DOI: https://doi.org/10.31073/mivg202202-346
Available at (PDF): http://mivg.iwpim.com.ua/index.php/mivg/article/view/346

UDC 628.16

DETERMINATION OF HYDRAULIC GRAIN SIZE OF NATURAL AND ARTIFICIAL SORBENTS FOR SIMULATION OF SETTLE FACILITY

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Abstract. *In the conditions of progressive contamination of surface sources of water supply and inefficient wastewater treatment when using existing water treatment technologies, the research problem and the justification of the use of sorption materials for the retention of specific pollutants, in particular heavy metal ions and radionuclides, is urgent. The parameters that determine the efficiency of sorbents are indicators of their sedimentation rate. The purpose of the experiments was to determine the sedimentation rate indicators for bentonite and copper ferrocyanide, build sorbent sedimentation graphs, and establish the estimated sedimentation rate of sorbents in the sedimentation tank based on the studied data considering temperature regime. Deposition of the sorbent in settling tanks occurs with the non-stop movement of water at a low speed in the direction from the inlet to the outlet. The experiments are aimed at substantiating the efficiency and criteria of a universal facility, which is able to work equally effectively with sorbents in different aggregate states. The process of sorbent sedimentation in water is characterized by the kinetics of sorbent flakes conglomerates sedimentation. These processes are displayed in the form of deposition kinetics graphs. The experiment used powdered bentonite and a solution of copper ferrocyanide, consisting of yellow blood salt and copper sulphate in a given proportional ratio. In the course of the study the following parameters were determined: the hydraulic grain size of bentonite powdery clay, the dependence of the sedimentation rate on the temperature regime. The liquid layer was divided into layers that show changes in the amount of suspended substances depending on the depth, which made it possible to determine the dimensions of the settling tank, the height of the liquid overflow, which, in turn, made it possible to conduct simulation experiments on virtual machines with a full-scale clarifier-absorber in accordance to geometric parameters.*

Key words**:** *water treatment facilities, preliminary water treatment, bentonite, clarifier-absorber, hydraulic gain size, suspended particles, sorbent*

Actuality of problem. In the conditions of progressive contamination of surface sources of water supply and inefficient wastewater treatment by existing water treatment technologies, problems of the study on the use of various sorption materials for the retention of heavy metal ions and radionuclides with further development on the basis of these studies of the appropriate technological facilities where adsorption and sedimentation processes will take place are urgent.

The results of studies of the effectiveness of various sorbents are necessary for choosing the most effective of them; it is their hydrodynamic characteristics that will directly determine the design of the facility. In modern conditions, it has become possible to set the parameters of a technological facility with the help of computer Computational Fluid Dynamics modeling by Volume of Fluid technique – the modeling of the free flow of liquid by the free surface method. To reduce the model to the permissible 30–50 million elements, it is necessary to accurately determine the hydrodynamic characteristics of sorbent particles. Currently, there are no data on the hydrodynamic characteristics of the vast majority of sorbents in the reference literature. This especially applies to colloidal conglomerates formed during the introduction of liquid reagents, the combination of which causes the formation of solid phases of uncertain hydrodynamic properties. An example is one of the most effective sorbents, copper ferrocyanide ($Cu_2[Fe(CN_6)]$), which is formed from a mixture of two solutions: potassium ferrocyanide (yellow blood salt) ($K_4(Fe(CN)_6)$) and copper sulphate ($CuSO_4$) directly in purified water. The hydrodynamic characteristics of a promising combination of copper ferrocyanide with bentonite clay powder are also unknown. Exactly the hydrodynamic characteristics of the most promising sorbents were determined for the further development of the universal design of the clarifier-absorber, capable to work effectively both with liquid reagents and with solid fractions of sorbents, similar to powdered bentonites and zeolites.

Analysis of recent research and publications. In papers [1–7] the authors investigated the influence of various sorbents on technologies and water quality during the extraction of heavy metal ions. Technologies based on the use of biological factors are considered in works [8–12] and sorbents based on bentonite clays are considered in [13–16]. Researches [3; 4] show bentonites and zeolites as the most promising sorbents mainly due to their availability and technological convenience.

