ЕКОЛОГІЯ НА ТРАНСПОРТІ

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INVESTIGATION OF ADMIXTURE SEDIMENTATION IN THE HORIZONTAL SETTLER

Purpose. Sedimentation by gravity is the most common and extensively applied treatment process for the removal of solids from water and wastewater and it has been used for over one hundred years. Sedimentation tanks are one of the major parts of a treatment plant especially in purification of turbid flows. Horizontal settlers are mainly used for purification of high quantity of water. In these tanks, the low speed turbid water will flow through the length of the tank and suspended particle have enough time to settle. Finding new and useful methods for calculating and increasing hydraulic efficiency of horizontal settlers is the objective of many theoretical, experimental and numerical studies. But currently used models and methods in Ukraine do not allow taking into account geometrical form and various design features. In this paper the numerical model was developed to evaluate the effectiveness of horizontal settler with modified structure. **Methodology.** Numerical model is based on: 1) equation of viscous fluid dynamics; 2) mass transfer equation. For numerical simulation the finite difference schemes are used. The numerical calculation is carried out on a rectangular grid. For the formation of the computational domain markers are used. **Findings.** The model allows obtaining the purification process in the settler with different form and different configuration of baffles. **Originality.** A new approach to investigate the mass transfer process in horizontal settler was proposed. This approach is based on the developed CFD model. The fluid dynamics model was used for the numerical investigation of flows and waste waters purification. To investigate influence of baffles on settler efficiency physical experiment was carried out. **Practical value.** The developed model has more capacity than the existing models in Ukraine. The developed model allows computing quickly the efficiency of water purification in settlers. The model is not computationally expensive. Calculation time of one variant of the problem takes few minutes.

Keywords: CFD model; settlers; mass transfer; water purification; physical experiment

Introduction

Horizontal settlers are essential hydraulic structures which have to be engineered, designed and constructed at all water treatment plants to remove most of suspended solids which enters the intake by polluted water. The bigger the settler, the best the settlement of pollutants, but the expenses are higher. Therefore, improvement of performance and increasing of removal efficiency of horizontal settlers by alternative method is necessary. Finding new and useful methods for calculating and increasing hydraulic efficiency of horizontal settlers is the objective of many theoretical, experimental and numerical studies [1, 6, 8, 10, 11, 12, 13, 14]. An approach in present paper for increasing horizontal settler performance is to use system of baffles and plates.

To obtain the horizontal settler efficiency the empirical models are used in Ukraine [2, 3]. But these models don’t allow calculating horizontal settlers with comprehensive geometrical form and different systems of baffles and plates. That’s why it is important to develop CFD models having more capabilities to simulate the process of the

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waste waters treatment in settlers and which do not need much computational time for running and allow taking into account the geometrical form of settlers [1, 8, 9].

Purpose

The objective of this paper consists of two parts. The first part is the experimental investigation of flow in horizontal settlers. The second part is development of the effective computer model (CFD model) which is more effective than the employed in Ukraine models and which can be used for prediction of the horizontal settler efficiency.

Methodology

Experimental investigation. The experiment was carried out in the hydraulics water channel, where the plates were established to form geometry of horizontal settler (Fig. 1). The main objective of the experiment was confirmation that plates influence on increasing of horizontal settler efficiency.

Physical experiments were carried out in horizontal settler (Fig. 1, Fig. 2) with dimensions 1:100 to real settler (height – 2 cm; length – 24 cm; width – 8 cm), which is in operating now at the coal mine «Stepova», Pavlograd region.

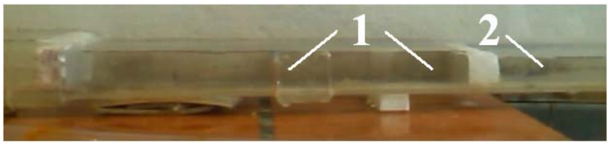

Fig. 1. Experimental model of horizontal settler without plates:
1 – distribution of the sludge inside the horizontal settler;
2 – distribution of the sludge outside the horizontal settler

Fig. 2. Experimental model of horizontal settler with plates (Г-shaped, vertical and horizontal):
1 – distribution of the sludge inside the horizontal settler in the first zone (in front of the Г-shaped plate);
2 – distribution of the sludge inside the horizontal settler in the second zone (in front of the vertical plate);
3 – distribution of the sludge inside the horizontal settler in the third zone

