Filtration materials of natural origin

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Abstract. The research reveals test results of physical and mechanical properties of filtration materials of natural origin (that is of crushed expanded-clay aggregate with 525 and 555 kg/m\(^3\) bulk density and "Diamix AQUA" with 670 kg/m\(^3\) bulk density). The raw materials for the production of expanded-clay aggregate are easily expansive clays containing such oxides as SiO\(_2\) (up to 60 %), Al\(_2\)O\(_3\) (up to 20 %), Fe\(_2\)O\(_3\) (from 4 to 20 %). "Diamix AQUA" is a material obtained on the basis of natural diatomite which contains exoskeletons of diatoms. The content of oxides in "Diamix AQUA" is as follows: SiO\(_2\) – no less than 83%, Al\(_2\)O\(_3\) – no more than 6%, Fe\(_2\)O\(_3\) – no more than 3.5 %. There are certificates of state registration for both types of filtration materials. The research results of the new filtration material "Diamix AQUA" used as a filter bed showed its acceptable physical and mechanical properties. "Diamix AQUA" regenerating requires an increased wash-water rate. Such filter media can be applied to newly constructed filtration facilities. When using "Diamix AQUA" in existing filter beds, it is necessary to check the capacity of the drainage and distribution system.

1. Introduction
When treating water for municipal and industrial water supply, in the vast majority of cases, granular-filter beds are used. Their main element is a filter bed, which provides high purification efficiency. Quartz sand, which is widely used as a filtration material with solid spherical grains, has such insufficient technological parameters as low contaminant capacity, heavy pressure losses and the intensity of their growth, considerable flow intensity for washing-off.

Quartz sand used as filter media is ineffective. For most parts of the country, it is a difficult-to-obtain and expensive material.

2. Research basis
For a number of years, the Water Supply and Wastewater Disposal Chair of the Academy of Construction and Architecture (Samara State Technical University) has been conducting a research to intensify the operation of filtration facilities by using highly porous granular filter beds with a wide specific surface area.

The scholars [1] investigated physical, mechanical and hydraulic properties of crushed expanded-clay aggregate obtained by crushing granulated expanded-clay with a grain size of 10-40 mm of different bulk density.
Studies [1-7] have shown that the use of crushed expanded-clay aggregate as a filtration material instead of quartz sand can improve water purification efficiency, increase filters performance and their contaminant capacity, reduce head losses and specific water consumption for filter media regeneration.

The resulting high technological efficiency of expanded-clay aggregate filter media contributed to a wide interest of researchers to other local filtration materials. Currently, they propose using for this purpose such local materials as light concrete with foamed carbon aggregate (known as shungizit, in Petrozavodsk) and ODM-2F (in Ekaterinburg).

3. Research Calculations

The authors of this paper carried out extensive research on a new filtration material obtained on the basis of natural diatomite "Diamix AQUA", produced by the company "Diamix", located in the town of Inza, Ulyanovsk region.

This filtration material was used for the preparation of drinking water from surface and underground water supply sources in rapid non-pressure and pressure filters of water treatment plants instead of the traditionally used quartz sand filters.

Technology assessment of filtration materials requires an account of such physical and mechanical properties as bulk density, standard fall velocity, apparent specific density, mechanical strength and wash-water rate.

Studies of "Diamix AQUA" with 670 kg/m³ bulk density were done in parallel with those of the filtration material prepared on the basis of crushed expanded-clay aggregate with 525 and 555 kg/m³ bulk density.

This filtration materials bulk density was calculated after drying to a constant weight by using a 100 cm³ pycnometer. The studied fraction was filled into the pycnometer up to the mark, then the filter media was compacted by vibration with additional filling until a constant volume was established. Then the filter media was weighed. The filter media bulk density, g/cm³, was determined by the formula:

\[ \gamma_0 = \frac{P_1 - P_2}{W}, \]  

where \( P_1 \) is the weight of crushed fraction along with the pycnometer, g; \( P_2 \) is the weight of the pycnometer, g; \( W \) is the volume of the pycnometer, cm³.