The aim of the research is to study hydrodynamic characteristics of promising sorption materials for their use in determining the parameters of facilities for effective retention of pollutants in natural and wastewaters.

Methodology of research. The experiments were aimed at studying the hydraulic characteristics of the most available domestic sorbents – powdered bentonite and copper ferrocyanide solution.

The process of sorbent sedimentation in water is characterized by the kinetics of sorbent flakes conglomerates sedimentation. These processes are displayed in the form of deposition kinetics graphs. During the experiment we used bentonite clay powder with fraction size of 0.1–0.072 mm and a solution of copper ferrocyanide ($(Cu_2[Fe(CN_6)])$) consisting of yellow blood salt ($(K_4(Fe(CN)_6))$) and copper sulphate ($CuSO_4$) in proportional ratio of 1.356 g of copper sulphate per 1 g of yellow blood salt. Mixing takes place in a measuring cup with the addition of no more than 50 ml of distilled water per 10 g of dry mixture. The solution of copper ferrocyanide is prepared exclusively before use, otherwise the effectiveness of the solution decreases with a delay.

Fig. 1. shows the laboratory model of a settling tank with the following geometric parameters: height – 700 mm, internal diameter – 176 mm, total volume – 17 dm^3, and working volume – 15 dm^3.

The experiment is carried out as follows: the sedimentation tank is filled with water up to the "working volume" mark with zero indicators of suspended particles and the absence of color, the working volume is 15 dm^3. The sorbent is being added in accordance with the proportion of 20 g/dm^3 to the tank and mixed until the sorbent is evenly distributed over the working volume. After the disturbances caused by mixing have stopped and the suspension has reached a state of rest, the sedimentation time is counted and data is collected according to the accepted time intervals: the amount of sediment at the bottom is measured using a ruler, cm; with the help of a pipette water is taken for the analysis on a photocolorimeter and a pH meter in the zones (Fig. 1) A, B, C, D; temperature measurements are carried out continuously in the working volume of the cylinder, °C. Water sampling was made taking into account the deviation from the classical method [17–18] to increase the reliability of the obtained results.

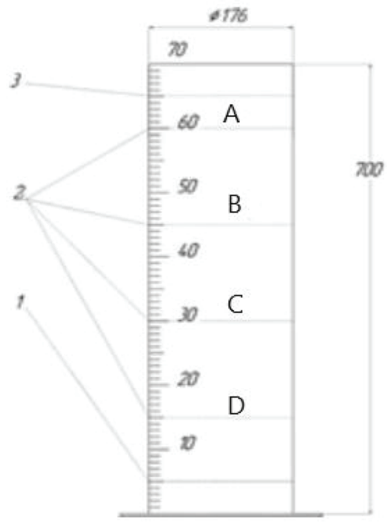

Fig. 1. The model of a vertical clarifier:
1 – the zone of accumulation of precipitated particles, 2 – the zone of collection of material (A, B, C, D) for the analysis with a photocolorimeter (turbidimeter); 3 – the height of the working volume of the settling tank.

The obtained data are summarized in a form of tables and graphs of the dependencies of hydraulic size (Fig. 2–4).

The following devices were used in the experiments: "Milwaukee Mi415" turbidity meter; Photocolorimeter "Hach DR2800"; Electronic thermometer with temperature sensor "NTC10K"; electronic scales with a resolution of 0.01 g; stopwatch.

According to the research results, a model of the sorbents deposition is built and the speed of their deposition is established (Fig. 2–4), Table 1 [18].

Calculation of hydraulic size [17; 18]:

$$U_0 = \frac{1000HK}{t_1\left(H\frac{K}{h_1}\right)^n}, \quad (1)$$

where H is the depth of the working part of the settling tank, m; K is the coefficient of settling volume utilization; t_1 is the duration of settling in a laboratory cylinder at the layer height h_1, during which the required lighting effect is achieved; n is the coefficient of proportionality, which depends

