The study of the silica clay dust elemental composition in building materials’ production

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Abstract. The paper discusses the physical properties of the silica clay used as building material and mineral. During crushing, pouring, packing and other processes the dust which enters the storage bunkers of dust removal systems, is formed; it is emitted from the dust collecting devices into the atmosphere, and a part of the dust enters the working area. The paper compares the elemental composition of the silica clay before the crushing operation; the dust collected in bunkers of dust removal systems; in the air emissions; the dust after using the dust collectors and working area air dust. The study was conducted using a Versa 3D Dual Beam scanning electron microscope. The dust characteristics’ comparative studies were carried out in three intake zones for three types of dust collectors used in dust removal systems: fabric filters, cyclones and swirling approach flows (SAF). The homogeneity hypothesis was tested using the Kolmogorov-Smirnov criterion. Based on the measurement results, it was concluded that the dust from the dust bunkers for all the dust collector options has a close elemental composition and can be returned to the additives’ production process. It is shown that the dust entering the working area air and in emissions into the atmosphere are close in their characteristics. The results of measuring the random distribution functions of the elemental composition and molecular weight are obtained, which allow calculating particle weight and other characteristics with 95% certainty, as well as evaluating the aerodynamic characteristics of dust particles, etc.

Introduction

In connection with the wide industrial construction methods’ development, the issue of the local durable stone materials’ rational use in constructions is of great importance. Not only cement, dry building mixtures, but also organogenic rocks can be used as building materials and minerals. These are sedimentary rocks, consisting of the animal and plant organisms’ remains and their waste products. Let us consider a silica clay as an example, which has a very wide range of uses, both as a sorbent and as an additive to building materials [1]. Silica clay can be used in concrete as small and large aggregate and an active mineral additive to cement. According to their physical and mechanical properties that affect the concrete properties and its preparation technology, silica clay can be divided into 3 types: dense silica clay, light porous silica clay, mixed silica clay [2].

During crushing, pouring, packaging and other operations, a large amount of dust, which enters the air of the working area and the dust removal system, is released. The main part is captured there, and a small part is released into the atmosphere. The amount of dust emitted into the atmosphere depends on the dust collector’s efficiency [3]. Dust overshoot is, for example, in a cyclone - up to 8%, in the swirling
approach flow (SAF) apparatus - up to 2.2%, in a fabric filter - up to 0.5%. Thus, dust enters the hopper of the dust collection system, into the working area and into the atmosphere. Therefore, the objective of the study was to assess how much the elemental composition of dust particles differs from the elemental composition of silica clay. It affects the settling speed and other aerodynamic characteristics that are important for the dust entering the air. And for the captured dust, the proximity of its characteristics to the starting material (silica clay prior to crushing) would allow it to be returned to the technological process, using further as additives.

The elemental composition was studied for two deposits, where the elemental composition of the silica clay obtained in the deposits was compared to the three types of the dust released during crushing, pouring, packing and other operations. The elemental composition of dust was determined during the operation of the following three types of apparatuses: a standard fabric filter with pulse blowing, standard cyclones and a dust collector on counter swirling flows (SAF). As the SAF was selected SAFSC with a dust concentrator installed inside the dust collector body with a spiral partition and a hollow cylindrical chipper (utility model patent 196477 Russian Federation, IPC B04C 3/00 (2006.01) Vertical dust collector) [4]. The vertical dust collector SAFSC consists of a cylindrical body with a conical dust collector, an upper axial outlet nozzle for purified gas, an upper tangential nozzle for a dusty gas inlet and a lower tangential nozzle for a dusty gas inlet, a conical swirl with a blow-off washer, and the apparatus is additionally equipped with a dust concentrator with different dust content, which facilitates their further dedusting, as well as a spiral partition installed inside the dust collector body and a hollow cylindrical chipper, which creates an intensive dusty gas flows’ swirling and the released dust’s separation.

Materials and methods
The silica clay was selected in the deposits of the Astrakhan and Volgograd regions. The studies were carried out on the elemental composition of the silica clay material coming from the field for processing and 3 types of dust: in the dust removal systems’ bunker, in emissions into the atmosphere, and also in the air of the working area.

Microscopic analysis of the dust samples was performed using a Versa 3D Dual Beam scanning electron microscope. The elemental composition of the samples under consideration was studied by the scanning transmission electron microscopy (STEM). High vacuum mode (Hi Vac) with the use of various detectors: secondary, backscattered and transmitted electrons (ETD, CBS, STEM), makes it possible to obtain the high-resolution images of metal, composite and powder materials. Dispersion analysis of dust samples was carried out using the micrographs obtained as a result of microscopic examination using the specialized Image J software [1,5,6].

The number of samples for each type of dust is 100. The samples’ homogeneity hypothesis was checked by the Kolmogorov-Smirnov criterion, and the normality of the distribution law of random variables was checked by the criterion $\chi^2$.

