dust suppression parameters, the effectiveness degree of this method reaches 60%. It is possible to increase the effectiveness of dust suppression up to 97-99% with an increase in the water consumption up to 1.5 liters and a decrease in the size of the droplets down to 0.03-0.05 mm. The particle size of the captured dust in this case will decrease to 4-5 μm [26].

4. Conclusion

Having studied the specific surface area of gas cleaning dust from the silicon production, we determined that this dust has a well-developed surface and sufficient adsorption capacity. Based on the analysis carried out using the BET method, we established the feasibility of implementing dust suppression measures at silicon enterprises using water irrigation methods.

Based on the technical characteristics of this dust suppression method, it is determined that the optimal irrigation parameters are: water consumption - up to 1.5 l, vapor pressure - from 0.5 - 0.6 MPa, volume-surface size of droplets in the fog - from 0.03 to 0.05 mm. Under these conditions, the possible size of captured dust will be up to 4-5 μm , and the effectiveness of dust suppression can reach 99%.

In the real silicon production, water consumption amounts to 3 l/h, the size of captured dust is up to 4 μm . However, this dust suppression method is used only in summer. In winter, due to the low temperatures in the hangars and shops, aspiration methods are used, which do not sufficiently protect the mucous membrane of the eyes and the respiratory organs of the workers.

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