Express-method of determining the water-yielding capacity of natural water sludge in modern dewatering technologies

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Abstract. Water treatment of surface sources for the purposes of public water service provision is impossible without waste build-up – sludge of water treatment plants. This kind of waste poses a considerable threat to the environment as it represents a complex organomineral structure with a high concentration of chemical reagents used for source water clarification and decolourization. In the present day, it is still international practice to discharge wastewater into surface water objects or onto the land surface, which causes severe damage to the natural environment. A tightening of environmental regulations encourages housing and utility services sector to undertake measures related to waste processing (waste dewatering). To implement these purposes mechanical machines (centrifuges, decanting tanks, filter presses, vacuum filters) are widely applied. An initial sludge quality, more particularly a filterability indicator – specific resistance to filtration – is a critical factor for the successful functioning of these machines. The higher the specific resistance to filtration, the worse the sludge gives away moisture, the more reagents and (or) mineral additives should be used before sending sludge for dewatering. Determining indicator of specific resistance to filtration using standard methods is quite a long process requiring the use of laboratory equipment. In this article, the author proposes an express-method enabling to determine within a short time span the water-yielding capacity of sludge based on the capillary suction speed of filtrate, standing out from its components. This method allows simplifying the start-up and commissioning of the modern sludge dewatering equipment as well as operation on the whole.

1. Introduction
Wastes (water sludge) that constitute a potential hazard to the environment are generated as a result of natural surface water treatment. Its processing, consisting of lowering the moisture content, is one of the most difficult technological water treatment processes that require considerable capital investments and permanent maintenance costs. Not less problematic is a natural water sludge utilization problem, a successful solution of which involves minimization of moisture content of utilized raw material [1]. Methods of sludge treatment are determined by its qualitative and quantitative composition characteristics, specific technological features of the water treatment plant, and also climatic characteristics of the region [2, 3]. In the present day, mechanical sludge dewatering technologies with centrifuges, decanting tanks, filter presses, vacuum filters are the most widely used technologies at large water treatment plants [4, 5, 6]; sludge dewatering in the natural conditions at drying sites finds a wide application in moisture-deficient southern regions [2, 7, 8], different devices and systems aimed at improving the process are also used; another technology which is in use, is to discharge natural water sludge into a sewage system for further processing at sewage treatment plants [9, 10, 11].
Mention should also be made of sludge discharged into surface water bodies and balka-type valleys, which can adversely affect the environment (pollution and siltation of water bodies, the decrease of their self-purification capacity, waterlogging of the territories).

2. Methods
One of the indicators of the sludge's ability to dewater by methods mentioned above is its specific resistance to filtration. Specific resistance to filtration (filtrability) is the resistance of unit mass of solid phase deposited per unit area of the filtrate being filtered at a constant pressure of suspension, the liquid phase viscosity of which equals 1.0 mPa·s [12]. According to the data [7] the value of specific resistance to filtration of natural water sludge ranges from $7 \cdot 10^{10}$ to $1400 \cdot 10^{10}$ cm/g. The higher this indicator (it is characteristic of sludge of water sources with intense colouration), the worse the sludge gives away moisture in the course of treatment. To lower specific resistance to filtration, flocculants and lime are most frequently used (as mineral additives).

The author together with the research team from Rostov state University of civil engineering has conducted for several years research on qualitative characteristics of low-turbidity and low-colour river water sludge, including the filterability indicator. Monitoring of indicators was carried out by using vacuum system with a Büchner funnel (figure 1). Sludge sampling was drawn for this study from horizontal settling tanks of the water treatment plant. Methodology for determining filterability in this way is extensively described in [13].

**Figure 1.** System scheme for modeling the sludge filtration process performed under vacuum: 1 – Büchner funnel; 2 – copper cylinder for collecting filtrate; 3 – vacuum hoses; 4 – manometer; 5 – vacuum-pump; 6 – electric motor.

In the course of experimental research, fully described in a PhD thesis of the author of the present article [15], it has been determined that the specific resistance of the sludge to filtration of low-turbidity and low-colour natural water sludge depends on a number of factors: season of the year, reagents used for water clarification, duration of sludge accumulation in the settling tank. In addition, it was found out that the sludge under examination tends to shrink: its structure alters during the filtration process under vacuum, which results in a rapid increase in specific resistance. In tables 1-3 dependencies of specific resistance of the sludge to filtration from initial parameters are shown: values are registered at the beginning and at the end of the process since the sludge under examination tends to shrink under the influence of vacuum filtration [15].