Discussions and Results
Figure 1 (a, b) presents the 3D scanned samples images of the silica clay from two deposits before crushing [7,8].

The analysis showed that in all samples, the fundamental elements are Si, Na, Al, Ca, Fe. However, there are differences, for example, Si varies from 26.87 to 28.70% for the silica clay from the Astrakhan deposit before crushing, and from the Volgograd deposit in the range of 35.55 - 26.71%.

Figure 2 (a, b) presents the 3D scanned dust samples images of the silica clay from two deposits (Astrakhan and Volgograd regions).
**Figure 1.** The surface microphotographs of the silica clay from various deposits before crushing: Astrakhan (a) and Volgograd (b) regions

**Figure 2.** The dust particles’ micrographs of the silica clay from various deposits: Astrakhan (a) and Volgograd (b) regions

Figure 3 shows the chemical composition and dust structure of the silica clay material taken in emissions into the atmosphere and air of the working area, based on quantitative and qualitative X-ray microanalysis (EDS) [9-14].
Figure 3. X-ray microanalysis of dust of the silica clay from the Astrakhan (a) and Volgograd region (b) deposits. Spot 1 - in air emissions, Spot 2 - in the air of the working area.

When performing the crushing operation, a small amount of dust enters the working area of the enterprise. Table 1 shows the elemental composition percentages, molecular weight and dust weight of the silica clay from two deposits. It is shown that all quantities can be considered as random normal values, which are described by the mean values and variance.

Table 1. The Elemental composition of the dust silica clay in the working zone air from the various deposits of the Astrakhan and Volgograd regions

| Deposit         | Element | Weight [%]     | Atomic [%]  |
|-----------------|---------|----------------|-------------|
| Astrakhan region| C       | 13.87 - 16.58  | 21.06 - 25.04|
|                 | O       | 45.69 – 52.21  | 51.8 – 66.22 |
|                 | Na      | 0.5 – 1.15     | 0.4 – 1.02   |
|                 | Mg      | 0.46 – 0.77    | 0.34 – 0.65  |
|                 | Al      | 2.76 – 3.37    | 1.86 – 2.53  |
|                 | Si      | 28.79 – 38.46  | 18.59 – 27.79|
|                 | Cl      | 0.45           | 0.26         |
|                 | K       | 0.94 – 2.00    | 0.44 – 0.93  |
|                 | Ca      | 0.42           | 0.22         |
|                 | Fe      | 2.12 – 3.23    | 0.77 – 1.05  |
| Volgograd region| C       | 9.89           | 15.51        |
|                 | O       | 42.87 – 52.7   | 55.35 – 68.19|
|                 | Mg      | 0.78           | 0.65         |
|                 | Al      | 1.23 – 5.22    | 0.86 – 3.93  |
|                 | Si      | 5.92 – 41.1    | 5.37 – 27.83 |
|                 | K       | 0.79           | 0.41         |
|                 | Ca      | 0.46           | 0.24         |
|                 | Fe      | 1.32 – 19.76   | 0.45 – 9.01  |
|                 | Ti      | 27.62          | 14.67        |
|                 | Mn      | 1.74           | 0.8          |

Tables 2 and 3 show the results of measuring the silica clay elemental composition before crushing, the trapped dust, the dust in the working area, the emissions into the atmosphere after a cyclone, emissions into the atmosphere after SAF, the emissions into the atmosphere after a fabric filter of deposits in the Astrakhan and Volgograd regions.
Table 2. The comparative analysis of the silica clay elemental composition from the deposit in the Astrakhan region before crushing and dust after crushing

| No . | Element                        | Weight elements’ share, % |
|------|--------------------------------|---------------------------|
|      | C     | O     | Na   | Mg   | Al   | Si   | S    | Cl   | K    | Ca   | Ti   | Fe   |
| 1.   | Silica clay before crushing    | 9.15-10.58               |
|      | 46.15 | 6.04  | 0.97 | 4.58 | 27.87 | 0.88 | 5.25 | 1.35 | 1.05 | 0.15 | 2.87 |       |
| 2.   | Trapped dust                   | 9.10-10.59               |
|      | 45.15 | 6.02  | 0.95 | 4.51 | 26.57 | 0.86 | 5.27 | 1.33 | 1.06 | 0.14 | 2.89 |       |
| 3.   | Dust in the working area       | 13.87                    |
|      | 45.69 | 0.5   | 0.46 | 2.76 | 28.79 | -    | 0.45 | 0.94 | 0.42 | -    | 2.12 |       |
| 4.   | Dust emission after cyclone   | 10.20                    |
|      | 46.55 | 0.92  | 0.52 | 3.06 | 27.90 | 0.90 | 1.03 | 0.89 | 0.78 | 0.13 | 2.15 |       |
| 5.   | Dust emission after SAF        | 10.23                    |
|      | 44.55 | 0.82  | 0.56 | 3.03 | 26.89 | 0.83 | 1.01 | 0.79 | 0.68 | 0.12 | 2.14 |       |
| 6.   | Dust emission after fabric filter | 10.18                 |
|      | 46.65 | 0.59  | 0.51 | 3.06 | 26.15 | 0.89 | 1.01 | 0.87 | 0.79 | 0.11 | 2.13 |       |

