International Journal of GEOMATE, Sept. 2023, Vol. 25, Issue 109, pp.69-76
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.109.m2304
Geotechnique, Construction Materials and Environment

MATHEMATICAL MODELING OF MOTION OF THE SOLID PARTICLES IN THE FILTER-COALESCER WASTEWATER TREATMENT

*Jamil Safarov[1]

[1]Department of Chemical and Metallurgical Engineering, Azerbaijan Technological University, Ganja, Republic of Azerbaijan

*Corresponding Author, Received: 15 March 2023, Revised: 24 April 2023, Accepted: 9 June 2023

ABSTRACT: The purpose of this article is to describe the method of calculation of the motion of particles in the filter-coalescer wastewater treatment based on the mathematical description of the motion of the cleaning fluid and the particles in the channel coagulator. It is found that fine particles in the coagulator move in a stream so that the process of consolidation and coalescence occurs at specific sites in the gap between the cones, with little flow velocity vector changes in direction and magnitude that the process provides an efficient aggregation of particles. The length of this section should be sufficient to ensure that the bulk of the particles reach a critical size. This allows the particles to migrate subsequent channel sections coagulator holding particles in the flow, and eliminating such deposition of particles on the internal surfaces of the device even when moving within the annular gap. The scheme of the electromagnetic filter of the coagulator, the two-dimensional scheme of the magnetic coagulator, the scheme of epure of speed vectors in the canal of the coagulator and the scheme of particle interaction in the canal of the coagulator are given too.

Keywords: Wastewater treatment; Coagulant; Mathematical model of the particle; Solid particles; The computational experiment.

1. INTRODUCTION

The potential benefits of wastewater management are vast, yet the unfortunate truth is that only a minuscule fraction of the total amount of wastewater generated is actually gathered and treated (Figure 1) [1]. This lack of proper wastewater management systems has severe implications for public health, environmental sustainability, and economic growth. Developing effective systems for wastewater treatment and reuse is crucial for ensuring clean water resources, preventing the spread of waterborne diseases, reducing pollution, and promoting sustainable development [1-5].

The treatment of discharged water at machine-building enterprises, which contains a considerable quantity of metal chips and used lubricating-cooling fluid (LCF), is pertaining to great technical difficulties as the emulsions differ with resistance and weak biological oxidability of mineral oil. They take the mechanical, physico-chemical and biological cleaning methods very hard [6-9]. In most cases, the operation wastewater form low-concentration suspension containing fine particles with dimensions of 0.1-15 micrometer. It may be said that the wastewater of many enterprises forms an aggregative stable system [10-15].

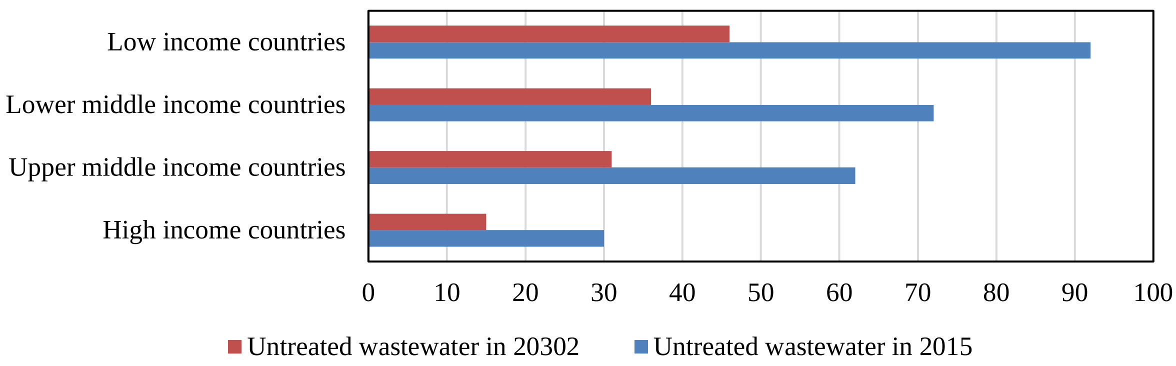

Fig. 1 Untreated wastewater percentage in countries of various income levels and future goals for 2030

