Study of humidity during sand dewatering using a cone-shaped installation

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**Abstract.** The issue of moisture content of sand, which is used in construction as an aggregate for asphalt concrete mixtures, in the production of silicate building materials, roofing roll materials, and various types of glass, is considered. The results of an experimental study of the process of dewatering construction sand samples in conical warehouses under the conditions of using vacuum systems, depending on the time and placement scheme of needle filters, are presented.

Introduction

Sand is a granular material consisting of particles of finely ground rock. The main and most common component of sand is silica (SiO2 or silicon dioxide), which is usually found in the form of quartz [1]. The size of the sand particles varies from 0.075 mm to 4.75 mm, depending on the type of sand (refer with: Fig. 1). Sand is one of the important building materials, the largest amount of this aggregate is used in the production of concrete and asphalt in the production of silicate building materials, in the production of ceramic products, roofing roll materials, etc. In addition, it should be noted that sand is a non-combustible, ecological and fire-resistant building material [2–6].

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| **a** | **b** | **c** |
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| **d** | **e** | **f** |

**Fig. 1.** Types of sand used in construction: a) quarry sand; b) river sand; c) sea sand; d) industrial sand; e) filling sand; f) utilitarian sand.

The key physical and chemical properties of this building material will vary depending on the degree of density, humidity, particle size composition, and the presence of impurities in it [7]. At the same time, the same amount of sand by weight can occupy a different amount of space. The classification of sand according to the following characteristics (refer with: Table 1, Table 2, Table 3) [8].

**Table 1.** Classification of sands depending on density.

|  |  |  |  |
| --- | --- | --- | --- |
| Sand class | Sand group by density | Average grain density, [g/cm³] | Bulk density, [kg/m³] |
| Dense | Very heavy | over 2.8 | more than 1800 |
|  | Heavy | from 2.0 to 2.8 inclusive | from 1300 to 1800 inclusive |
|  | Average | from 1.2 to 2.0 inclusive | from 800 to 1300 inclusive |
| Porous | Lungs | from 0.6 to 1.2 inclusive | from 400 to 800 inclusive |
|  | Very light | less than 0.6 | less than 400 |

**Table 2.** Classification of sands according to the coefficient of water saturation .

|  |  |
| --- | --- |
| A type of sand | Coefficient of water saturation *Sr*  |
| Low degree of water saturation | 0.00≤ *Sr* ≤0.50 |
| Medium degree of saturation | 0.50≤ *Sr* ≤0.80 |
| Saturated with water | *Sr* ≥0.80 |

**Table 3.** Classification of sands by particle size composition.

|  |  |  |
| --- | --- | --- |
| A type of sand | Grain size, particle *d* , [mm ] | Content of grain particles by mass, [%] |
| Engraved | > 2.00 | > 25 |
| Coarse | > 0.50 | > 50 |
| Medium size | > 0.25 | > 50 |
| Small | > 0.10 | ≥ 75 |
| Dusty | > 0.10 | < 75 |

Sand is extracted by river, quarry and artificial methods. At the same time, the place of extraction should be taken into account, in terms of environmental friendliness and the presence of harmful and dangerous impurities [9–13], which in turn can affect the condition of the construction mortar [14]. In this regard, such equipment as sand bunkers and warehouses of various configurations, accumulators, mechanical classifiers, hydrocycles and vibrating dewaterers, centrifuges, vacuum installations, thermal drying equipment and combined methods are used for sand cleaning and dewatering. Taking into account the above, we can say that the process of sand extraction with its subsequent dehydration takes place due to the use of conical and prismatic installations made of steel elements. The main indicator of sand dewatering installations is the final percentage of moisture during extraction. These installations and their components (engines, pumps, etc.) [15–17] work in an aggressive environment [18,19] and are subject to special protection [20–23] and their location [24–26].

Many studies are conducted to determine the feasibility of using sand cleaning and dewatering. So in work [27] the results of the analysis of sand drainage in the bunker of different fractions are described . It was determined that the initial humidity of the sand of all fractions is 25 %, within 5 hours it decreased: for small fractions to 23.17 % and for large fractions to 11.5 %. For additional dewatering of sand after the spiral classifier, bunkers and warehouses with a special dewatering device are used [28]. After dewatering in the bunker for 90 hours, the moisture content in sand of fraction 0–2 mm was 9 %, and sand of the same fraction as a result of drainage in the warehouse obtained a similar result within 140 hours. According to the obtained results of the assessment of the drainage process, the general regularities of the process of sand dewatering in the warehouse with sediment were established.

