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METHOD OF CALCULATION OF THE SEDIMENT DRYING STRUCTURE IN NATURAL CONDITIONS

Dewatering of sediments of natural water treatment plants is one of the most important technological and environmental problems of their operation. The use of drying in natural conditions ensures low energy consumption with the achievement of the necessary results in the moisture content of the sediment. The increase in the rate of dehydration is facilitated by the use of structures using the capillary effect to increase the rate of dehydration. The designs of dewatering sites with such elements have been developed and the article presents the method of their calculation.

Keywords: *natural water purification, sediment, capillary effect, dehydration.*

Introduction

Any liquid is limited by the interface surfaces separating it from any other medium - vacuum, gas, solid, other liquid. The energy of the surface molecules of the liquid is different from the energy of the molecules inside the liquid precisely due to the fact that both have different neighboring molecules - the surrounding molecules are the same for the inner molecules, the surface molecules have the same molecules located only on one side. The difference of these energies is called surface energy. The surface energy is proportional to the number of surface molecules (i.e. the area of the interface) and depends on the parameters of the media in contact. This dependence is usually characterized by a surface tension coefficient.

The use of a material with a large number of capillaries for dewatering precipitation has been known before. So back in the 70s of the twentieth century, a method for dewatering sludge was patented using a structure loaded with a filler of the hemp rope type [1]. However, the use of this device requires periodic extraction of the filler with subsequent pumping of water from the container in which it was located, which is not very convenient with a significant amount of sludge formed at large water treatment plants. The use of the capillary effect for the purpose of dewatering the sediment of stations in the south of the Russian Federation has not been studied before, therefore, the task was set to study the properties of various materials in terms of intensification of moisture removal. In this case, an important condition of the dehydration process is the spontaneous evaporation of liquid from the surface of the capillary element. In the future, we will call a capillary element a structure located in the sediment, which ensures the extraction of water from it by means of a capillary effect.

The use of the capillary effect for the purpose of dewatering the sediment of water supply stations as a method was developed by the staff of the Department of Water Supply and Sanitation of Rostov State University of Civil Engineering (now DSTU).

The essence of the method lies in the fact that the sediment of settling facilities previously compacted in thickeners (facilities for the reuse of washing water of rapid filters, sedimentation clarifiers with a layer of suspended sediment) with a humidity of 91 to 97 percent is pumped into a container in which a special material is placed along the walls that has the ability to create capillary pressure directed upwards (Fig. 1). The maximum height to which capillary water can rise through the material will be the height of the raised column of water, counting from the surface of the sediment, to the height at which the weight of the column of water per unit cross-section of the tube will be equal to the lifting force of the meniscus. In this regard, the height of the walls above the sediment level is assumed to be less than the maximum, providing overflow.

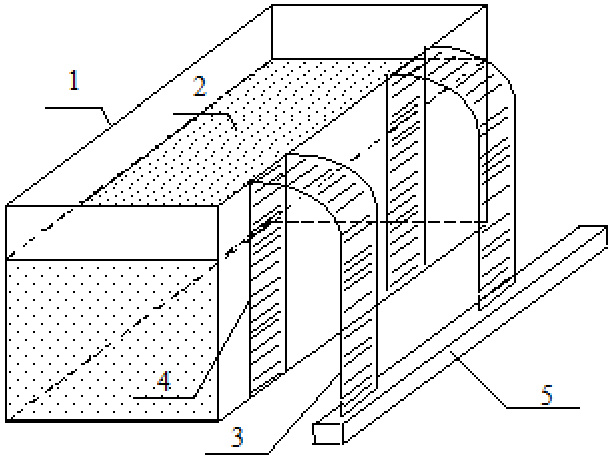

Fig. 1. *Scheme of the method of dewatering water sludge using capillary pressure.*
1 - *container,* 2 - *sediment,* 3 - *overflow,* 4 - *capillary material,* 5 - *water collection tray*

The capillary material allows water to be removed not only by lifting in the capillaries with the movement of liquid into the collecting tank, but also by forming an additional evaporation area with drying patterns different from evaporation from the liquid surface. As a result, depending on the climatic characteristics of the region (lack of humidity, wind speed), the increase in the rate of dehydration can reach 2-3 times with a final humidity of 75 to 60%.