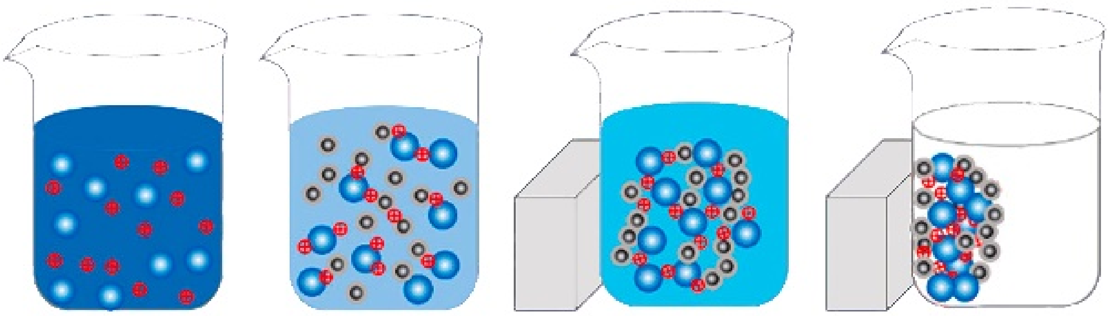

Fig. 2 Schematic mechanism of work of magnetical coagulator

The particles with dimensions of 0.1-5 micrometers and less filtrate with little to no and remaining in suspension state are taken by water flow to extended distance, they are deposited on the internal surface of the aggregates, and it has a negative impact on their working capacity. However, it is known that in the process of filtration out of wastewater, the particles with dimensions of 5-10 micrometers and more are extracted quite easily, which is why the aggregation (enlarging) of the small particles to such dimensions let to manage the process of particles filtration and to fully exclude the settlement of hard deposits on the internal surface of the aggregates in case of right organization of cleaned liquid flow [16-18].

There are three methods of aggregation development: electrolytic coagulation, flocculation with hydrophobizated reagents, and flocculation with polymers. For ferromagnetic particles, there are methods of magnetical coagulation (Figure 2) [19-22]. The deficiency of the majority of the facilities used for coagulation based on prior art is polishing of the internal surfaces because of the settlement of fine particles in the dimensions of 0,3–5 micrometers. It is necessary to protect the machinery, which provides the process of coagulation with the help of modern instrumental facilities, which use the mathematic models of the motion of both small and large particles in the flow of cleaned liquid [23-26]. Such an approach allows for determining the optimal parameter of the facility providing the effective conduct of the process of small particle aggregation. For his reason, the issues of mathematical modeling of particle motion, investigation and elaboration of self-cleaning methods of the internal surfaces come to the fore and are important today [27-30].

The paper considers the coagulator, which allows effective magnetizing of the particles and their coagulation in the ramjet mode. For a decrease in the particle's settlement process on the internal surface of coagulator, it is suggested to use the vertical scheme of wastewater flow with the changing speed and flow direction.

The suggested method of calculation of the particle motion process in the coagulator for effluent treatment represents a scientific novelty as it proposes a new approach to understanding the coagulation process in the equipment. The method is based on the mathematical description of the cleaned liquid and particle motion in the canal of the coagulator, which provides a more accurate understanding of the process than previous methods. Furthermore, the research proposes changes to the construction of the cone circular coagulation and lengthening the working surface of the magnetic gap to improve the filter-coagulator set in the complex for effluent treatment. These changes are based on the analysis of the received data and experimental research, which confirms the theoretical results.

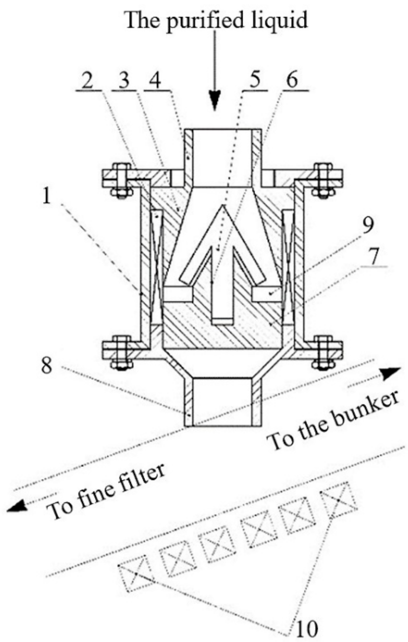

Fig. 3 Scheme of the electromagnetic filter of coagulator.

The scheme of the coagulator is shown in Figure 3. The concerned equipment consists of main body 1; magnetic field generator 2, inner magnetic circuit submerged in the main body 5, made in the form of a cone with tail 6, which has a possibility of central axial movement in reference to the main body and cylindro-wedge member 7, which is situated with the split in relation to outside cone 3; inlet branch 4; grooves 9 slotted in the cylindrical belt of the parts 7 for the liquid flow to the outlet fitting 8; electromagnet system 10. The equipment is working as follows: the cleaned liquid enters the inlet branch 4, then it goes to the cone backlash of the magnetic circuit of the coagulator, formed by cones 3 and 5. Here the magnification of the particles and their aggregation takes place. Then the liquid containing the large particles flows to the outlet fitting through the grooves 9. After that, the separation of the large particles takes place on the magnetic separator and the liquid enters the filter of fine purification.

2. RESEARCH SIGNIFICANCE

The research described has significant relevance in the field of wastewater treatment, which is a critical issue in modern society due to the increasing demand for clean water resources. The study focuses on developing a method for efficiently removing fine particles from wastewater using a filter-coalescer system which is essential as fine particles are challenging to remove from wastewater and can cause severe environmental problems if not treated properly. The research contributes to the advancement of knowledge in the field by providing a detailed mathematical description of the motion of cleaning fluid and particles in the coagulator channel. The study finds that the process of consolidation and coalescence occurs at specific sites in the gap between the cones, which provides an efficient aggregation of particles and prevents their deposition on internal surfaces. This research has practical applications in the development of more effective and efficient wastewater treatment systems, which can help reduce environmental pollution and ensure the availability of clean water resources for future generations.

