Pulsed electric discharge for environmentally friendly cleaning and crushing of quartz sand

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Abstract. The paper presents the results of research on the use of a pulsed electric discharge in aqueous media for the pretreatment (preliminary crushing and washing) of quartz sand in the glass industry. The averaged granulometric and elemental composition of quartz sands of the Muraevnya deposit has been studied (explored reserves are 31 million tons). The efficiency of the proposed method for treating quartz sand for its subsequent cleaning from undesirable impurities (primarily iron and clay oxides) is shown, preliminary parameters of the treatment process, changes in the granulometric and elemental composition of raw materials, and specific energy consumption for its treatment are determined. The main advantage of the technology is that it makes it possible to obtain such a degree of purification of quartz sand from impurities due to the destruction of impurities aggregated with silicon oxide particles, which is unattainable with standard flushing.

1. Introduction

The concept of sustainable development, among other things, implies the need to reduce the specific amount of industrial emissions and waste per unit of production. In large-scale production processes, this requirement is an unconditional priority for improving technologies, since even a minimal reduction in emissions and waste leads to a significant absolute reduction in environmental impact and economic costs. It is also important to refuse to use (minimize the use) of unique types of raw materials, the reserves of which are limited (difficult to develop), since their depletion (rise in price) calls into question the sustainable operation of enterprises in the future. The glass industry combines scale, the need for high-quality raw materials and high energy intensity, so the use of innovative methods of cleaning and pretreating raw materials is an important element in ensuring its sustainable development.

2. Materials and methods

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The source material is quartz sand of the Muraevnya mining and processing plant (Miloslavsky district, Ryazan region, Russia - Google Maps coordinates 53.4828254,39.4700061).

For the general characteristics of the sand of the deposit, 30 samples were taken from various areas. For technology experiments, sand was taken from the alluvial map of Muraevnya MPP in the amount of 150 kg.

The study of the samples was carried out using an MBS-10 optical microscope manufactured by LLC LOMO (Russia) and a TESCAN VEGA 3 SBH2 scanning electron microscope manufactured by TESCANBRNO (Czech Republic). Electron-optical system: electron source - tungsten cathode with thermionic emission. Signal detectors: Everhart – Thornley type secondary electron detector and scintillator type detector of reflected electron based on a highly sensitive YAG crystal (yttrium aluminum garnet). Sample preparation - gold sputtering.

2.1 Preparation of an experimental electrohydraulic plant

The electrohydraulic plant [1, 2] (Figure 1) consists of an electrical part (not shown in the figure) and a mechanical part, which is a container equipped with a discharge chamber with a working spark gap and a system for circulating the working fluid and pulp.

The receiving part, in which the crushed material is accumulated, is made in the form of a straight vertical pipe.

Fig. 1. Plant layout.

Figure 2 shows a general view of the experimental plant. Water is fed into the working tank from the bottom and flows out through the four upper polyethylene drain pipes to the geotextile filter.

The first stage of separation of fractions takes place in a working vessel. The size of the washed out fraction is determined by the flow rate of the liquid inside the working vessel. By adjusting the water flow rate, it is possible to adjust the size of the washed out fraction.

The second stage of separation takes place on a geotextile filter. Fractions remain on the geotextile that it does not let through.

Fractions passing through the geotextile are deposited in a special container under the geotextile. This is another step in the separation of fractions. According to the experience of similar work, the flow rate of the flushing water flow was set at 17 l/min.

Fig. 2. Experimental electro-hydraulic plant for quartz sand beneficiation.

3. Results and discussion

At the first stage, an averaged granulometric characteristic of the field sand was obtained and compared with the sand from the batch selected for the study (Figure 3).

Fig. 3. Original sand sample.

The comparative diagram (Figure 4) shows that, in general, the original quartz sand does not differ too much in fractional composition from the average sand for the quarry. But there are much more coarse fractions and less of the finest fractions in the original sand.

Fig. 4. Comparative histogram of the granulometric composition of the sand selected for the experiment (purple bars) and the average value for the field (brown bars).

The elemental composition of the sand selected for the experiment was determined using an electron microscope (Figure 5). Quantitative data are presented in table 1.

Fig. 5. Study of the trace element composition of sand from the original batch.

Table 1. Elemental composition of a sand sample from the original batch

The point in the image shown in Figure 3	Content of elements, %wt.									Σ
	C	O	Mg	Al	Si	K	Ca	Ti	Fe	
Spectrum 1		67.82		2.44	29.74					100.00
Spectrum 2		54.86		3.14	22.80				19.20	100.00
Spectrum 3	4.01	54.91	0.33	3.01	36.32	0.37			1.05	100.00
Spectrum 4	0.00	62.78	0.58	7.48	25.27	0.72	0.30	0.18	2.69	100.00
Spectrum 5	7.44	54.26	0.41	3.10	32.44	0.20	1.63		0.52	100.00
Spectrum 6		69.51		2.20	28.29					100.00
Spectrum 7	7.94	59.36		1.88	29.97				0.85	100.00

The presence of a large amount of iron in the original sample of sand is confirmed by the well-known qualitative reaction using ammonium thiocyanate [3].

