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Environmental and economic damage from the dust waste formation in the silicon production

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Abstract. In this paper, we presented the results of the silicon production dust waste studies. We also estimated the expected efficiency and, as a result of its calculation, the reduction in fees for the disposal of man-made raw materials of hazard class 4 at Kremny CJSC, when used in the composition of the gas cleaning dust batch, could reach 743,772.17 rubles/year. The paper substantiates the necessity to use the method of batch material pelletizing based on man-made raw materials.

1. Introduction

The metallurgical industry plays an important role in the Russian economy, therefore, the improvement of technological processes for the production of metals and the expansion of the raw materials base through the involvement of new deposits and production waste back into the technological process is a necessary stage in the process of improving the situation on the world market [1].

The demand for silicon is extremely high from both the semiconductor industry and the manufacturers of solar cells [2, 3]. Many experts consider the current situation critical since existing suppliers operating at full capacity are not capable of meeting the growing needs. A distinct feature of the silicon market is that only a few countries in the world have the capacity to produce it, and the relevant technologies are not for sale [4,5].

In Russia, there are two main manufacturers of metallurgical silicon: Kremny CJSC and SUAL-Kremny-Ural LLC [6]. Both companies are members of UC RUSAL.

On an industrial scale, metallurgical silicon is obtained by high-temperature reduction of silica, the SiO₂ content in which must be at least 98%, by carbon, namely, petroleum coke, which is manufactured at ANHK JSC according to GOST 22898–78, black coal (GOST 22898–78), charcoal A and B according to GOST 25543 – 88 [4,7,8].

It is known that the carbothermic process of obtaining silicon is accompanied by the formation of a large amount of man-made waste in the form of quartz fines, charcoal, black coal and petroleum coke fines, fine fraction silicon screenings and refining slags. A significant part of the waste is cyclone dust and sludge from wet gas cleaning (1 ton of silicon accounts for 280 - 900 kg of dust waste) [4,9], which has a negative impact on the environment near existing enterprises and on human health, especially on respiratory organs [5].



2. Materials and methods

In the study, we applied man-made materials in the form of gas cleaning dust produced by Kremny CJSC. This man-made material is the result of dust being emitted from the electric furnace forge. The dust can be of three product types:

1. Dispersed products of chemical reaction in the batch (Si and SiO₂ type) obtained by the disproportionation reaction: SiO₂ is a product of vapor oxidation of Si and SiO; CaO is the result of the oxidation of calcium vapor; Al₂O₃ is a product of deproportionation and oxidation of Al₂O, AlO [4,9].

2. Fine fraction particles of the batch from the top layer formed after the check screening and separation of fines. Resulting from grinding during dosing, transportation and loading of the batch into the ore-smelting furnace [10].

3. Products of batch raw materials grinding in the forge of quartzite and particularly carbonaceous materials during the recovery and downsizing of the reacting particles during the batch top layer settling [4].

So far, there is only partial solution to the issues of efficient dust extraction from gases, sorting this material by some useful features, its storage, disposal and sale as a commercial product, not to mention the development of measures to reduce its output during the process, so it goes to sludge depository [7].