3. MATERIALS AND METHODS

On the basis of this model, it is planned to create the instrumental facilities of coagulator projectors with the vertical flow of liquid and to receive the recommendations on the optimal parameter choice of coagulator. Figure 4 shows the scheme of the coagulator canal in the two-dimensional formulation. Also, all dimensions are shown, determining the duct geometry of the coagulator. These particular dimensions determine the character of flow motion and the speed at the point of particle location $\bar{\boldsymbol{V}}_{\boldsymbol{i}} = \left(\boldsymbol{V}_{\boldsymbol{x}}, \boldsymbol{V}_{\boldsymbol{y}}, \boldsymbol{V}_{\boldsymbol{z}}\right)^{\boldsymbol{T}}$, which is the managing effect of the particle flow process in the coagulator canal.

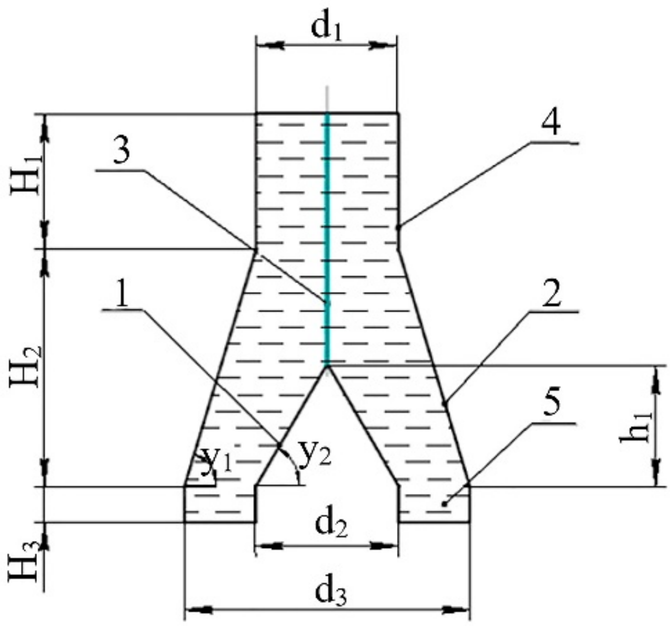

Fig. 4 Two-dimensional scheme of the magnetic coagulator: 1 – internal cone, 2 – external cone, 3 – reference axis, 4 – inlet fitting, 5 – outlet fitting.

4. RESULTS AND DISCUSSION

For the determination of the flow speed, the finite-element method was used, which was realized in the ANSYS package. Such a method of speed determination allows *finding* the speed of water at any point of the cutset of the coagulator. For this task, there were formed the boundary conditions which are determined by the duct geometry of the coagulator [31; 32].

As the result of modeling, the epures of speed vectors are received and the margins of velocity conditions of liquid flow in the canal (Figure 5), on which there is shown the scheme of distribution of velocity vector of the flow points, received by the calculation method.

The authors considered the flow of fluid on the different parts of the coagulator. It is necessary to divide the channel part of the coagulator into five sections. In Section I, the flow speed to the length of the inlet branch changes with little to no, and in cross-sectional view in the area of the boundary layer, it is equal to 0,5 m/s, and in the flow center – 1.5 m/s. In Section II the flow deflection takes place, herewith the form of liquid distribution epure becomes unsymmetrical, but the best speed value on the module scarcely changes. The trajectory of particles here is curvilinear; in these sections in liquid, the fine particles with dimensions of d_i prevail.

Further in Section III, the stricture takes place, and this causes the growth of flow speed in the flow center from the value of 1,5 m/s up to 4,5 m/s. The calculations show that in this section, the uniformly accelerated motion of the liquid takes place [15; 33]. In this section, the process of particle aggregation takes place, and their size grows up to D_i, but the fine particles with dimensions of d_i also can remain. In Section IV, the flow deflection of the liquid through 90^0 takes place, the motion takes place by curvilinear trajectory, the area bordered upon the internal surface of the outlet fitting, where the speed decreases nearly to zero level, is seen well.

The speed in the flow center which is 4,4 m/s at the start of the section decreases almost to the level of 3 m/s, the uniformly retarded motion of the liquid takes place. In section V the flow goes almost regularly with the speed of 3 m/s in the center. The received velocity fields allow researching the particles' motion in the flow on the different sections of the motion. The epure of velocity distribution over a cross-section is presented in the form of a differential equation [28].