Froude number was chosen as criterion

$$Fr = \frac{V^2}{gl} = idem$$

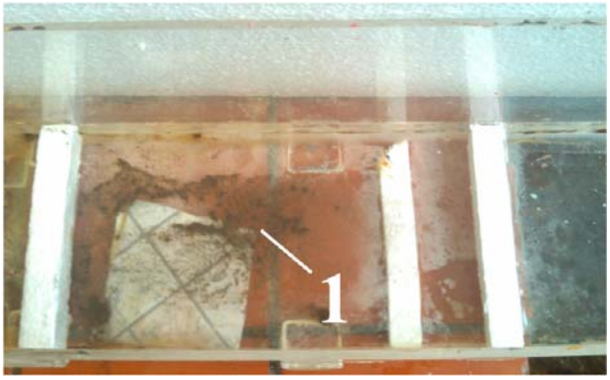

Fig. 3. Sludge (1) on the bottom of the classical horizontal settler (top view)

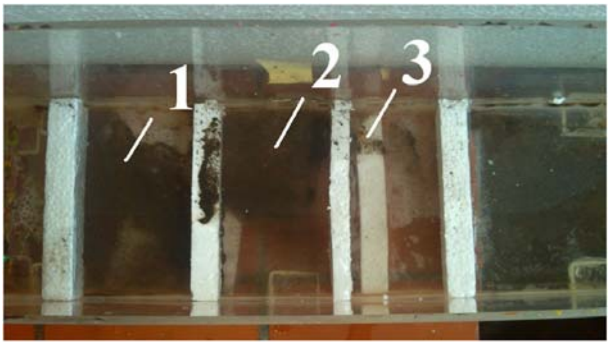

Fig. 4. Sludge on the bottom of the modified horizontal settler (top view):
1 – zone before Г – shaped plate; *2* – zone before vertical plate; *3* – zone after vertical plate

At Fig. 3, Fig. 4 results of physical experiments are shown. Table 1 presents mass of sludge, which was settled at the bottom of each horizontal settler. As we can see, mass of sludge at the bottom of modified settler is higher, than in classical one.

Table 1

Results of the experimental investigation

Model of settler	settling velocity, cm/sec		
	0,75	0,90	1,05
classical horizontal settler, g	1,1	1,9	4,2
modified horizontal settler, g	1,8	2,5	5,1

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CFD model. For numerical modeling of mass transfer process in horizontal settler CFD model was developed. It consists of two models: mass transfer model and model of viscous fluid flow.

Mass transfer model. To simulate the process of water purification in the horizontal settler the transport equation (1) is used [1, 5, 7, 9]:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial(\nu-w)C}{\partial y}+\sigma C=$$
$$=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right) \quad (1)$$

where C is the concentration; u, v are the velocity components in x, y direction respectively; w – is the settling velocity; σ – is the parameter taking into account the process of flocculation and decay; μ_x, μ_y are the coefficients of turbulent diffusion in x, y direction respectively; x_i , y_i are the Cartesian coordinates;

The transport equation is used with the following boundary conditions [1, 5, 8, 9]:

– inlet boundary: $C|_{inlet}=C_E$, where C_E is the known concentration (in the case study of this paper it is dimensionless and equal to $C_E=100$);

– outlet boundary: in numerical model the condition $C(i+1,j)=C(i,j)$ is used. Here, *C(i+1,j)* is the concentration at the outlet boundary cell (this boundary condition means that we neglect the process of diffusion at this plane). $C(i,j)$ is the concentration in the previous cell.

Initial Condition:

C=0, for t=0 [12].

Fluid Dynamics Model. To simulate the flow in the horizontal settler fluid dynamics model of viscous flow was used.

The governing equations of fluid dynamics model are equation (2) and equation (3).

Equation (2) is Poisson equation for flow function [4]:

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=-\omega \quad (2)$$

Equation (3) describes vorticity transfer in fluid [4]:

$$\frac{\partial\omega}{\partial t}+\frac{\partial u\omega}{\partial x}+\frac{\partial v\omega}{\partial y}=\frac{1}{\mathrm{Re}}\left(\frac{\partial^2\omega}{\partial x^2}+\frac{\partial^2\omega}{\partial y^2}\right) \quad (3)$$

where $\mathrm{Re}=\frac{V_0L}{\nu}$ is Reynolds number.