The most common equipment for dewatering and sand cleaning is spiral classifiers [29]. In the work, the shortcomings of the classifiers were determined, and it was established that over time, during technological operations, clay and dusty particles accumulate in the bedding layer on the side of the trough between two adjacent spirals, while they form compacting layers that prevent water filtration, as a result of which the final moisture content of the sand increases. When the research was conducted [30] it was determined that the degree of sand dehydration is 19–25 %, further reduction of moisture in the sand during dehydration in spiral classifiers is practically impossible, it was established that the intensity of moisture release at the final stage drops sharply.

The work proposed a laboratory installation [31] that simulates the operation of industrial equipment for dewatering and cleaning sand. With the help of the installation, research was carried out, where the main goal of the work was to investigate the performance of individual nodes and equipment units, in relation to the properties of sand and its humidity. The possibilities of mechanized moisture removal are defined, taking into account the designs of removable devices on the selected filter or centrifuge [32]. The rational modes of operation of the laboratory installation were determined by experimental and calculation methods, which ensure maximum productivity with a given quality of cleaning and dehydration.

The authors defined in the work [33] that the humidity of the sand practically stabilizes when gravitational water is removed from it. The ability of sand to retain moisture in this case approaches the smallest value of capillary moisture, the value of which depends on the mechanical composition of the sand and the method of laying its particles in the mass. Results of work [34] establish that in technological schemes of sand production, in all cases, it is necessary to provide measures for the maximum removal of gravity moisture from the final product.

In the article, an analysis of the operation of vibrating screens used for dewatering and sand cleaning [35, 36] was carried out. It was determined that among its advantages is high productivity of dehydration and drainage, low operating costs and a high level of recovery of solids. Given the importance of such an operation, the article proposed a mathematical model that allows understanding the mechanisms of dehydration in mesh filtration. The leachate flow rate was considered depending on the hydraulic forces described by the Ergun equation, on local pressure losses through the sieve openings (hydraulic accidents) and mechanical forces associated with the movement of the vibrating sieve. In addition to flow, the model allows the prediction of residual moisture as a function of time. A computer system was developed to simulate different scenarios of dewatering screens.

Installed that in the main period of sand dehydration, a decrease in the water flow pressure with no filtration mode set, correspond to a proportional decrease in the amount of rarefaction in needle filter unit [37]. As a result, the area of the contact zone of the filtering surface of the filter with the liquid flow decreases, while the length of the filtering surface zone at the time of air breakthrough into the needle filter decreases by at least 2 times [38]. The scheme of the appropriate placement of needle filters, where the range in a row is set, is determined from 1.5 m to 5 m in the zone of which there are water intake holes, in the direction of the depth of the warehouse with sand.

This paper proposes the development of a mathematical model of the process of dewatering construction sand samples in conical warehouses under the conditions of using vacuum systems with a ring arrangement of needle filters, which is subsequently used in construction, as an aggregate for the production of concrete and asphalt in the production of silicate building materials, etc.

The purpose of the work is to determine the dependence of sand dehydration time on the adopted technology of sand storage (conical shape), with annular and linear placement of needle filters of the suction system.

**Materials and Research Methods**

To solve the considered problem of sand dewatering by a vacuum system in conical warehouses with a circular base, where the location of a linear and ring drainage system with needle-filtering units is provided, we reduce the spatial problem to an asymmetric one in the assumption where water waste can be spread along the perimeter of the cone base.



**Fig.2.** Compliant scheme of a vacuum installation for dewatering sand in conical warehouses : 1. warehouse of conical shaped sand; 2. catchment collector; 3. needle filters; 4. reception hatch of the stacking gallery; 5. belt conveyor; 6. loading ektakada; 7. valves of the suction and pressure lines.

To conduct research and develop a mathematical model for sand dewatering, we use the cone-shaped installation (refer with: Fig. 3).



**Fig. 3.** In the setting of a conical shape

For a mathematical description of the processes occurring during sand dehydration, we use the following system of equations, starting from the linearized Boussinesq equation in the form:

; where \_ (1)

or in cylindrical coordinates

 (2)

In the case of central symmetry for an annular drain, this equation has the form:

 (3)

where, – a new function is introduced for consideration; – conductivity level coefficient; H0 is the initial height of the stream; *k* – sand filtration coefficient; *m i* – water discharge coefficient; *r, φ* are cylindrical coordinates.