A number of structures have been developed using capillary elements [2,3,4,5], including a closed-type tank structure for sludge dewatering [5] (Fig. 2).

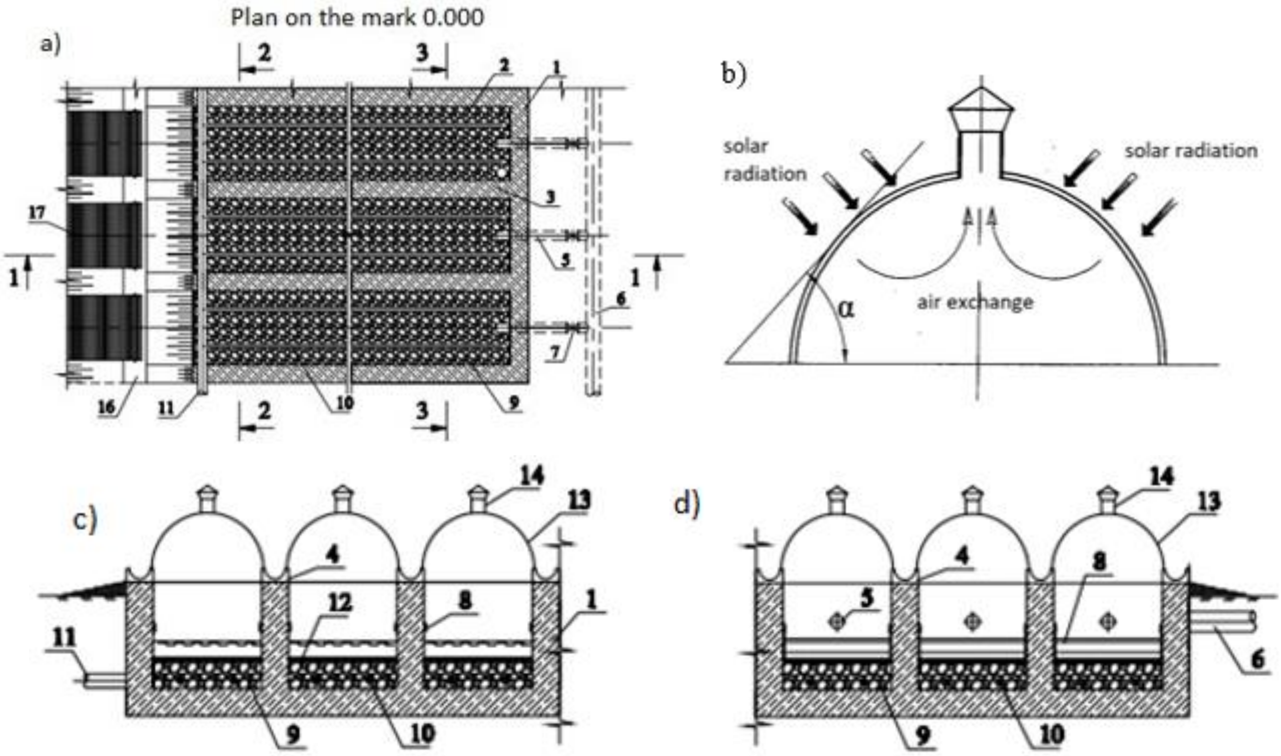

Fig. 2. *A closed-type tank structure for dewatering sediment*
a) longitudinal section, b) roof scheme, c) transverse section through the filtrate discharge pipeline, d) transverse section through the sediment supply pipeline. 1 - reinforced concrete tank, 2 - working corridor, 3 - reinforced concrete walls, 4 - concrete condensate collection trays, 5 - inlet pipeline, 6 - sludge supply pipeline, 7 - cold - free valve, 8 - scraper mechanism, 9 - gravel drainage, 10 - drainage pipes, 11 - filtrate drainage pipeline, 12 - drainage plates, 13 – roofing, 14 - deflector

