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Silicon Metallurgy and Ecology Problems

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Abstract

Modern silicon production technology is associated with a risk of negative environmental impact due to the fact that in addition to the final product, other reaction products are formed, including dust, from the incomplete use of charge materials. Gases released during silicon smelting in ore-thermal furnaces are characterized by the content of a large amount of fine dust. Dust consists of 94–96% of silicon dioxide. As a result of the use of sulfur-containing raw materials in furnaces as sulfur reducing agents, sulfur compounds in the form of SO2 are present in the furnace gases entering for purification, and nitrogen oxides are also present. The developed silicon recovery smelting technology reduces the technological energy consumption and increases the furnace productivity in proportion to the amount of carbon replaced by silicon carbide. Replacing carbon with silicon carbide reduces the dust content and the amount of exhaust furnace gases, and changes their composition. Thus, reducing the amount of pollutants reduces their anthropogenic impact on the environment.

Keywords: silicon, gas cleaning dust, gas capture system, microsilica

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The electrothermal production of metallic silicon is associated with the emission of reaction gases into the atmosphere. Purification of industrial gases from dust is one of the stages to reduce the environmental impact of industrial production [1]. Another direction of reducing the environmental impact is the development of technologies for a more complete use of natural resources and technologies for the utilization of waste from metallurgical industries.

Quartzite, charcoal, bituminous coal, petroleum coke and wood chips are used as charge materials in the production of metallic silicon. The reduction of silicon occurs from the total reaction

$$SiO_2 + 2C = Si + 2CO \quad (1)$$

According to modern theory, the process of silicon reduction in ore-thermal furnaces occurs in several stages. The first of them in the low-temperature zone of the furnace is the formation of silicon carbide by reaction

$$SiO_2 + 3C = SiC + 2CO \tag{2}$$

As the charge is introduced into the high-temperature zone of the furnace with increasing temperature, the formed silicon carbide interacts with the residual silica of quartzites by the reaction

$$SiO_2 + 2SiC = 3Si + 2CO \tag{3}$$

The result of this interaction is crystalline silicon, and silicon carbide in this case is the carrier of the reduction potential. Therefore, the replacement of part of the carbon reducing agents with silicon carbide is of certain practical and economic interest [2].

When comparing reactions 1 and 3, it is seen that in the first case, when preparing silicon, two moles of CO are formed per mole of silicon, while in reaction 3, two moles of CO are formed when three moles of silicon are obtained. The significance of this ratio served as the basis for the creation of technology for the production of technical silicon using its carbide. To test this technology, industrial tests were conducted on the use of silicon carbide materials in the production of technical silicon in powerful industrial electric furnaces. Silicon carbide of industrial production was used as a material.

Industrial silicon carbide is obtained in batch resistance electric furnaces by reduction of silica with carbon by reaction

$$SiO_2 + 3C = SiC + 2CO \tag{4}$$

As raw materials, quartz sand containing a minimum amount of impurities, and carbon reducing agents are used: petroleum coke or other low-ash carbon materials [3]. To increase the efficiency of using silicon carbide as a reducing agent, all small classes of raw materials for the production of technical silicon can be applied, which are formed when the mixture is prepared for smelting, namely, small classes of quartzite 0–20 mm and screenings (0–5 mm) of all types of reducing agents: charcoal, petroleum coke, coal.

Testing. When conducting experimental melts, the raw materials typically used at the plant for the production of silicon were used: quartzite, charcoal, petroleum coke, coal from Colombia and Kazakhstan in the proportions established by the factory production program for quality [4].

Table 1 shows the data on the consumption of charge materials, electricity and furnace productivity, obtained as a result of an industrial campaign to partially replace carbon-containing materials with silicon carbide. It is easy to notice a significant increase in productivity and a decrease in specific energy consumption as the carbide-containing additive increases. Of course, this is mainly caused by the introduction into the technological process of the finished intermediate of the total reduction reaction (1), the production of which does not require energy. However, having a higher electrical resistivity than carbon reducing agents, silicon carbide increases the resistance of the furnace charge zone and, accordingly, increases the arc component of the power, and, consequently, the intensity of silicon reduction.

TABLE 1: Furnace operation performances with the use of silicon carbide.

	Consumption per 1 ton of silicon, t/t			
	typical charge	replacement 7% C	replacement 10% C	replacement 20% C
Quartzite	3.046	2.787	2.658	2.324
Silicon carbide	–	0.323	0.409	0.627
Electricity, mWh/t	16.28	16.200	14.623	13.223
Productivity, t/day	29.40	30.96	34.47	37.96

The modern silicon production technology used in world and domestic practice is associated with a risk of negative environmental impact due to the fact that in addition to the final product, other reaction products are formed, including dust, from the incomplete use of charge materials. Gases released during silicon smelting in ore-thermal furnaces are characterized by the content of a large amount of fine dust. Dust consists of 94–96% of silicon dioxide. As a result of the use of sulfur-containing raw materials in furnaces as sulfur reducing agents, sulfur compounds in the form of SO2 are present in the furnace gases entering for purification, and nitrogen oxides are also present.

For a typical and experimental charges, the amount of reaction gases generated during the reduction smelting process was calculated. The calculation results are presented in table 2. Data on the dust content of the exhaust gases are shown in Figure 1. A positive environmental effect can be noted due to a significant (25–30%) reduction in the amount of exhaust gases and a decrease in their dust content. The composition of gases also changes significantly, which leads to a decrease in adverse environmental load in the area of dislocation of enterprises producing technical silicon.

TABLE 2: The amount of occurring gases per 1 ton of silicon.

gases	typical charge	replacement 10 % C
CO	2414 m^3	1985 m^3
CO_2	1134 m^3	803 m^3
H_2O	3041 m^3	2079 m^3
Total	6589 m^3	4867 m^3

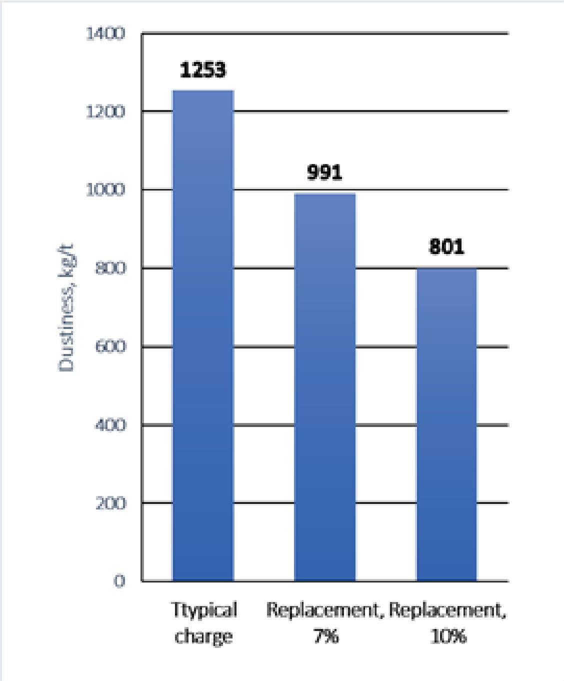

Figure 1: Change in the dust content of furnace gases.

1. Conclusions

The developed silicon recovery smelting technology reduces the technological energy consumption and increases the furnace productivity in proportion to the amount of carbon replaced by silicon carbide. Replacing carbon with silicon carbide reduces the dust content and the amount of exhaust furnace gases, and changes their composition. Thus, reducing the amount of pollutants reduces their anthropogenic impact on the environment.

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