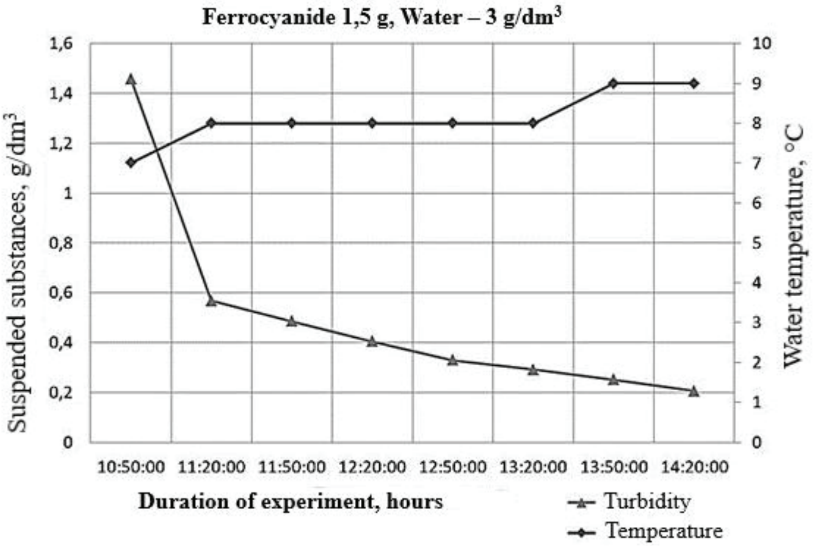

Fig. 2. Dependencies of the hydraulic grain size of the copper ferrocyanide solution for the duration of the experiment of 4 hours and the temperature of the suspensions of 7–9 ºC

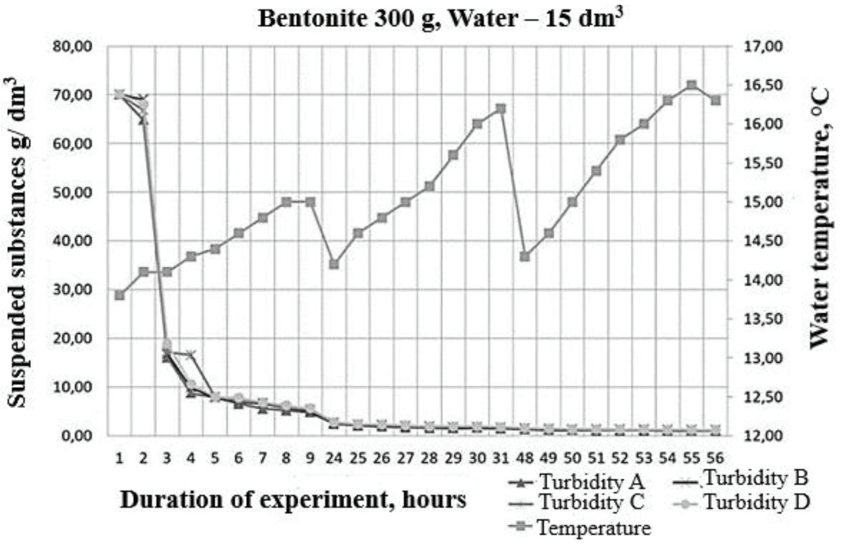

Fig. 3. Dependencies of hydraulic grain size of bentonite for the duration of the experiment of 56 hours and the temperature of suspensions of 14–16 ºC

on the agglomeration of suspended particles of substances in the process of sedimentation in different layers of water ($h_1 > h_2$) and is calculated using the formula:

$$n = \frac{lgt_1 - lgt_2}{lgh_1 - lgh_2}, \quad (2)$$

where h_1 and h_2 are the heights of settling layers, cm; t_1 and t_2 are the durations of settling in the corresponding layers, sec.

The efficiency of the sedimentation of the suspension is calculated as the difference between the values of the concentration of suspended substances in the water before and after the sedimentation:

$$P = \frac{\mu_{input} - \mu_i}{\mu_{input}} \cdot 100, \quad (3)$$

where μ_{input} is the content of suspended substances in the input water; μ_i is the content of suspended substances in settled water, g/dm^3, after the settling time [19].

Research results. During the study, the following parameters were determined: the hydraulic grain size of bentonite powdery clay and copper ferrocyanide, the dependency of the sedimentation rate on the temperature regime, and the full settling cycle.