The structure is a reinforced concrete tank with enclosing walls dividing it into independently operating corridors, which are equipped with drainage and a scraper mechanism, as well as a slurry water supply pipeline, inlet and drainage pipelines, and a dedicated filtrate discharge pipeline. The main difference between a closed-type structure is the presence of a coating of a special design - a roofing with deflectors installed in it, and a concrete tray is laid along the top of the enclosing walls. The roofing is made of a light–permeable material, which not only effectively protects the sediment from rain and snow, but also contributes to maximum radiation absorption when it is oriented in the west - east direction. The optimal angle of inclination of the roof (α) is recommended to be taken equal to the geographical latitude of the terrain. The sun's rays, passing through the roofing, heat the air inside the corridor and create a favorable microclimate for the evaporation of moisture, and deflectors contribute to the activation of convection currents, along with which water vapor escapes into the atmosphere. For the removal of thawed and rainwater along the upper edge of the reinforced concrete walls, the device of concrete trays with the removal of water into the industrial sewer is provided.

Reinforced concrete walls, in addition to the enclosing function, act as a capillary-porous material for the capillary lifting of moisture and its further evaporation from the concrete surface. The construction of reinforced concrete walls is made according to the "sandwich" principle - the bearing part of the wall made of heavy concrete and the capillary material between which the waterproofing layer is arranged (Fig. 3). Such a wall design allows you to simultaneously ensure the strength of the structure and the possibility of replacing the capillary material in case of its clogging.

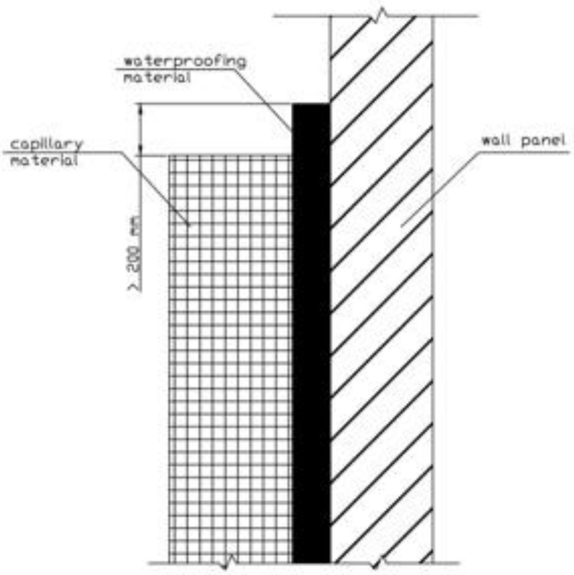

Fig. 3. *The version of the wall of the "sandwich" capacitive structure*

The introduction of structures into practice required the development of a methodology for calculating the structure.

Materials and Methods

According to the classification of materials undergoing drying proposed by academician A.V. Lykov [6], the sediment refers to colloidal capillary-porous materials (earlier, Turovsky I.S. came to the same conclusion regarding the sediment of sewage stations [7]). It is impossible to remove all moisture from the sediment during drying in its natural state - exposure to air and solar radiation, because the drying process can only be brought to an equilibrium moisture content and the corresponding humidity. In this case, the concept of the removed moisture content is used - the difference between the moisture content and the equilibrium moisture content, depending on the humidity of the air.