Equation of curve:

$$\boldsymbol{V_x = a_1 + a_2 \cdot x + a_3 \cdot x^2} \quad (1)$$

The points the curve has to path through:

$$\boldsymbol{A} = [\boldsymbol{L},\ \boldsymbol{0}], \quad (2)$$

$$\boldsymbol{M} = [\boldsymbol{L} \cdot (\boldsymbol{1} - \boldsymbol{cos}(\boldsymbol{\gamma})),\ \boldsymbol{L} \cdot \boldsymbol{sin}(\boldsymbol{\gamma})], \quad (3)$$

$$\boldsymbol{D} = [\boldsymbol{c},\ \boldsymbol{d}] \quad (4)$$

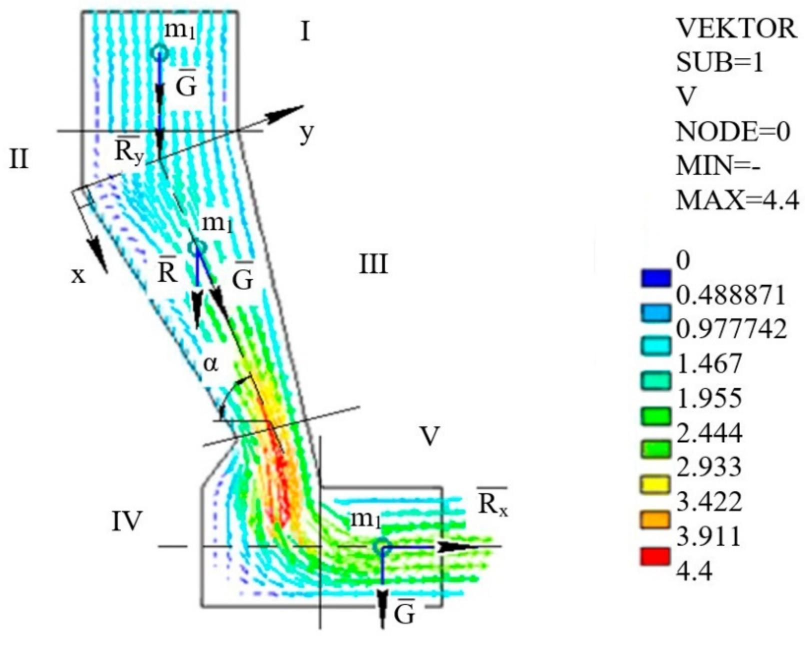

Fig. 5 Epure of speed vectors in the canal of the coagulator.

$$\boldsymbol{Fmy_{i,j}} = \frac{r_{i,j}}{k_{i,j}+(x_j-x_i)^2+(y_j-y_i)^2} \cdot \frac{x_j-x_i}{\sqrt{(x_j-x_i)^2+(y_j-y_i)^2}}, \quad (9)$$

$$\boldsymbol{Fmy}_{i,j} = \frac{r_{i,j}}{k_{i,j}+(x_j-x_i)^2+(y_j-y_i)^2} \cdot \frac{y_j-y_i}{\sqrt{(x_j-x_i)^2+(y_j-y_i)^2}}, \quad (10)$$

In Figure 6, the scheme of particle interaction in the canal of the coagulator is presented. Let us consider that each particle is influenced by the force of hydrodynamic resistance determined by the differential speed of the water flow in the place of particle location and the particle's own speed, weight force, buoyancy force, and force of magnetic action on a particle. Differential equations of particle motion in the canal in the projection of the reference axis are presented as follows.

$$\boldsymbol{m_i} \cdot \frac{d\dot{x}_i}{dt} = \boldsymbol{R^R}_{xi} + \boldsymbol{F}_{mxi}, \quad (5)$$

$$\boldsymbol{m_i} \cdot \frac{d\dot{y}_i}{dt} = \boldsymbol{m_i g} - \boldsymbol{F}_{ai} + \boldsymbol{R}^R_{yi} + \boldsymbol{F}_{myi}, \quad (6)$$

$$\boldsymbol{R^R}_{x_i} = \boldsymbol{cS\rho}(\boldsymbol{V}_{x_i} - \dot{x}_i)|\boldsymbol{V}_{x_i} - \dot{x}_i|/2, \quad (7)$$

$$\boldsymbol{R^R}_{y_i} = \boldsymbol{cS\rho}\left(\boldsymbol{V}_{y_i} - \dot{y}_i\right)|\boldsymbol{V}_{y_i} - \dot{y}_i|/2. \quad (8)$$

The authors will determine the forces bringing about the aggregation of particles by the eq. 9, 10 in which $\boldsymbol{r}$, к - are the magnetic interaction figures.