Note. Turbidity A, Turbidity B, Turbidity C, Turbidity D are the turbidity samples taken at the

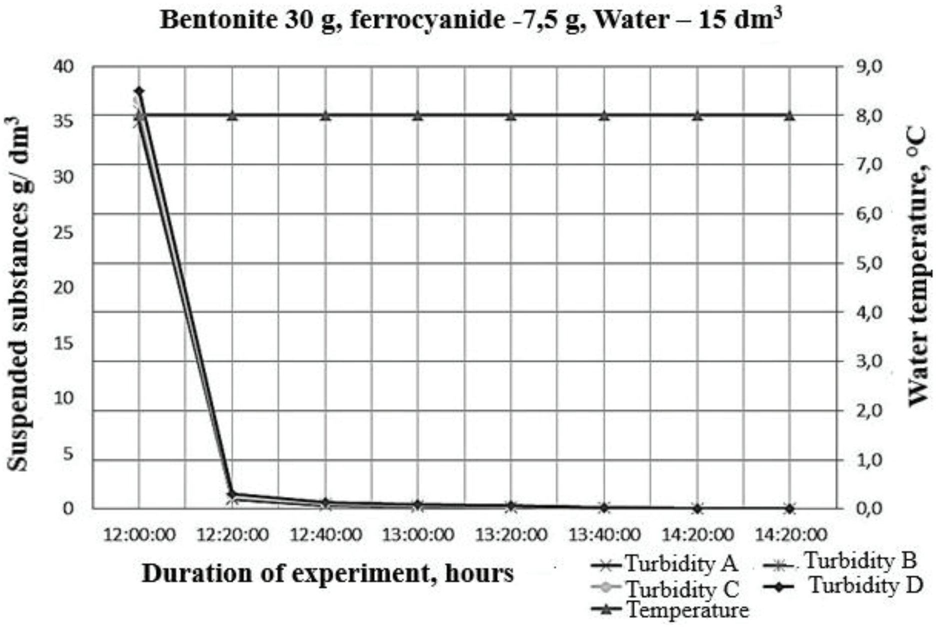

Fig. 4. Graphs of dependencies of the hydraulic grain size of bentonite and copper ferrocyanide mixture for the duration of the experiment of 2 hours and 20 minutes and the suspension temperature of 8 ºC

1. Calculated data of hydraulic grain size (mixtures of bentonite clay powder, zeolite and copper ferrocyanide)

№	Name	Settling time, *t*, hours	Hydraulic grain size, U_0, mm/sec.	Coefficient of proportionality, *n*	Concentrations of suspended substances, *P*, %
1	Copper ferrocyanide	6	1.44	0.54	87.9
2	Bentonite	56	0.11	1.39	98.26
3	Bentonite + copper ferrocyanide	2.20	6.185	0.29	99.8

same time from different depths of the settling tank. From the bottom of the sedimentation model, A = 60 cm, B = 45 cm, C = 30 cm, D = 15 cm (Fig. 1).

The best result of 99.8% precipitation of suspended particles and complete decolorization of purified water from copper ferrocyanide residues was recorded in an experiment with a mixture of bentonite powdery clay and copper ferrocyanide solution in the proportion of 2/0,5 g/dm^3 of dry matter.

Based on the obtained data empirical models were built to describe the change in water turbidity depending on the settling time.

The change in water turbidity over time during settling of the sorbent – copper ferrocyanide – is described by Equation (4)

$$CK = 0,287 + e^{(1,321-1,174 \cdot t)}, \quad (4)$$

where *CK* is the turbidity concentration, mg/dm^3; *t* is the settling time, hours.

Multiple correlation of the model is $R = 0.987$; explained variance – 97; $p < 0.00001$

The change in water turbidity over time during settling of the sorbent – dusty bentonite – is described by Equation (5)

$$CK = 16,589 - 0,781 \cdot t + 14,506 \cdot \sqrt{t} - 19,007 \cdot ln(t) - 11,171 \cdot \left(\frac{1}{t}\right), \quad (5)$$

where *CK* is the turbidity concentration, mg/dm^3; *t* is the settling time, hours.

Multiple correlation of the model is $R = 0.983$; coefficient of determination – $R^2 = 0.965$; adjusted determination – $R^2_{adj} = 0,953$; Fisher's $F(4.20) = 139.37$; $p < 0.00000$; standard estimated error – 0.71870.