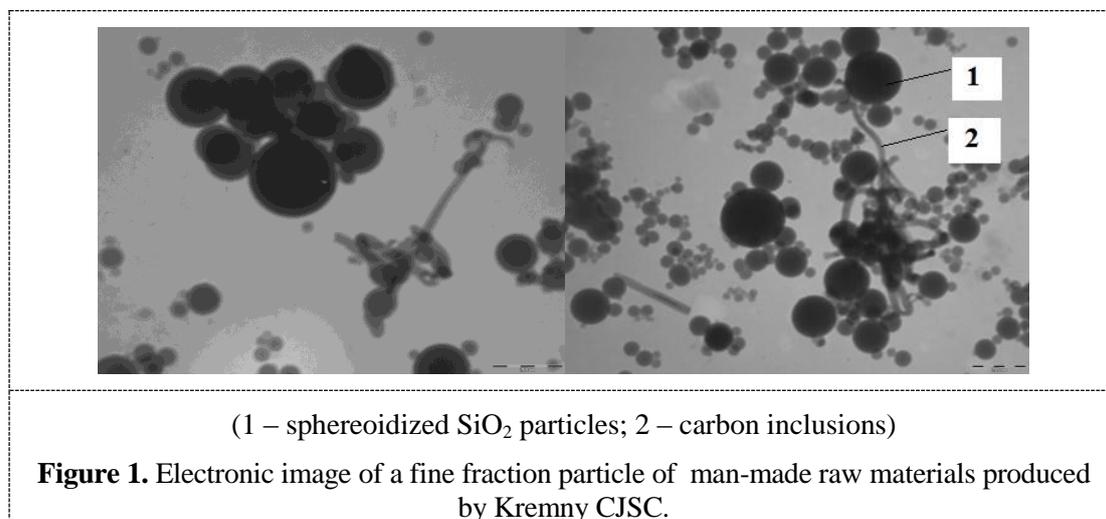
At the first stage, dry cleaning of gases in chambers or cyclones is carried out with settling of a coarser fraction amounting to 20% of the total dust mass. At the second stage, there are Venturi tubes installed, where the dust of a finer fraction is absorbed by the aqueous solution of soda ash according to reaction (1)



and in the form of sludge is directed by the hydrotransporter to the sludge storage area [9].

Dust from Venturi tubes contains the main mass of silicon lost with fumes and is the most finely dispersed product. 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 dumped and irretrievably lost with production waste [11]. Moreover, the very capture of fine dust particles using soda solutions requires a significant consumption of reagents, continuous expansion of sludge storage area, which ultimately represents a threat to the environment (due to the formation of alkaline aerosols and alkaline drains) [12,13].

Studies of the composition of man-made dust materials produced by Kremny CJSC, carried out using a JEOL JIB-Z4500 electron microscope equipped with an OXFORD INSTRUMENTS energy dispersive X-max 80 mm² detector, showed that SiO₂ in the sludge is represented as balls and spheres (Figure 1) [4,13].



According to production data, the dust of Kremny CJSC is represented on average by 86% of silicon

dioxide, Table 1 (results of XRF performed using AARL–9900 instrument (USA) and chemical gravimetric analysis); also there were studies performed using scanning microscopy [3,14,15].

Table 1. Chemical composition of gas cleaning dust produced by Kremny CJSC.

Components											
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	C _{fr.}	Na ₂ O	SO ₃	P ₂ O ₅	K ₂ O	TiO ₂	SiC
Content, % wt.											
86.3	0.37	0.30	1.4	1.20	5.8	0.07	0.14	0.12	0.28	0.02	4.15

As can be seen from the data in Table 1, the gas cleaning dust in the ore smelting furnace can be considered as the ore component of the batch as additional to the main raw material, since it is mainly represented by spheroidized SiO₂ particles [14,16].

Thus, it can be concluded that man-made dust materials of the silicon production captured by the gas cleaning system should be reused as an additive to the main raw material for smelting silicon, which will allow utilizing man-made waste and improving the environmental situation in the industrial production zone [17].

However, loading of dust waste into the ore-thermal furnace due to its finely dispersed structure is impossible, therefore this man-made raw material must be pelleted in advance [4].

3. The results of the study and their analysis

Palletizing is one of the crucial tasks in the preparation of the batch for metallurgical treatment [18]. Complete or partial replacement of the traditional lump charge with the pelleted one using man-made materials would solve the problem for enterprises that need not only to reduce the impact on the environment and improve working conditions, but also to provide the enterprise with additional resources [19,20].

Thus, it is possible to trace the reduction in fees for the disposal of man-made materials belonging to hazard class 4 at Kremny CJSC after the implementation of the proposed pelletizing method.