**Table 1.** The average specific resistance of the sludge to filtration, with sludge being sampled in the period of river water treatment using aluminium oxychloride combined with flocculant (PolyDADMAC).

| Time of sampling | Duration of operation of a settling tank by the time of sampling, months | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the beginning of filtration | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the end of filtration | Color/Turbidity Ratio, degree of numerator·dm$^3$/mg |
|------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|----------------------------------|
|                  |                                                 |                                                 |                                                 |                                  |
| Time of sampling | Duration of operation of a settling tank by the time of sampling, months | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the beginning of filtration | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the end of filtration | Color/Turbidity Ratio, degree of numerator·dm$^3$/mg |
|------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| January          | –                                                             | –                                                             | –                                                             | 8.2                                                            |
| February         | –                                                             | –                                                             | –                                                             | 7.0                                                            |
| March            | 6                                                             | 32                                                            | 75                                                            | 2.5                                                            |
| April            | 6                                                             | 30                                                            | 80                                                            | 2.3                                                            |
| May              | 2                                                             | 52                                                            | 105                                                           | 2.0                                                            |
| June             | –                                                             | –                                                             | –                                                             | 2.2                                                            |
| July             | 2                                                             | 38                                                            | 98                                                            | 2.0                                                            |
| August           | 2                                                             | 50                                                            | 135                                                           | 2.8                                                            |
| September        | 1.5                                                           | 84                                                            | 165                                                           | 2.9                                                            |
| October          | 2                                                             | 40                                                            | 130                                                           | 3.2                                                            |
| November         | 2                                                             | 41                                                            | 125                                                           | 6.0                                                            |
| December         | –                                                             | –                                                             | –                                                             | 5.2                                                            |

Note: «–» sign means that the collection of sludge samples hasn't been carried out in the period under consideration.

Table 2. The average specific resistance of the sludge to filtration, with sludge being sampled in the period of river water treatment using flocculant (PolyDADMAC – VPK-402) as a coagulant.

| Time of sampling | Duration of operation of a settling tank by the time of sampling, months | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the beginning of filtration | Specific resistance of the sludge to filtration, $r \cdot 10^{10}$ cm/g at the end of filtration | Color/Turbidity Ratio, degree of numerator·dm$^3$/mg |
|------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| January          | –                                                             | –                                                             | –                                                             | 5.5                                                            |
| February         | –                                                             | –                                                             | –                                                             | 7.6                                                            |
| March            | 4                                                             | 22                                                            | 58                                                            | 1.4                                                            |
| April            | 4.5                                                           | 25                                                            | 52                                                            | 1.0                                                            |
| May              | –                                                             | –                                                             | –                                                             | 1.2                                                            |
| June             | 1.5                                                           | 78                                                            | 102                                                           | 2.0                                                            |
| July             | –                                                             | –                                                             | –                                                             | 1.0                                                            |
| August           | 2.5                                                           | 42                                                            | 163                                                           | 1.0                                                            |
| September        | 2.0                                                           | 43                                                            | 138                                                           | 0.5                                                            |

Note: «–» sign means that the collection of sludge samples hasn't been carried out in the period under consideration.

Table 3. The average specific resistance of the sludge to filtration, with sludge being sampled in the period of river water treatment using flocculant (PolyDADMAC – Floquat FL 4540) as a coagulant.
It should be mentioned that filtration test using Büchner funnel requires laboratory equipment and takes a long period of time (circa 1 hour per each sample). Thus, an express-method is of great interest because it enables to determine specific resistance of the sludge to filtration – the capillary suction time test [13, 14]. The author of the present article has set herself the aim to determine the dependence of the capillary suction time of filtrate, coming from the sludge, from its specific resistance, and to use this dependence for indirect estimate of sludge filtrability.

To conduct experimental research aimed at determining the capillary suction time of the sludge filtrate, a system was prepared (figure 2) which is a prototype of systems proposed in research papers [13, 14]. The experimental sequence was the following [15]: onto a flat plate (5) a filter paper "blue ribbon" was placed 110 mm in diameter (4); a transparent plastic plate was mounted onto the filter (3), in the centre, the plate had a hole, equal to the outer diameter of the hollow cylinder (2), intended for pouring sludge sample under examination (1). The filtrate, coming gradually from the sludge, goes far beyond the cylinder under the influence of capillary absorption. At the moment the filtrate reached the small circle (32 mm diameter) engraved on the plate (3) a stopwatch turned on, at the moment the filtrate reached the big circle (45 mm diameter) a stopwatch turned off. Every sludge sample was tested beforehand to determine specific resistance of the sludge to filtration under vacuum. On the basis of a comparison of the capillary suction time of the sludge filtrate and its specific resistance a curve was obtained (approximating curve with the value for the reliability more than 0.95), shown in Figure 3.