If (R_i+R_j)2 = $\boldsymbol{\delta}_{i,j}^{2}$, in which $\boldsymbol{\delta}_{i,j}^{2}$ is the squared distance between the particles, then the contact between particles attended by sticking and aggregating takes place. Further on they move together. The equation of such movement is written as:

$$(\boldsymbol{m_i} + \boldsymbol{m_j})\frac{d\bar{v}_i}{dt} = \bar{\boldsymbol{R}}_i^R + \bar{\boldsymbol{G}}_i + \bar{\boldsymbol{F}}_{a_i} \quad (11)$$

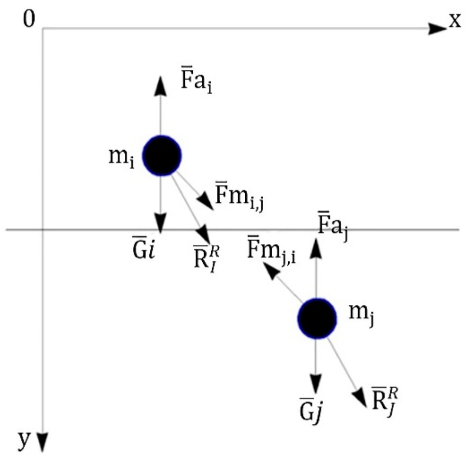

Fig. 6 Scheme of particle interaction in the canal of coagulator.

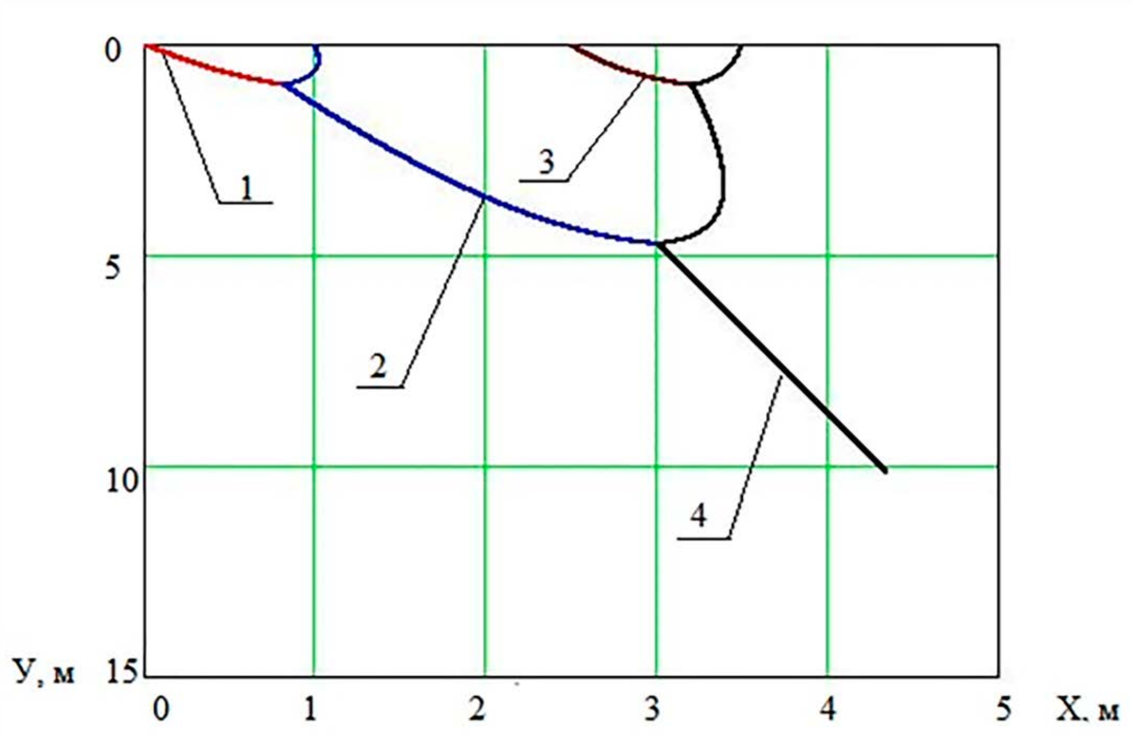

Fig. 7 Particles trajectory: 1 - $y_1(x_1)$, 2 - $y_2(x_2)$, 3 - $y_3(x_3)$, 4 - $y_4(x_4)$