According to the data provided by the company, the volumes of fine fraction materials formed are given in Table 2 [4].

Table 2. Annual volume of dust-like materials produced by Kremny CJSC and silica content in them (according to data for 2017).

Material	Formation volume, t	Silica content in man-made materials, %
Gas cleaning dust	2,062.56	85.41 %
Gas cleaning sludge	30,961.3	95.86 %
Total:	33,023.86	≈ 90.635

Suppose that a part of the standard batch is replaced by 10% with the pelleted one, 5.66% of which is gas cleaning dust and sludge taken in a 1:1 ratio; hence, the formation of dust-like materials will be reduced by the same amount [4]. Accordingly:

$$1) 33,023.86 \cdot 5.66\% / 100\% = 1,869.15 \text{ (t);}$$

2) $33,023.86 - 1,869.15 = 31,154.71$ t/year is the estimated annual volume of the produced man-made materials of silicon production after the implementation of our proposed technical solutions.

The reduction of environmental fees for the negative impact on the environment due to the disposal of silica-containing silicon production materials in sludge storage areas was calculated taking into account the reduction in their volumes due to the use of the pelletized batch in the process of obtaining silicon [4].

The reduction of environmental fees was calculated using the formula (1) [21]:

$$F = V \cdot k_1 \cdot k_2 \cdot Q, \text{ rub/year}, \quad (1)$$

where F is the fee for disposal of man-made materials in sludge storage areas,

V is the estimated annual volume of silica-containing man-made raw materials produced, located in sludge storage areas, t/year;

k_1 is an additional factor for territories and objects under special protection – 2;

k_2 is a reduction factor of 0.3 when disposing of waste at specialized landfills equipped in accordance with the established requirements and located within the negative impact source industrial zone;

Q is the fee for disposal of 1 ton of man-made materials taking into account their hazard class, in rubles.

Since gas cleaning dust and sludge have 4 hazard class and the fee for disposal of 1 ton of materials of this type amounts to 663.2 rubles [21], then the reduction of environmental fees ΔF (rubles/year) is calculated as follows:

$F_1 = 33,023.86 \cdot 2 \cdot 0.3 \cdot 663.2 = 13,140,854.3712$ rubles/year (average annual fee for disposal of hazard class 4 waste before the implementation of the proposed technological solutions);

$F_2 = 31,154.71 \cdot 2 \cdot 0.3 \cdot 663.2 = 12,397,082.2032$ rubles/year (average annual fee for disposal of hazard class 4 waste after the implementation of the proposed technological solutions).

Accordingly, $\Delta F = 13,140,854.3712 - 12,397,082.20032 = 743,772.17$ rubles/year [4].

The complete elimination of environmental fees for the disposal of man-made materials in sludge storage areas is possible only if gas cleaning dust and sludge generated in the process of obtaining silicon will be used by third-party consumers. For example, in the construction industry as an additive to cementitious materials or as a raw material for the manufacture of bricks, concrete blocks and other products used in construction [4,22-24].

4. Conclusion

During the silicon production in ore-smelting furnaces, a significant amount of dust emissions is generated, having a negative impact both on the environment and on the human body, causing a number of respiratory diseases.

This type of man-made materials contains 86% of the SiO_2 component, which makes it possible to consider gas cleaning dust as an additional source of raw materials. However, before using in the carbothermic process, this material must be pelleted because of its fine fractional structure.

The proposed method of pelletizing man-made raw materials based on the silicon production dust makes it possible not only to improve working conditions and reduce the environmental burden through the involvement of dust waste into the silicon production process, but also to reduce the fee for the disposal of this type of waste in the enterprise area.

The reduction in fees for the disposal of man-made materials of hazard class 4 at Kremny CJSC after the implementation of the proposed technological solutions for obtaining silicon will amount to 743,772.17 rubles/year.

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