The dynamics of sludge drying (both water and sewer) according to the works of V.M. Lyubarsky [8] and I.S. Turovsky [7] includes periods of sludge heating, a period of stable drying speed and falling drying speed, at the boundary of which it is customary to allocate the first critical point – the point of change in the slope of the drying curve. V.M. Lyubarsky leads to the results of drying precipitation with a different ratio of turbidity and chromaticity. Precipitation formed during the clarification of water with turbidity exceeding chromaticity, during drying in the region of constant velocity (constant temperature of the sediment), free and physicomechanically bound moisture is released from itself, reaching a humidity of up to 64% (the first critical point). In relation to dewatering sites in natural conditions, the author considers and takes into account two drying areas: heating of the sludge to the temperature of a wet thermometer and drying at a constant speed (constant temperature of the sludge). The proposed scheme of dewatering using capillary elements makes it possible to speed up the drying process by extracting water from the thickness of the sediment layer. The contact of the sediment with the capillary element, in which the lower moisture content in the element in comparison with the sediment creates a moisture content gradient at the sediment-element boundary. Thus, moisture from the sediment passes into the element and due to capillary rise through open pores, an additional evaporation area is formed in it.

It is possible to determine the time of sludge dewatering by filtration either using the equation of Prof. N.N. Verigin derived for sewage sludge, or by transforming the formula for determining resistance [10].

Filtering time by N.N. Verigin:

$$t = \frac{100H}{K}\left\{\left[1 + aa_1\left(\frac{\delta_s}{H} + 1\right)\right] ln\frac{\delta_s + H}{a_2\delta_s + H} - aa_1\frac{\delta_s}{H}(1 - a_2)\right\}, \text{day}, \quad (1)$$

where H – the thickness of the filter layer, m, should be taken equal to the thickness of the sediment at the end of the second phase of compaction without mechanical mixing of the sediment,

δ_s – initial thickness of the unconsolidated sediment layer, m,

$a = \frac{C}{\rho_v}$, C – concentration of the solid phase in the unconsolidated sediment, kg/m^3:

$$C = \frac{\rho_l \rho_s (1 - W_s)}{\rho_l + (\rho_s - \rho_l) W_s}, \quad (2)$$

where ρ_l and ρ_s – accordingly, the density of water and solid sediment, kg/m^3,

W_s – humidity of unconsolidated sediment – sediment entering the sealer, fractions of a unit,

ρ_v – the density of the bulk mass of the skeleton of the compacted sediment:

$$\rho_v = \frac{\rho_l \rho_s (1 - W_{h.s.})}{\rho_l + (\rho_s + \rho_l) W_{h.s.}}, \quad (3)$$

where $W_{h.s.}$ – humidity of the sediment in the sealer after the end of the second phase of the seal, fractions of a unit: $W_{h.s.} = \frac{W_s - \frac{H}{\delta_s}}{\left(1 - \frac{H}{\delta_s}\right)}$,

$a_1 = \frac{K}{K_{h.s.}}$ (K - drainage filtration coefficient, $K_{h.s.}$ - filtration coefficient of compacted sediment, m/s),

$a_2 = \frac{a}{1 + a}$ – dimensionless parameters.

Based on the formula for determining the filtration resistivity (at a liquid temperature 10°C)

$$t = \frac{r \cdot V^2 \cdot C \cdot \eta}{2pF^2} = \frac{r \cdot h^2 \cdot C \cdot 1{,}3 \cdot 10^{-3}}{2 \cdot h_r \cdot 10000} = 7.52 \cdot r \cdot h^2 \cdot C \cdot 10^{-12} / h_g, day, \quad (4)$$

where h_g - geodesic difference of the mark of the top of the compacted sediment and the center of the drainage pipeline drainage water from the site, m.

The value of the monthly evaporation layer E_m

$$E_m = 0.15 \cdot T(l_0 - l_{200})(1 + 0.72V_{200}), \quad (5)$$

where T is the number of days per month during which sediment dehydration occurs, day,

l_0 is the elasticity of saturated water vapor corresponding to the average air temperature for the month, mb,

l_{200} – average monthly absolute humidity at a height of 200 cm from the water surface, mb, equal to

$$l_{200} = l_1 + M(l_{\text{lim}} - l_1) \, , \tag{6}$$

where l_1 – absolute humidity of air over land for a given month, mb,

l_{lim} – the maximum humidity of the air with an unlimited stay of the air flow over the reservoir, approximately can be assumed equal to 0.8 l_0,

M – empirical coefficient depending on the duration of the air flow over the reservoir.