The results of bulk density calculations are summarized in Table 1, which shows that the filtration materials bulk density depends on the size of its particles and increases with particles decrease.

| Fraction, mm | Average filter media diameter, mm | Bulk density of the granular material, g/cm³ |
|--------------|----------------------------------|---------------------------------------------|
|              |                                  | Crushed expanded-clay aggregate  | "Diamix AQUA" |
|              |                                  | \( \gamma_0 = 0.525 \) | \( \gamma_0 = 0.555 \) | \( \gamma_0 = 0.670 \) |
| 0.25-0.5     | 0.375                            | –                              | –              | 0.830                     |
| 0.5-0.8      | 0.650                            | –                              | –              | 0.825                     |
| 0.8-1.0      | 0.900                            | 0.696                          | 0.643          | 0.823                     |
| 1.0-1.2      | 1.100                            | 0.590                          | 0.607          | 0.822                     |
| 1.2-1.5      | 1.350                            | 0.553                          | 0.594          | 0.821                     |
| 1.5-2.0      | 1.750                            | 0.561                          | 0.592          | 0.820                     |
Standard fall velocity was determined at a water temperature of 20°C. For each fraction (by size and bulk density) of the materials under consideration, at least 20 experiments were conducted. Table 2 shows data on materials standard fall velocity depending on their bulk density and the diameter of filter media grains.

| Average filter media diameter, mm | Crushed expanded-clay aggregate | "Diamix AQUA» | Bulk density, g/cm³ |
|----------------------------------|---------------------------------|---------------|--------------------|
|                                  | γ₀ = 0.525                      | γ₀ = 0.555     | γ₀ = 0.670         |
| 0.65                             | 2.6                             | 3.1           | 6.82               |
| 0.90                             | 3.8                             | 4.3           | 8.34               |
| 1.10                             | 4.0                             | 4.5           | 8.6                |
| 1.20                             | 4.8                             | 5.0           | 8.67               |
| 1.50                             | 5.5                             | 6.1           | 8.78               |

Table 2. The materials standard fall velocity.

Standard fall velocity of the studied samples of crushed expanded-clay aggregate varies from 2.6 cm/s for a filter media with its particles diameter of 0.65 mm with 525 kg/m³ bulk density to 6.82 cm/s for a grain diameter of 1.5 mm and 670 kg/m³ bulk density. "Diamix AQUA” standard fall velocity ranges from 3.1 to 6.1 cm/s for a grain diameter of 0.65 mm to 8.78 cm/s for an average grain diameter of 1.5 mm.

Apparent specific density. The existence of the apparent specific density of crushed expanded-clay aggregate is determined by the existence of closed pores inside the particles. By analogy with crushed expanded-clay aggregate, "Diamix AQUA” apparent specific density was also calculated. Samples of this filter media with a given fraction of 50 g were brought to a constant weight and poured into volumetric flasks. Distilled water was poured into the flasks (two-thirds of their volume) and the samples were being boiled for 30 minutes to remove air from the pores. At the end of the boiling cycle, the flasks were cooled to 20°C and weighed.

The apparent specific gravity Ra was calculated by the formula

\[ P_a = \frac{P_1 \cdot \gamma_w}{P_1 + P_2 - P_3}, \]  \hspace{1cm} (2)

where \( P_1 \) is the weight of crushed filtration material, g; \( P_2 \) is the weight of the flask with distilled water, g; \( P_3 \) is the weight of the flask with water and weigh, g; \( \gamma_w \) is the water specific density, g/cm³.

Table 3 shows the apparent specific density of "Diamix AQUA” and crushed expanded-clay aggregate after 30 minutes of boiling. As the data given in Table 3 indicates, the apparent specific density depends on the bulk density of the filtration material and the particles size. As the particles size increases, the apparent specific density decreases.

Mechanical strength. The study of the mechanical strength of crushed expanded-clay aggregate and "Diamix AQUA” was performed according to the generally accepted methodology. In the course of research, the degree of grinding and abrasion of these filtration materials samples was determined after 24 hours of shaking in a shuttle machine (kind of a mixer). The surface of grains of crushed expanded-clay aggregate and "Diamix AQUA” was studied after 24 and 48 hours of shaking. Photomicrographs of these filtration materials grains taken after the shaking showed that the only changes which occurred with increasing time of shaking caused sharp edges chipping. No significant changes were observed. Grains of crushed expanded-clay aggregate remained porous and had a more extended surface than that of quartz sand.
Table 3. The apparent specific density after boiling.

| Fraction, mm | Average filter media diameter, mm | Bulk weight of the granular material, g/cm³ |
|--------------|----------------------------------|--------------------------------------------|
|              |                                  | Crushed expanded-clay aggregate           | "Diamix AQUA"                               |
|              |                                  | $\gamma_0 = 0.525$                        | $\gamma_0 = 0.555$                          |
|              |                                  | $\gamma_0 = 0.670$                        |                                            |
| 0.25-0.5     | 0.375                            | -                                         | 3.000                                      |
| 0.5-0.8      | 0.650                            | -                                         | 2.976                                      |
| 0.8-1.0      | 0.900                            | 2.14                                      | 2.22                                       |
| 1.0-1.2      | 1.100                            | 2.08                                      | 2.18                                       |
| 1.2-1.5      | 1.350                            | 2.05                                      | 2.12                                       |
| 1.5-2.0      | 1.750                            | 2.03                                      | 2.09                                       |

The surface of the "Diamix AQUA" grains was smooth and had a rounded configuration. The pores in the "Diamix AQUA" grains were of an isometric shape isolated from each other. Single large pores had the form of communicating interstices.