We will form the initial and boundary conditions as follows:

; ; (4)

the function *U0 (r)* in the form:

 (5)

where *a* is the distance from the coordinate axis to the drain.

Solving the task by the Fourier method, we obtain the expression for the function *U (r,t)* :

 (6)

where, are eigenvalues of the problem obtained from boundary conditions (4); *М0к* is the integral root of the zero-order Bessel function .

Coefficient *A k* we find, based on the properties of cylindrical functions, using the scientific condition (4). After calculations, we have the form:

 (7)

Finally, *U = (r, t)* looks like:

 (8)

Let's move on to the solution of the spatial problem, the solution of which is reduced to the determination of the water inflow to one of the point drains, which are located on the line of a circle with a radius *r = a* at the base of the conical composition.

At the same time, the planes of separation pass along the radius of the base of the conical structure through the drains, cutting off the arc of the circle of the base of the cone and limits the central angle by the value:

 (9)

where, S ≥ 6 – the number of sectors formed by adjacent flows; 2α 0 is the central angle of the selected conical sector.

The selected volume preserves the similarity of the geometric dimensions and the physical picture of filtration from the sand of the conical composition.

**Discussions of Results**

The obtained results of the research on changes in the moisture content of the sand samples before and after the tests (refer with: Table 4).

**Table 4.** Results of sand dehydration research.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Research options taking into account the placement of needle filters | H, [cm] | granulometric composition [%] | initial humidity, [% ] | final humidity, [% ] |
| grain size, particle d, [mm] |
| 3 | 2.5 | 1.25 | 0.63 | 0.315 | 0.14 | ≥ 0.14 |
| circular | 400 | - | 1.3 | 3.6 | 13.0 | 53.9 | 24.6 | 2.7 | 30 | 5–8 |
| linear | 400 | 3.8 | 9.7 | 5.6 | 6.2 | 27.2 | 46.6 | 4.7 | 30 | 7–10 |
| circular | 200 | 0.5 | 8.2 | 5.5 | 27.0 | 24.0 | 33.0 | 1.6 | 33 | 4–7 |
| linear | 200 | 2.0 | 1.7 | 3.4 | 3.2 | 23.9 | 65.0 | 2.8 | 28 | 6–8 |

|  |  |
| --- | --- |
| a) | b) |
| c) | d) |

**Fig. 4.** Dependence of the change in moisture content of construction sand samples on time in the cone-shaped installation: a), c) – ring placement of needle filters; b), d) – linear placement of needle filters (solid line – calculated curve, dashed – experimental curve).

Taking into account the results obtained from Tab.4 and the proposed system of equations (1-9), we will plot the graphical dependence of the cone-shaped installation on time during sand dehydration. The resulting graphical dependencies are presented in Fig.4.

Thus, in the work, research was carried out on changes in the moisture content of sand samples used in construction (concrete, asphalt, silicate building materials, ceramics, roofing roll materials, etc.). Based on the results of the research, the time and humidity of construction sand samples were determined (fig. 4), as well as the change in humidity of construction sand before and after the test (tab.4). Based on the results of the research, it was established that when using cone-shaped installations with a ring arrangement of needle filters of a suction system and a vacuum installation, the time of dewatering of building sand is reduced, compared to a linear arrangement of needle filters. It should be noted that when using the ring scheme at the initial stage, the intensity of dehydration of building sand is high, at 20 hours the humidity was 18%, for the linear scheme the humidity was 22%. It was determined that over time the intensity of dehydration of building sand decreases and after 50 hours the indicators almost do not change in all variants of the conducted research. This means that the dehydration of construction sand reached the final indicators, which were 5-8% for the ring scheme and 7-10% for the linear scheme. Based on the results of the research, it was determined that it is better to use suction systems with a ring arrangement of needle filters, where the obtained indicators of moisture content in construction sand do not exceed the value of natural humidity, which is 4-8%.

Summary

Experimental studies were conducted to determine the time of change in the humidity of construction sand before and after the tests, which are used in construction as an aggregate for asphalt concrete mixtures, in the production of silicate building materials, roofing roll materials, and various types of glass. The dependence of the time of dehydration of sand samples on the accepted technology of sand storage (installation of a conical shape), when applying a ring or linear arrangement of needle filters of the suction system, was determined. Based on the results of the research, it was established that the moisture level of the sand samples after the specified time in the operating area of the installation decreased to the best indicators on average from 28-32% to 6-8% when applying the ring scheme of placement of needle filter elements of the suction system in the cone-shaped installation.

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