Boundary and initial conditions of this fluid dynamics model are discussed in [7].

Computation of settling velocity. To compute the settling velocity the following model is used [11, 13]

$$w=w_0(e^{-K_1(C-C_{\min})}-e^{-K_2(C-C_{\min})})$$

where K_1, K_2 are experimental constants [11, 13].

Numerical solver. Numerical integration of governing equations is carried out using rectangular grid. The geometrical form of the horizontal settler in the numerical model is created using porosity technique (markers method) [5, 7].

To solve Poisson equation (2) the following difference scheme of splitting is used [7]:

− at the first step of splitting the difference equation is

$$\frac{\psi_{ij}^{n+\frac{1}{4}}-\psi_{ij}^{n}}{\Delta t}=\frac{\overline{\psi_{ij}}}{2};$$

− at the second step of splitting the difference equation is

$$\frac{\psi_{i,j}^{n+\frac{1}{2}}-\psi_{i,j}^{n}}{\Delta t}=-\frac{\psi_{i,j}^{n+\frac{1}{2}}-\psi_{i-1,j}^{n+\frac{1}{2}}}{\Delta x^2}-\frac{\psi_{i,j}^{n+\frac{1}{2}}-\psi_{i,j-1}^{n+\frac{1}{2}}}{\Delta y^2};$$

− at the third step of splitting the difference equation is

$$\frac{\psi_{i,j}^{n+\frac{3}{4}}-\psi_{i,j}^{n+\frac{1}{2}}}{\Delta t}=\frac{\psi_{i+1,j}^{n+\frac{3}{4}}-\psi_{i,j}^{n+\frac{3}{4}}}{\Delta x^2}+\frac{\psi_{i,j+1}^{n+\frac{3}{4}}-\psi_{i,j}^{n+\frac{3}{4}}}{\Delta y^2};$$

− at the last step the difference equation is

$$\frac{\psi_{ij}^{n+1}-\psi_{ij}^{n+\frac{3}{4}}}{\Delta t}=\frac{\overline{\omega_{ij}}}{2},$$

where

$$\overline{\omega_{i,j}}=\frac{1}{4}\left(\omega_{i,j}+\omega_{i-1,j+1}\omega_{i-1,j-1}+\omega_{i,j-1}\right).$$

Velocity components are calculated using the following expressions

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$$u_{i,j} = \frac{\psi_{i,j+1} - \psi_{i,j}}{\Delta y}; v_{i,j} = -\frac{\psi_{i+1,j} - \psi_{i,j}}{\Delta x}.$$

To solve equation (3) the change triangle difference scheme is used [7]. First of all velocity components are written in the following form

$$u = u^+ + u^- = \frac{u + |u|}{2} + \frac{u - |u|}{2},$$

$$\nu = \nu^+ + \nu^- = \frac{\nu + |\nu|}{2} + \frac{\nu - |\nu|}{2}. \qquad (11)$$

After that the convective derivatives are approximated using the following expressions:

$$\frac{\partial u^+ \omega}{\partial x} \approx \Lambda_x^+ \omega = \left(u_{i+1,j}^+ \omega_{i,j} - u_{i,j}^+ \omega_{i-1,j}\right) / \Delta x,$$

$$\frac{\partial u^- \omega}{\partial x} \approx \Lambda_x^- \omega = \left(u_{i+1,j}^- \omega_{i+1,j} - u_{i,j}^- \omega_{i,j}\right) / \Delta x,$$

$$\frac{\partial \nu^+ \omega}{\partial y} \approx \Lambda_y^+ \omega = \left(\nu_{i,j+1}^+ \omega_{i,j} - \nu_{i,j}^+ \omega_{i,j-1}\right) / \Delta y,$$

$$\frac{\partial \nu^- \omega}{\partial y} \approx \Lambda_y^- \omega = \left(\nu_{i,j+1}^- \omega_{i,j+1} - \nu_{i,j}^- \omega_{i,j}\right) / \Delta y.$$