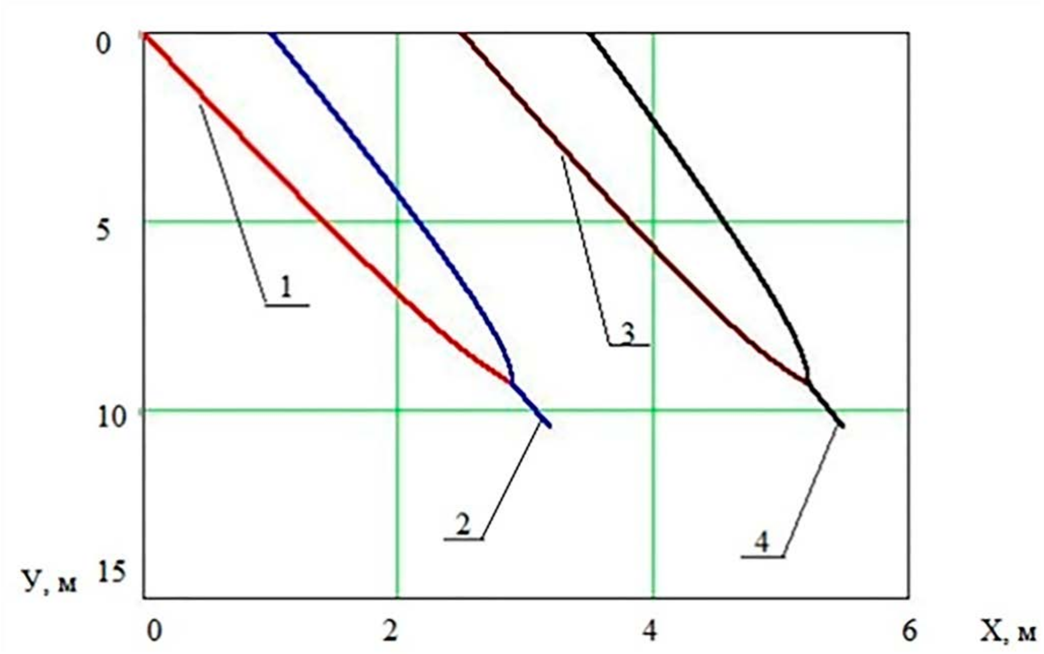

Fig. 8 Particles trajectory: 1 - $y_1(\mathbf{x_1})$, 2 - $y_2(\mathbf{x_2})$, 3 - $y_3(\mathbf{x_3})$, 4 - $y_4(\mathbf{x_4})$

An aggregate composed of two particles can join some more particles to itself, or can leave the canal. For the determination of the initial rate of the particles in the 3rd section, the flat motion of the liquid in the canal of the coagulator was researched in the 2nd section.

The appearance of a particle at any point at the start of section III of the canal takes place by accident. The size of fine particles changes by the normal law. Modeling the movement of n-particles entering the 3rd section, the authors can study the process of large particle formation in the process of coagulation. Further on, the calculations were conducted for the following parameters $\boldsymbol{\mu_{1i}}$=225, $\boldsymbol{\mu_{2i}}$=15 и $\boldsymbol{r_{ij}} = \mathbf{3 \cdot 10^{-11}}$. Let us integrate the differential equation for entry conditions:

$$\begin{matrix} \boldsymbol{x_1 = 0} & \boldsymbol{x_1 = 1} & \boldsymbol{x_1 = 2.5} & \boldsymbol{x_1 = 3.5} \\ \boldsymbol{y_1 = 0} & \boldsymbol{y_1 = 0} & \boldsymbol{y_1 = 0} & \boldsymbol{y_1 = 0} \end{matrix} \quad (12)$$

After integration, the functions indicated in Figure 7 will be received.

The authors integrated the differential equation for changed parameters $\boldsymbol{\mu_{2i} = 1}$ и $\mathbf{r_{ij} = 2 \cdot 10^{-12}}$ and entry conditions:

$$\begin{matrix} \mathbf{x_1 = 0} & \mathbf{x_1 = 1} & \mathbf{x_1 = 2.5} & \mathbf{x_1 = 3.5} \\ \mathbf{y_1 = 0} & \mathbf{y_1 = 0} & \mathbf{y_1 = 0} & \mathbf{y_1 = 0} \end{matrix} \quad (13)$$

After integration, it is possible to obtain the functions indicated in Figure 8.

The analysis of these functions shows that the type of particle motion essentially depends on the parameters $\boldsymbol{\mu_{2i}}$,$\boldsymbol{r_{ij}}$,$\boldsymbol{k}$, which determine the forces of particle interaction, and also the size of the particles $\boldsymbol{m_i}$. You can clearly see the process of particles' motion in the canal, their sticking and aggregates motion. As the value $\boldsymbol{\mu_{2i}}$,$\boldsymbol{r_{ij}}$ decreases, the distance on which the sticking process takes place increases, and this allows us to relate with the magnet field parameters and geometrical dimensions of the canal of the coagulator.

5. CONCLUSIONS

In recent times, effluent treatment has become a crucial aspect of environmental management. The discharge of untreated industrial effluent can have significant negative impacts on the environment, including the degradation of aquatic life and ecosystems, soil contamination, and even health hazards for humans.

To address these concerns, researchers have put forth various methods of effluent treatment. Among these methods, the use of a coagulator has emerged as a popular approach. A coagulator is a device that helps in the process of coagulation - the formation of larger particles from smaller ones, which can then be easily separated and removed from the liquid. However, the effectiveness of a coagulator depends on its ability to agglomerate particles effectively and prevent them from settling on the internal surfaces of the equipment.

In this context, the authors of the present paper have proposed a novel method for calculating the particle motion process in the coagulator during effluent treatment. The method is based on the mathematical description of the cleaned liquid and the particle motion within the canal of the coagulator. Through their research, the authors have identified specific areas within the backlash clearance between the cones where fine particles move in the flow and undergo sticking and enlarging processes. During this process, the speed vector of the flow changes direction and value only slightly, leading to an effective aggregation of particles.