The volume of water removed from the surface during evaporation from the surface of the capillary material

$$V_{\text{k.s.}} = F_{k.s.} \cdot \sum \text{E}_{\text{m}}^{/} \, , \tag{7}$$

where $F_{\text{k.s.}}$ – the area of capillary rise for all capillary materials above the water level in the site, m^2,

$\text{E}_{\text{m}}^{/}$ – the value of the monthly evaporation layer from the surface of the capillary material located above the water level, mm.

The height of elevation in the capillary material is taken according to the formula of Juren:

$$h = \frac{2 \cdot \sigma}{\rho \cdot g \cdot r_0} \, , \tag{8}$$

where r – drop radius, m,

σ - surface tension, H/m,

□ - water density, kg/m^3.

Results and Discussion

The calculation of the dewatering site with capillary elements is based on a known ratio for the rate of moisture loss with the introduction of an additional term for the evaporation of moisture from the capillary material:

$$Q = \frac{dV}{dt} = \frac{dV_{dr}}{dt} + \frac{dV_{k.s.}}{dt} + \frac{dV_f}{dt} + \frac{dV_d}{dt} \, , \tag{9}$$

where V – total water content in the sediment,

V_{dr} – the volume of water removed from the sediment surface as a result of drying,

$V_{\text{k.s.}}$ – volume of water evaporating during drying of capillary material,

V_{f} – the volume of water removed during filtration into the drainage system,

V_d – volume of water removed by decantation.

Based on this, it is fair to say that the total volume of water removed from the sediment will be equal to the sum of the volumes of water removed by drying, filtering through the drainage system and from the surface of the sediment after its decantation. If the design of the site does not provide for the possibility of removing decanted water, then V_{d} should be taken equal to zero.

Volume of water removed from sediment:

$$\Delta V = V_b - V_{end} \, , \tag{10}$$

where V_{b} – the volume of water in the sediment corresponding to the humidity of the sediment entering the site,

V_{end} – the volume of water in the sediment corresponding to the calculated moisture content of the sediment or the moisture content of the sediment removed from the site.

Based on the determination of humidity and taking the humidity of the sediment after the sealer at least 95%, it is possible to determine the volume of water removed in the sediment compactor (sealer-averager) or at the site of natural dehydration:

$$\Delta V = V_b \left(\frac{W_b - W_{tnd}}{100 - W_{end}}\right), \tag{11}$$

where W_b and W_{end} – accordingly, the humidity of the sediment entering the drying area and removed from it, %.

We determine the volume of sediment formed in sedimentation tanks per month with the maximum content of suspended solids in the water source, the volume of sediment in the facilities of repeated use of flushing for the same period. We calculate the volume of the mixture with a humidity of 91-93% after the sedimentation compactor (sealer-averager) W_s.

The area of the sludge dewatering facility (F, m^2) is proposed to be calculated using the formula:

$$F = \frac{W_s}{h}, \tag{12}$$

where h – the height of the sediment inlet layer to the site, m, accepted 0.4÷0.6 m.

Being structurally determined by the thickness of the capillary element $b_{c.e.}$ (no more than 200 mm), we determine the width of the corridor "in the light":

$$B_к = 2 \cdot 5 b_{c.e.}. \tag{13}$$

Number of working corridors:

$$N_w = \frac{F}{B_c L_c}, \tag{14}$$

where $L_к$ – the length of the corridor, m, is accepted no more than 40 m.

The number of working corridors should be taken at least two.

The construction height of the structure can be calculated using the formula:

$$h_{bul} = \sum h_{seal} + h_{dr} + h_{scr.} + h_{pip.} + 0.5, \tag{15}$$

where h_{dr} – drainage height, m, representing the sum of the outer diameter of the drainage pipe, the thickness of the drainage backfill layer (at least 10 cm), the thickness of the drainage plates,
$h_{scr.}$ – vertical size of the scraper mechanism, m,
$h_{pip.}$ – the outer diameter of the intake pipeline, m.