**Figure 2.** Instrument measuring the efficiency of the capillary suction time of the sludge filtrate: 1 – sludge; 2 – hollow cylinder; 3 – upper plate with reference circles; 4 – paper filter; 5 – lower plate
Approximation shown in figure 3 allows to determine indirectly a specific resistance of the sludge to filtration from the capillary suction time of its filtrate without using vacuum equipment in the shortest time span. The proposed method (described in detail in a PhD thesis of the author of the present article [15]) appears to be useful in the commissioning phase aimed at sludge dewatering, when adjusting operational parameters of the devices, when determining the dosage of reagents and mineral additives for preparatory treatment of sludge and in other operations at water treatment plants.

Over the past two decades, there is a tendency in Russia to tighten environmental regulations. This has led to the large-scale reconstruction and modernization of housing and utility services sector. More particularly, sludge treatment (dewatering) processes become an integral element of functioning of all operating and newly commissioned water treatment plants. As it was mentioned above, mechanical devices are quite popular in Russia (national production, China, Switzerland and Turkey). An overview of the media showed that most widely used devices in mechanical dewatering shops are:

1) Decanting tanks, centrifuges (figure 4): the separation of the sludge into cake and centrate is done within the interior space of the centrifuge drum equipped with screw conveyor device. Under centrifugal forces the solid fraction of the sludge is distributed along the walls of the drum, the liquid is removed through the drain holes. With the aid of the conveyor the dewatered cake is transported to the cone tank and is further removed from the machine. Centrifuges ensure high sludge dewatering indicators owing to powerful hydraulic pressure within the machine. At present there are lots of types of centrifuges: filtering centrifuges (a rotor is equipped with perforated partitions, which enables to lower the concentration of suspended solids in the centrate at the outlet), decanting centrifuges (the operating principle of the device is based on the centrifugal settling of the solid components on the solid bowl), combined centrifuges (they combine the operating principles of the first two machines), inertial centrifuges (cake discharge is achieved by tangential component of the centrifugal force), vibrating centrifuges (cake is discharged owing to basket vibration upon completion of the separation of mediums), straight-flow and counter-flow centrifuges (depending on forward or backward movement of the centrate inside the drum). The number one decanter and centrifuge producer in Russia is OOO «EkoTekhAvangard». The maximum number of revolutions per minute in the available models is ranging from 2000 to 5500, productive capacity is ranging from 2 to 200 m³/h.

2) Filter presses (filter belt presses, chamber filter presses, membrane filter presses, chamber and membrane filter presses, tower filter presses): the sludge dewatering technology of these machines differs essentially depending on a particular modification, but it is common for all of them,
that they have a system putting pressure on the medium (press rolls, chambers, membranes) and belong to periodically acting machines. Owing to the pressure the sludge is separated into filtrate and filter cake: the solid particles form layer of cake on the filter cloth, and the liquid, that has been filtered through the cloth, exits the machine through canals (figure 5). Machines present in the market differ by degree of automation, they can be delivered together with thickener. Among Russian producers of filter presses the following can be distinguished: GK «Anser», OOO «Gidrotrend», OOO «EkoTekhAvangard».

3) Vacuum filters (belt vacuum filters, drum vacuum filters): the dewatering principle on these periodically acting machines in based on vacuum pressure, under the influence of which the liquid is released from the sludge content distributed on a filter base (figure 6). The filter cloth in such filters moves along closed trajectory, passing through different functional zones (distribution of the sludge onto the cloth, sludge washing, vacuum dewatering of sludge, cake blowing and removal, filter ribbon washing). Production of vacuum filters in Russia is carried out by scientific and industrial enterprise «Devices and machinery of chemical technology», OOO «Gidrotrend». Producers on their official websites announce the possibility of delivery of enclosed machines that minimize the spread of odors indoors.

4) Figure 4. Centrifuge (an open source image taken from the internet)  
Figure 5. Filter belt press (an open source image taken from the internet)

Apart from all the above-listed machines screw press separators and dewatering bags are also used at low-capacity waste treatment plants. Considering their relatively low performance these machines are not recommended for utilities, but they work well for water preparation (waste-water treatment) at industrial facilities. It should be mentioned that some modern screw dewaterer models are equipped with a built-in sludge thickening zone, which allows avoiding the use of thickeners.

A widespread problem of the above-listed machines (according to the opinion of operators and the general scientific public) is high water content of the cake at the outlet of the machine, which makes it difficult to solve the further disposal problems. That is why one must not neglect constant control of the value of specific resistance of the initial sludge to filtration as the main indicator of the potential dewatering level. Taking account of specific resistance to filtration enables if necessary prompt adjustment of dose rates of reagents and mineral additives, used prior to mechanical dewatering, it also enables to adjust operational parameters of the devices.