The second order derivatives are written as following:

$$\frac{\partial^2 \omega}{\partial x^2} \approx L_{xx}^+ \omega - L_{xx}^- \omega =$$
$$= \left(-\omega_{i,j} + \omega_{i-1,j}\right) / \Delta x^2 + \left(\omega_{i+1,j} - \omega_{i,j}\right) / \Delta x^2,$$

$$\frac{\partial^2 \omega}{\partial y^2} \approx L_{yy}^+ \omega - L_{yy}^- \omega =$$
$$= \left(\omega_{i,j-1} - \omega_{i,j}\right) / \Delta y^2 + \left(\omega_{i,j+1} - \omega_{i,j}\right) / \Delta y^2,$$

The difference approximation of the equation (3) can be written as follows

$$\frac{\omega_{i,j}^{n+1} - \omega_{i,j}^n}{\Delta t} +$$
$$+ \left(\Lambda_x^+ + \Lambda_x^- + \Lambda_y^+ + \Lambda_y^-\right)\left(\omega^{n+1}\xi + (1-\xi)\omega^n\right) =$$
$$= \frac{1}{\text{Re}}\left(L_{xx}^+ + L_{xx}^- + L_{yy}^+ + L_{yy}^-\right)\left(\omega^{n+1}\xi + (1-\xi)\omega^n\right)$$

or

$$\left(E + \Delta t \xi\right)\left(\Lambda_x^+ + \Lambda_x^- + \Lambda_y^+ + \Lambda_y^-\right)\omega^{n+1} -$$
$$- \frac{\Delta t}{\text{Re}}\xi\left(L_{xx}^+ + L_{xx}^- + L_{yy}^+ + L_{yy}^-\right)\omega^{n+1} =$$
$$= \left(E - \Delta t (1-\xi)\left(\Lambda_x^+ + \Lambda_x^- + \Lambda_y^+ + \Lambda_y^-\right)\right)\omega^n +$$
$$+ \frac{\Delta t}{\text{Re}}(1-\xi)\left(L_{xx}^+ + L_{xx}^- + L_{yy}^+ + L_{yy}^-\right)\omega^n.$$

where ξ is parameter.

If $\xi = 1/2$ we have the difference scheme which has the second order of accuracy in time.

The change triangle difference scheme for equation of vorticity transfer is written as follows

$$\left(E + \frac{\Delta t}{2}\left(\Lambda_x^+ + \Lambda_y^+\right) - \frac{\Delta t}{2\,\text{Re}}\left(L_{xx}^+ + L_{yy}^+\right)\right)\omega^{n+\frac{1}{2}} =$$
$$= \left(E - \frac{\Delta t}{2}\left(\Lambda_x^- + \Lambda_y^-\right) + \frac{\Delta t}{2\,\text{Re}}\left(L_{xx}^- + L_{yy}^-\right)\right)\omega^n;$$

$$\left(E + \frac{\Delta t}{2}\left(\Lambda_x^- + \Lambda_y^-\right) - \frac{\Delta t}{2\,\text{Re}}\left(L_{xx}^- + L_{yy}^-\right)\right)\omega^{n+1} =$$
$$= \left(E - \frac{\Delta t}{2}\left(\Lambda_x^+ + \Lambda_y^+\right) + \frac{\Delta t}{2\,\text{Re}}\left(L_{xx}^+ + L_{yy}^+\right)\right)\omega^{n+\frac{1}{2}}.$$

Using these expressions the unknown meaning of vorticity is computed using «running calculation» [7].

To solve the mass conservation equation (1) the implicit difference scheme of splitting is used [1, 7]. At first step the physical splitting of equation (1) is carried out:

$$\frac{\partial c}{\partial t} + \frac{\partial u c}{\partial x} + \frac{\partial (v - w) c}{\partial x} + \sigma c = 0$$

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(\mu_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu_y \frac{\partial c}{\partial y}\right)$$

At the second step the following approximation of the first order derivatives are used [5]:

$$\frac{\partial C}{\partial t} \approx \frac{C_{ij}^{n+1} - C_{ij}^n}{\Delta t},$$