The formula (11) calculates the amount of water removed from the sediment when the humidity changes from 91-93 to 60% per month with the maximum content of suspended solids.

The volume of water to be decanted and (or) filtered is defined as the difference between the height of the sediment inlet layer (h) and the thickness of the sediment at the end of the second phase of compaction on the area of the structure (you can take 0.4-0.45 h). The filtering time is calculated by formulas (1) and (4), taking a smaller value.

Based on the value of the filtration time and the volume of water to be filtered, the volume of water discharged by the drainage system per month is calculated.

For each of the months of the year, the amount of water evaporated from the surface and from capillary elements is calculated (formulas 5-8). For example, in the following tabular form:

Month	Average monthly temperature, T, °C	Average elasticity of saturated water vapor l_0, mb	Absolute humidity of air over land, l_1, mb	Average elasticity of water vapor l_{200}, mb	Wind speed , V_{ref}, m/s	Wind speed at a height of 200 cm, V_{200}, m/s	Volume removed per month from the surface, m^3	Volume removed per month from capillary elements, m^3
January								
….								

The calculation of the dehydration time at the sites is performed according to the least (summer precipitation, dehydration November-March) and the most (winter precipitation, dehydration April-October) favorable periods. When calculating, you should take:

a) drainage filtration coefficients:
   - drainage layer of porous concrete (expanded clay concrete) – 0.004÷0.0058 m/s,
   - the drainage layer of gravel is 0.0012÷0.023 m/s.

b) sediment filtration coefficient (at a water temperature of 10°C):

$$K_{\text{h.s.}} = \frac{1,54 \cdot 10^{10}}{rC} . \tag{16}$$

c) the empirical coefficient "M":
   - for open areas is determined based on V_{200}, the location of the site on the cardinal directions, the wind rose in the area of construction of the site, and the size of the site in the prevailing direction of winds,
   - for closed sites, it is accepted within 0.2□0.3,

d) V_{200} – average wind speed at a height of 200 cm, m/s:

$$V_{200} = 0.8K \cdot V_{ref} , \tag{17}$$

where V_{ref} – wind speed, m/s,

K – is a coefficient depending on the local conditions of the location of the meteorological station, taking values (Table III-10[9]):

- forest areas of the Russian Federation – 1.6□3.0,
- treeless areas of the Russian Federation – 1.3□1.9,
- shores of sea bays, lakes and large rivers – 1.05□1.6.

e) the radius of the capillary (capillary pore) is taken according to reference materials based on the type of material, for example:
   - heavy concrete 0.01 – 1 microns,
   - ceramic brick – 0.1 – 20 microns.

Considering that the pore radius is represented as an interval for each material, we consider it correct to calculate for the maximum radius and introducing a reduction factor of 0.5. This creates a certain margin in the amount of evaporated water from the capillary element.

f) capillary rise area

$$F_{k.s.} = P_{k.s.} \cdot h_{k.s.min} . \tag{18}$$

The annual amount of sediment is determined after the compactor-averagers (sedimenters), based on the average annual content of suspended solids. The possibility of dehydration in the remaining months of the volume of sediment not dehydrated in the previously calculated periods is checked.

If the sum of the dehydration time does not exceed one year, then the number of working corridors calculated according to formula (14) is left unchanged. If the amount exceeds one year, then the number of corridors should be increased.

Conclusion

The capillary effect during the dewatering of natural water sediments makes it possible to intensify the process of drying the sediment in natural conditions up to a humidity of 60%. The method of sediment dewatering in natural conditions using the capillary effect, as well as the dewatering site has been developed and patented. The method of calculating sites is based on the radiation-convective form of drying of the capillary element, evaporation from the liquid surface, filtration into the drainage system allows the calculation of structures located in places with a constant or prevailing humidity deficit throughout the year.

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