The results of abrasiveness and grindability tests are summarised in Table 4.

Table 4. The results of abrasiveness and grindability tests.

| Material wear characteristics | Expanded-clay aggregate | "Diamix AQUA" |
|------------------------------|--------------------------|---------------|
|                              | $\gamma_0 = 0.525$      | $\gamma_0 = 0.555$ |
| Grindability                 | 3.23                     | 1.84          |
| Abrasiveness                 | 1.0                      | 0.93          |
| Total wear and tear in 24 hours | 4.23                     | 2.77          |

According to the generally accepted methodology, any filtration material is considered to be mechanically strong if the material's grinding capacity does not exceed 4% and the abrasion rate does not exceed 2.5% after being shaken in a shuttle machine for 24 hours. Table 4 data analysis shows that the strength of the considered filter media meets the requirements for filtration materials.

Chemical resistance. Samples of the studied material were tested for their chemical resistance to alkaline and acidic environments according to generally accepted methods. Research results are given in Table 5.

Table 5. The results of chemical resistance.

| Filtration material | Indicator of resistance to aggressive environment |
|---------------------|-----------------------------------------------|
|                     | Acid environment | Alkaline environment |
|                     | increase in permanganate oxidability, mg/dm³ | increase in silicic acid, mg/dm³ |
| Expanded-clay aggregate | 1.6            | 4.80            |
| "Diamix AQUA"        | 0.8            | 2.48            |
The filtration materials in question are chemically stable in both acid and alkaline environments. The increase in permanganate oxidability and silicic acid does not exceed the standard values of 10 and 10 mg/dm³, respectively.

The intensity of wash-water rate was determined by the degree of expansion of crushed expanded-clay aggregate with 0.525 and 0.555 mg/cm³ bulk density and "Diamix AQUA" with 0.670 g/cm³ bulk density. The studies were conducted at a water temperature of 20°C.

Figure 1 shows the obtained dependences of the wash-water rate and the degree of filter media expansion on the bulk density of filtration materials (crushed expanded-clay aggregate and "Diamix AQUA").

![Figure 1](image)

**Figure 1.** Wash-water rate dependence on crushed expanded-clay aggregates bulk density and "Diamix AQUA" bulk density and the degree of filter media expansion with a grain diameter of 1.1 mm.

The filter media wash-water rate with an equivalent grain diameter of 1.1 mm made from crushed expanded-clay aggregate with 0.525 mg/cm³ bulk density and an expansion coefficient of 1.2 is 8 h/p m². For the specified equivalent grain diameter made from crushed expanded-clay aggregate with 0.555 mg/cm³ bulk density, the wash-water rate is 14 h/p m² and the expansion coefficient is 1.4.

The filter media wash-water rate (dₑ𝑞 = 1.1 mm) made from "Diamix AQUA" with 670 kg/m³ bulk density ranges from 13 h/p m² with an expansion coefficient of 1.07 to 27.2 h/p m² with an expansion coefficient of 1.4. The water consumption for washing-off the filter media made from "Diamix AQUA" is 1.9 times higher compared to that of crushed expanded-clay aggregate.

4. **Conclusions**

The results of tests of two types of filtration materials made from crushed expanded-clay aggregate with 525 and 555 kg/m³ bulk density and from "Diamix AQUA" with 670 kg/m³ bulk density revealed the following conclusions:

- their mechanical strength characteristics meet the requirements for filtration materials;
- these filtration materials are chemically stable in both acid and alkaline environments;
• the standard fall velocity of the filter media made from "Diamix AQUA" is almost 2 times higher than that of the filter media made from crushed expanded-clay aggregate;
• the filter media made from "Diamix AQUA" requires an increased wash-water rate during its re-generation. It should be noted that before using the filter media made from "Diamix AQUA" in treatment facilities, it is necessary to check the capacity of the drainage and distribution system of filters and specify the rate of water consumption for washing-off.

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