Thus, it is necessary to process the original sand to remove unwanted impurities, primarily iron oxide (Fe2O3). We propose the treatment of sand with an electric discharge in an aqueous medium, while part of the sand is crushed and particles of impurities are released, which makes it possible to obtain almost pure quartz sand.

The selection of conditions for sand treatment was carried out by the method of a full factorial experiment. We studied the yield of fractions, elemental composition, color of sand, and energy costs. The plan of the experiment, the yield of fractions, and energy consumption are shown in Table 2 (the mass of the experimental sample is 5 kg by dry weight).

For further research, the samples were selected by color organoleptically. Samples from experiments 6.1, 7.1 and 8.1 had the purest white color. These samples were dispersed on analytical sieves, and the iron content was determined in them.

Table 2. Sand cleaning experiment plan and results.

Experiment number		1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1
Factors:	Working capacitor capacity, μF	25	25	40	40	25	25	40	40
	Discharge voltage, kV	0.25	2	0.25	2	0.25	2	0.25	2
	Number of discharges	200	200	200	200	600	600	600	600
Entrainment of fine fractions, wt%. by dry weight		5.75	14.66	6.59	52.28	4.12	31.68	20.62	69.21
Energy consumption, kW/h		0.05	0.05	0.06	0.16	0.06	0.14	0.10	0.30

The obtained data on the granulometric composition of the selected options, summarized in one histogram (Figure 6), allow a comparative analysis of the change in the fractional composition of quartz sand during the beneficiation process.

Figure 6 shows that the treatment modes affect the fractional composition - there is a significant decrease in the largest fraction in all variants. Thus, additional crushing of large fractions and erosion of clay aggregates takes place. The number of fractions decreases sharply to 2.5 mm and less than 0.1 mm. Small fractions are washed out by the working fluid. At the same time and in connection with this, there is a steady increase in the content of fractions of 0.2-2 mm.

Further, the elemental composition of enriched quartz sand was determined. The results are shown in Figures 7-9 and tables 3-5. From tables 3-5 it can be seen that in experiment 7.1, the iron content decreased by half, and they are completely absent in experiments 6.1 and 8.1. Since iron was detected in version 7.1, this mode should be excluded from consideration.

Fig. 6. Granulometric composition of samples obtained as a result of processing the original quartz sand (color of the columns: red - option 6.1; green - 7.1; blue - 8.1).

Fig. 7. Study of the trace element composition of sand (option 6.1).

Table 3. Elemental composition of the treated sand sample (option 6.1).

The point in the image shown in Figure 8	Content of elements, %wt.				Σ
	C	O	Al	Si	
Spectrum 1	8.19	57.01		34.80	100.00
Spectrum 2		65.53		34.47	100.00
Spectrum 3		61.43		38.57	100.00
Spectrum 4		57.80		42.20	100.00
Spectrum 5		63.40		36.60	100.00
Spectrum 6		60.79		39.21	100.00
Spectrum 7	5.99	59.81	0.41	33.79	100.00

Fig. 8. Study of the trace element composition of sand (option 7.1.).

Table 4. Elemental composition of the treated sand sample (option 7.1).

The point in the image shown in Figure 9	Content of elements, %wt.					Σ
	C	O	Al	Si	Fe	
Spectrum 1		45.39		54.61		100.00
Spectrum 2		60.72		39.28		100.00
Spectrum 3		70.28		29.72		100.00
Spectrum 4		59.93	0.42	36.78	2.87	100.00
Spectrum 5		56.83		43.17		100.00
Spectrum 6		69.39		30.61		100.00
Spectrum 7	3.95	60.14		35.91		100.00

Fig. 9. Study of the trace element composition of sand (option 8.1).

Table 5. Elemental composition of the treated sand sample (option 8.1).

The point in the image shown in Figure 10	Content of elements, %wt.				Σ
	C	O	Al	Si	
Spectrum 1	3.34	63.36	0.21	33.09	100.00
Spectrum 2	3.12	58.10		38.78	100.00
Spectrum 3		65.96		34.04	100.00
Spectrum 4		38.21		61.79	100.00
Spectrum 5		65.26		34.74	100.00
Spectrum 6		56.00		44.00	100.00
Spectrum 7	24.46	52.61		22.93	100.00

In addition to sand enrichment, the method can be successfully used for disinfection of liquid and solid waste [4]. Sand similar in consistency, very significant (from 5-10 [5, 6] to 20-34% [7, 8]) and problematic (moisture $\approx 80\%$ wt., Microbiological contamination 109-1010 CFU / g [9]) fraction of the municipal solid waste can be successfully sanitized in the same way.

4. Conclusions

1. Treatment of quartz sand with a pulsed electric discharge in an aqueous medium makes it possible to almost completely remove unwanted impurities, primarily iron oxides.
2. The fractional composition of the obtained material and the degree of its enrichment are regulated by the selection of modes.
3. Energy consumption for the enrichment of one ton of original quartz sand can be up to 12 kWh.

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