The change in water turbidity over time during settling of a mixture of sorbents – copper ferrocyanide and dusty bentonite – is described by Equation (6)

$$CK = 0,20267 + e^{(7,377-3,799 \cdot t)}, \quad (6)$$

where *CK* is the turbidity concentration, mg/dm^3; *t* is the settling time, hours.

Multiple correlation of the model – $R = 0{,}999$; explained variance – 99; $p < 0{,}0001$.

These equations in the further modeling of suspension sedimentation processes in the adsorber-settler make it possible to move away from "pseudo bitmaps" arrays of particles with billions of dimensions to "pseudo-vector" calculations already with tens of millions of "vector" particles and thus significantly reduce the requirements for computer performance, which makes it possible to move away from the use of computer clusters and conduct simulations on an individual workstation.

Conclusions. Physical modeling of the sorbent deposition process using a model of settling tank made it possible to determine the hydraulic grain size of the sorbents, which will be used in the future to justify technological and structural parameters of the combined adsorber-clarifier facility, which ensure effective extraction, first of all, of heavy metal ions and radionuclides from natural and sewage water.

The empirical equations of water/sorbent suspension sedimentation built on the basis of experiments will significantly reduce the requirements for computer capabilities.

Prospects for further research. On the basis of the received data, it is planned to carry out simulation experiments using the virtual machine "FlowVision simulation CFD (Computational Fluid Dynamics)", which works on the basis of the finite element method (FEM) and the finite volume method (FME). Experiments are carried out by modeling in a virtual environment using a software package for working with spatial models.

In the virtual experiment, a simplified model of the clarifier-absorber is used, since the clarifier-absorber with a vertical flow has an axisymmetric geometry, the three-dimensional flow modeling mode can be simplified to a two-dimensional model with the corresponding possibilities of saving resources and ease of working with the model.

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УДК 628.16

ВИЗНАЧЕННЯ ГІДРАВЛІЧНОЇ КРУПНОСТІ ПРИРОДНИХ І ШТУЧНИХ СОРБЕНТІВ ДЛЯ МОДЕЛЮВАННЯ КОНСТРУКЦІЙ ВІДСТІЙНИКА

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Анотація. *В умовах прогресуючого забруднення поверхневих джерел водопостачання та неефективного очищення стічних вод при використанні існуючих технологій водопідготовки актуальним є завдання дослідження та обґрунтування застосування для затримання специфічних забруднень, зокрема іонів важких металів та радіонуклідів, сорбційних матеріалів. Параметрами, що визначають ефективність сорбентів, є показники швидкості їх осаджування. Метою експериментів було визначення показників швидкості осадження для бентоніту та фероціаніду міді, побудова графіків осадження сорбентів та встановлення за досліджуваними даними розрахункової швидкості осадження сорбентів у відстійнику з урахуванням температурних даних. Осадження сорбенту у відстійниках відбувається при безупинному русі води з малою швидкістю в напрямку від входу до виходу. Досліди спрямовані на обґрунтування ефективності та критеріїв універсальної споруди, яка здатна однаково ефективно працювати з сорбентами у різних агрегатних станах. Процес седиментації сорбенту у воді характеризується кінетикою осадження конгломератів пластівців сорбенту. Дані процеси відображаються у вигляді графіків кінетики осадження. В досліді використовувався пудроподібний бентоніт та розчин фероціаніду міді, що складається з жовтої кров'яної солі та сульфату міді у заданому пропорційному співвідношенні. В ході дослідження було визначено наступні параметри: гідравлічна крупність бентонітової пудроподібної глини, залежність швидкості осадження від температурного режиму. Товщу рідини було розділено на шари, які показують перепади кількості завислих речовин в залежності від глибини, що дало змогу визначити розміри відстійника, висоту переливу рідини, що, в свою чергу, дає змогу проводити імітаційні досліди на віртуальних машинах з повномасштабним освітлювачем-адсорбером у відповідності до геометричних параметрів.*

Ключові слова: *водоочисні споруди, водопідготовка, бентоніт, адсорбер-відстійник, гідравлічна крупність, завислі частки, сорбент*