It is determined that in the coagulator the fine particles move in the flow, such as the sticking and the enlarging process takes place on the special areas in the backlash clearance between the cones, herewith the speed vector of the flow varies its direction and value only slightly, and this provides the effective process of aggregation of the particles. The length of this area must be enough to let the basis weight of the particles reach the critical size $\boldsymbol{S = 10^{-10}}$. This allows transferring the particles to the further areas of the canal of the coagulator holding the particles in the flow and excluding the settlement of such particles on the internal surfaces of the equipment even during the motion inside the circular clearance.

In such a way, the liquid with large aggregates transfers to the zone of magnetic separation and filter. The analysis of the received data allows us to make changes to the construction of the cone circular coagulation and to length the working surface of the magnetic gap, and by this to improve the filter-coagulator set in the complex on effluents treatment. The experimental research confirmed the received theoretical results.

6. REFERENCES

[1] Wastewater as a resource, European Investment Bank, 2022, pp. 1-29. https://www.eib.org/attachments/publications/wastewater_as_a_resource_en.pdf

[2] Ivanchina E.D., Ivashkina E.N., Nazarova G.Y., and Seitenova G.Z., Influence of Feedstock Group Composition on the Octane Number and Composition of the Gasoline Fraction of Catalytically Cracked Vacuum Distillate, Petroleum Chemistry, Vol. 58, Issue 3, 2018, pp. 225-236.

[3] Galymbek B., Adilet K., Moldir M., and Nurbol T., Highly pressurized hydraulic fracturing fluid behavior in oil-bearing rocks, International Journal of Chemical Sciences, Vol. 13, Issue 2, 2015, pp. 963-970.

[4] Nazarova G., Ivashkina E., Shafran T., Oreshina A., and Seitenova G., Prediction of residue coke content and operating modes of regenerator in the catalytic cracking technology, Petroleum Science and Technology, Vol. 38, Issue 24, 2020, pp. 1017-1025.

[5] Nadirov K.S., Moldabayeva G.Z., Baibotayeva S.E., Zeygman Y.V., and Sadyrbayeva A.S., Reagent preparation for oil treatment and its use in the process of dehydration, Journal of Industrial Pollution Control, Vol. 33, Issue 1, 2017, pp. 1075-1084.

[6] Semeshko O., Saribekova J., Asaulyuk T., and Myasnikov S., The influence of electrical discharge nonlinear bulk cavitation on the structural and chemical changes in water during the wool fiber bleaching, Chemistry and Chemical Technology, Vol. 8, Issue 4, 2014, pp. 451-454.

[7] Brazhko O.A., Yevlash A.S., Zavgorodnii M.P., Kornet M.M., Brazhko O.O., and Lagron A.V., Basic approaches to the synthesis of pyrrolo[1,2-a]quinolines derivatives: A review, Voprosy Khimii i Khimicheskoi Tekhnologii, Vol. 2019, Issue 6, 2019, pp. 6-16.

[8] Moldabayeva G.Z., Metaxa G.P., and Alisheva Z.N., Scientific-technical basics of viscosity reduction of the Kazakhstani oils, which provide a significant increase of oil reservoirs, News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, Vol. 3, Issue 430, 2018, pp. 186-194.

[9] Nazarova G.Y., Ivashkina E.N., Oreshina A.A., Vymyatnin E.K., Seytenova G.Z., and Burumbaeva G.R., Vacuum distillate catalytic cracking technology modelling: Feedstock and products composition and properties investigation, Petroleum and Coal, Vol. 62, Issue 2, 2020, pp. 380-389.

[10] Li B., Xu B., and Yang, B., Role of geomechanics in petroleum production in Xinjiang oil field, China, Lecture Notes in Civil Engineering, Vol. 230, 2022, pp. 95-104.

[11] Yang D., Peng X., Peng Q., Wang T., Qiao Ch., Zhao Z., Gong L., Liu Y., Zhang H., and Zeng H., Probing the interfacial forces and surface interaction mechanisms in petroleum production processes, Engineering, Vol. 18, 2022, pp. 49-61.

[12] Yascun S.F., Safarov D.I., Mischenko V.Y., and Loktionova O.G., Vibration machines and technologies, Elm, Baku, 2004, pp. 1-408.

[13] Safarov D.I., and Yascun S.F., Vibraton technological processes of effluents treatment. Elm, Baku, 2004, pp. 1-315.

[14] Ojedapo B., Ikiensikimama S.S., and Wachikwu-Elechi V.U., Petroleum production forecasting using machine learning algorithms, SPE Nigeria Annual International Conference and Exhibition, 2022, article number: 181613.