Considering the issue of sludge dewatering in the natural conditions reference should be made to such innovation in Russia (over the past few years), as using geotubes [16, 17] which represent toroid-shape shell made from filtering wear-resistant material (figure 7). The incontestable positive effect of using such a method is the absence of direct contact of the sludge with the atmosphere and this excludes (reduces to a minimum) the spread of foul odors all over the territory. Different modifications of geotubes [17] allow for repeated use of filtering shells and simplify the removal of dewatered sludge from the landfill area.
4. Conclusions
A specific resistance of the sludge to filtration is an indicator, that characterizes in a relatively precise way its water yielding capacity. It is important to control this indicator not only when developing sludge treatment technology during the commissioning phase in the mechanical dewatering shops, but also during operation of mechanical devices. Since the value of the specific resistance of the sludge to filtration is subject to considerable fluctuations, which is associated with a change in the sludge quality depending on the season of the year, duration of accumulation in facilities, types of reagents and dose rates for water purification, it is highly important that the water treatment operator (process engineer) has convenient control techniques of this indicator enabling prompt adjustment of the operating mode of sludge processing equipment. The operating experience of modern sludge dewatering devices and equipment proves that the successful implementation of the process (in terms of residual moisture of the cake at the outlet) can be achieved only under constant control of initial parameters of sludge under processing.

Acknowledgements
The author gratefully acknowledges the work done by Elena Rudenko, for translating the article from Russian into English.

References
[1] Buharina D N 2006 Technologies eliminating negative environmental impact of natural and waste water sludge: PhD thesis in Technical Sciences 25.00.36 (Saint-Petersburg) p176
[2] Lubarsky V M 1980 Natural water sludge and its treatment methods (Moscow: Stroizdat) p 128
[3] Khramenkov S V 2008 Sludge treatment at the water treatment plants J. Water supply and sanitary engineering No. 10 pp 67-76
[4] Kerin A S and Nechaev I A 2005 Filter belt presses and cellular thickeners sludge treatment technologies J. Water supply and sanitary engineering. No. 5. pp 41-44
[5] Zagorsky V A, Shutorov V N and Danilovich D A 2003 Research and practical realization of
the dewatering of water treatment plant sludge (Moscow: Mozhajsk-Terra) p 150

[6] Hang Xu, Kunlun Shen, Tonggang Ding and Jianfeng Cui 2016 Dewatering of drinking water treatment sludge using the Fenton-like process induced by electro-osmosis J. Chemical Engineering Journal Vol. 293 pp 207-215

[7] A Resource Manual on SNiP 2.04.02-84* 1984 Design of facilities for dewatering precipitates from natural water treatment stations (Moscow: Stroyizdat) p 40

[8] Lukov S A 2006 On the problem of wastewater sludge J. Water supply and sanitary engineering No 12 pp 30-32

[9] Khamidov M G 2007 Technological interaction between water distribution systems and sewage systems in processes of water treatment and sludge processing: Extended Abstract of PhD thesis in Technical Sciences 05.23.04 (Moscow) p 20

[10] Khamidov M G 2007 Experience of treatment of water treatment station sludge at sewerage treatment facilities J. Water supply and sanitary engineering No 3 pp 41-44

[11] André Luiz Marguti, Sidney Seckler Ferreira Filho and Roque Passos Piveli 2018 Full-scale effects of addition of sludge from water treatment stations into processes of sewage treatment by conventional activated sludge Journal of Environmental Management Vol. 215 pp 283-293

[12] Turovsky I S 1984 Wastewater sludge processing (Moscow: Stroyizdat) p 160

[13] Technical reference on water treatment: in 2 v. V. 1 2007 Edited by Alekseeva M I, Ivanova V G, Kurganova A M et al. (Saint-Petersburg: The New Review)

[14] Pat. 1562787 USSR, MPK G 01 N 15/08 Apparatus for determining the capillary suction time

[15] Ryltseva Y A 2016 Optimization of sludge treatment processes of low-turbidity and low-colour natural water at water treatment stations: PhD thesis in Technical Sciences 05.23.04 (Rostov-on-Don) p 195

[16] Rublevskaya O N 2013 Measures to prevent the spread of foul odors at facilities of SUE «Vodokanal of St. Petersburg» J. Water supply and sanitary engineering No 10 pp 46-55

[17] Pat. 2712603 Russian Federation, MPK B 01 D 29/11 Geotube and device for separating suspensions with the aid of filtration using geotubes (variants)