Table 3. The comparative analysis of the silica clay elemental composition from the Volgograd region deposits before crushing and dust after crushing

| No . | Element                        | Weight elements’ share, % |
|------|--------------------------------|---------------------------|
|      | C     | O     | Na   | Mg   | Al   | Si   | S    | Cl   | K    | Ca   | Ti   | Fe   | Mn   |
| 1.   | Silica clay before crushing    | 7.48                      |
|      | 55.11 | 0.26  | 0.39 | 3.22 | 36.68 | -    | -    | 1.42 | 0.32 | -    | 2.43-2.45 |       |
| 2.   | Trapped dust                   | 7.46                      |
|      | 55.04 | 0.23  | 0.36 | 3.21 | 36.64 | -    | -    | 1.38 | 0.31 | -    | 2.42-2.50 |       |
| 3.   | Dust in the working area       | 9.89                      |
|      | 42.87 | -     | 0.78 | 1.23 | 5.92  | -    | -    | 0.79 | 0.46 | 27.62 | 1.32 | 19.7 | 1.74 |
| 4.   | Dust emission after cyclone   | 7.89                      |
|      | 44.80 | 0.25  | 0.45 | 4.42 | 23.08 | -    | -    | 0.98 | 0.34 | 27.23 | 2.56 | 16.1 | 1.01 |
| 5.   | Dust emission after SAF        | 7.87                      |
|      | 43.80 | 0.20  | 0.44 | 4.38 | 23.08 | -    | -    | 0.97 | 0.33 | 27.13 | 1.15 | 9.6 | 1.03 |
|      | -    | 54.48 | 0.56 | 0.69 | 4.94  | -    | -    | 1.35 | 0.42 | 27.61 | -    | 1.41 |       |
The dust trapped by all 3 types of devices has a close composition. For example, the Fe average content for dust in the bunkers of the devices of the three types under consideration: for the Astrakhan deposit in the range of 2.89 - 2.97%, the average value of the random variable Fe is 2.94%, and for silica clay before crushing, the average value of this parameter has a close value to 2.91%. Accordingly, for the Volgograd deposit, the average value of the random variable Fe is 2.46%, and for silica clay before crushing it is 2.44%.

Although the dust dispersed composition studies showed that after the fabric filter, the dust is finer, but the elemental composition for all three types of dust collectors has similar distribution laws. Although some values fall outside the 95% changes range. So, for example, for the dust from the Volgodograd region deposit after a fabric filter, 97% of the measurement values showed that Fe is in the range 1.32 - 2.49%. For 95% of the experiments, the average value of the Fe share in the emissions into the atmosphere after a fabric filter is 1.91%, for the emissions into the atmosphere after SAF - 2.12%, for the emissions into the atmosphere after a cyclone - 2.3%, for the dust in the working area it is 2.31%. So, the changes range in the average values of the Fe proportion in the working zone air and after the typical dust collectors with a 95% probability is in the range from 1.91 to 2.31%.

A similar conclusion can be made for other components. The distribution laws and other elements, for all 4 considered cases, are close, and can also be described by the normal distribution laws. According to Fe, for the Astrakhan region deposit, the average content for the dust in the working area is 2.68%, in the emissions to the atmosphere after a cyclone - 2.61%, in the emissions into the atmosphere after SAF - 2.51%, in the emissions into the atmosphere after fabric filter - 2, 37%, i.e. the range of average values variation for Fe is in the range of 2.37-2.61%. That is higher than the value of this deposit of the Volgodograd region. In the silica clay before crushing the average Fe content is 2.91%.

**Summary**

1. The dust caught by all types of the dust collectors: cyclones, SAFs, fabric filters - is close in its elemental composition to the silica clay before the crushing operation. So, for example, for the silica clay from the Astrakhan deposit, the average Fe content in the captured dust is 2.94%, and in the silica clay before crushing - 2.91%, respectively for the Volgograd deposit - 2.46% and 2.44%. Therefore, it can be returned to the technological process in the additives’ production, etc.

2. The elemental composition of the dust entering the working area air and into the atmosphere after typical fabric filters, cyclones and SAF has a large scatter in the maximum and minimum values, but with a 95% probability it has close distribution laws typical for each deposit, for example, the average Fe value in the silica clays dust from the Astrakhan deposit is in the air within 2.37% - 2.61%, and for the Volgodograd deposit - 1.91% - 2.31%.

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