[15] Udourioh G.A., Epelle E.I., Achugasim O., Solomon M.M., and Okafor P.C., A study on the composition of heavy organic precipitates at various locations of a petroleum production line: wellhead, separator, and flowline,

Petroleum Science and Technology, Vol. 40, Issue 4, 2022, pp. 469-485.
[16] Rahmadyanti E., Wiyono A., Firmansyah and G.A., Integrated system of biofilter and constructed wetland for sustainable batik industry, GEOMATE Journal, Vol. 18, No. 70, 2020, pp. 138-144.
[17] Kvasnytskyi V., Korzhyk V., Lahodzinkyi I., Illiashenko Y., Peleshenko S., and Voitenko O., Creation of Volumetric Products Using Additive Arc Cladding with Compact and Powder Filler Materials, Proceedings of the 2020 IEEE 10th International Conference on "Nanomaterials: Applications and Properties", Vol. NAP 2020, 2020, art. 20209309696.
[18] Metaksa G.P., Moldabayeva G.Z., and Alisheva Z.N., Mechanism of structure formation in fluid-bearing minerals, Mining Informational and Analytical Bulletin, Vol. 2019, Issue 2, 2019, pp. 78-84.
[19] Huang H., Lin J., Wang W., and Li S., Biopolymers produced by sphingomonas strains and their potential applications in petroleum production, Polymers, Vol. 14, Issue 9, 2022, article number 1920.
[20] Baruah B., Kalita P., Pandey L., and Tiwari P., Petroleum reservoirs and oil production mechanisms, Green Energy and Technology, 2022, pp. 1-21.
[21] Pillai P., Maiti M., and Mandal A., Mini-review on recent advances in the application of surface-active ionic liquids: Petroleum industry perspective, Energy and Fuels, Vol. 36, No. 15, 2022, pp. 7925-79394.
[22] Naidek B.P., Conte M.G., Cozin C., da Silva M.J., and Morales R.E.M., Influence of liquid viscosity on horizontal two-phase slug flow, Lecture Notes in Mechanical Engineering, 2022, pp. 275-282.
[23] Fetouh M., Rustum R., and Adeloye A.J., A comparative study of conventional extended aeration and modern membrane bioreactor methods of sewage treatment from the environmental and financial perspectives, GEOMATE Journal, Vol. 20, No. 78, 2021, pp. 50-56.
[24] Bolatbek K., Brodskiy A.R, Ivanov S.I, Gordienko M.G, and Menshutina N.V., Modeling of substances adsorption process in aerogel pores, International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, Vol. 3, Issue BOOK 6, 2016, pp. 83-90.
[25] Chuzlov V.A., Ivanchina E.D., Dolganov I.M., Sejtenova G.Z., and Ivanov S.Y., The branched C5-C6 hydrocarbons synthesis on Pt-catalyst, Current Organic Synthesis, Vol. 14, Issue 3, 2017, pp. 332-341.
[26] Kulyk K., Ishchenko V., Palyanytsya B., Khylya V., Borysenko M., and Kulyk T., A TPD - MS study of the interaction of coumarins and their heterocyclic derivatives with a surface of fumed silica and nanosized oxides CeO2/SiO2, TiO2/SiO2, Al2O3/SiO2, Journal of Mass Spectrometry, Vol. 45, Issue 7, 2010, pp. 750-761.
[27] Abd A.A., Naji S.Z., Tye Ch.Th., and Othman M.R., Evaluation the effect of the ambient temperature on the liquid petroleum gas transportation pipeline, Chemical Product and Process Modeling, Vol. 17, No. 5, 2022, pp. 479-488.
[28] Hossain M.N., and Howladar M.F., Risk perception and safety analysis on petroleum production system of three gas fields in Bangladesh, Journal of Safety Science and Resilience, Vol. 3, No. 4, 2022, pp. 362-371.
[29] Zhai L., Xia H., Wu Y., and Jin N., Gas holdup measurement of horizontal gas-liquid two-phase flows by using a novel combined ultrasonic-conductance sensor, IEEE Sensors Journal, Vol. 21, No. 24, 2021, pp. 27590-27600.
[30] Safarov D.I., Yemelyanova O.V., Loktionova O.G., Modelling of pollution particles motion process in liquid flow, News of the South-West State University, Vol. 4-2, Issue 43, 2012, pp. 225-227.
[31] Loktionova O.G., Safarov D.I., and Yemelyanova O.V., Research of the particle motion in liquid flow during effluents treatment, News of the South-West State University, Series: Technics and technologies, Vol. 2, Issue 1, 2012, pp. 163-172.
[32] Tileuberdi N., Zholtayev G.Z.H., Abdeli D.Zh., and Ozdoev S.M., Investigation of drainage mechanism of oil from pores of oil saturated rocks using nitrogen at the laboratory condition, News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, Vol. 5, Issue 449, 2021, pp. 146-152.
[33] Moldabayeva G.Zh., Suleimenova R.T., Bimagambetov K.B., Logvinenko A., and Tuzelbayeva S.R., Experimental studies of chemical and technological characteristics of cross-linked polymer systems applied in flow-diversion technologies, News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, Vol. 4, Issue 448, 2021, pp. 50-58.