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$$\frac{\partial uC}{\partial x}=\frac{\partial u^{+}C}{\partial x}+\frac{\partial u^{-}C}{\partial x},$$

$$\frac{\partial vC}{\partial y}=\frac{\partial v^{+}C}{\partial y}+\frac{\partial v^{-}C}{\partial y},$$

$$\frac{\partial u^{+}C}{\partial x}\approx\frac{u^{+}_{i+1,j}C^{n+1}_{ij}-u^{+}_{ij}C^{n+1}_{i-1,j}}{\Delta x}=L^{+}_{x}C^{n+1},$$

$$\frac{\partial u^{-}C}{\partial x}\approx\frac{u^{-}_{i+1,j}C^{n+1}_{i+1,j}-u^{-}_{ij}C^{n+1}_{ij}}{\Delta x}=L^{-}_{x}C^{n+1},$$

$$\frac{\partial \nu^{+}C}{\partial y}\approx\frac{\nu^{+}_{i,j+1}C^{n+1}_{ij}-\nu^{+}_{ij}C^{n+1}_{i,j-1}}{\Delta y}=L^{+}_{y}C^{n+1},$$

$$\frac{\partial \nu^{-}C}{\partial y}\approx\frac{\nu^{-}_{i,j+1}C^{n+1}_{i,j+1}-\nu^{-}_{ij}C^{n+1}_{ij}}{\Delta y}=L^{-}_{y}C^{n+1}.$$

The second order derivatives are approximated as following:

$$\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)\approx\mu_{x_1}\frac{C^{n+1}_{i+1,j}-C^{n+1}_{ij}}{\Delta x^2}-$$
$$-\mu_{x_2}\frac{C^{n+1}_{i,j}-C^{n+1}_{i-1,j}}{\Delta x^2}=M^{-}_{xx}C^{n+1}+M^{+}_{xx}C^{n+1},$$

$$\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right)\approx\mu_{y_1}\frac{C^{n+1}_{i,j+1}-C^{n+1}_{ij}}{\Delta y^2}-$$
$$-\mu_{y_2}\frac{C^{n+1}_{i,j}-C^{n+1}_{i,j-1}}{\Delta y^2}=M^{-}_{yy}C^{n+1}+M^{+}_{yy}C^{n+1}$$

Here we use notation *v=v-w*. In these formulas $L^{+}_{x},L^{-}_{x},L^{+}_{y},L^{-}_{y},L^{+}_{z},L^{-}_{y},M^{+}_{xx},M^{-}_{xx}$, etc. are the notations of the difference operators [7].

After the approximation the solution of the difference equation is splitted in 4 steps [1, 7]:

– at the first step $k=\frac{1}{4}$ the difference equation is:

$$\frac{C^{n+k}_{ij}-C^{n}_{ij}}{\Delta t}+\frac{1}{2}\left(L^{+}_{x}C^{k}+L^{+}_{y}C^{k}\right)+\frac{\sigma}{2}C^{n}_{ij}=0;$$

– at the second step $k=n+\frac{1}{2};c=n+\frac{1}{4}$ the difference equation is:

$$\frac{C^{k}_{ij}-C^{c}_{ij}}{\Delta t}+\frac{1}{2}\left(L^{-}_{x}C^{k}+L^{-}_{y}C^{k}\right)+\frac{\sigma}{2}C^{k}_{ij}=0;$$

– at the third step $k=n+\frac{3}{4};c=n+\frac{1}{2}$ the difference equation is:

$$\frac{C^{k}_{ij}-C^{c}_{ij}}{\Delta t}=$$
$$=\frac{1}{2}\left(M^{-}_{xx}C^{c}+M^{+}_{xx}C^{k}+M^{-}_{yy}C^{c}+M^{+}_{yy}C^{k}\right);$$

– at the fourth step $k=n+1;c=n+\frac{3}{4}$ the difference equation is:

$$\frac{C^{k}_{ij}-C^{c}_{ij}}{\Delta t}=$$
$$=\frac{1}{2}\left(M^{-}_{xx}C^{k}+M^{+}_{xx}C^{c}+M^{-}_{yy}C^{k}+M^{+}_{yy}C^{c}\right)$$

The developed numerical models where coded using FORTRAN.

Findings

The developed computer model was used to compute water purification in the horizontal settler with two vertical plates (Fig. 5)

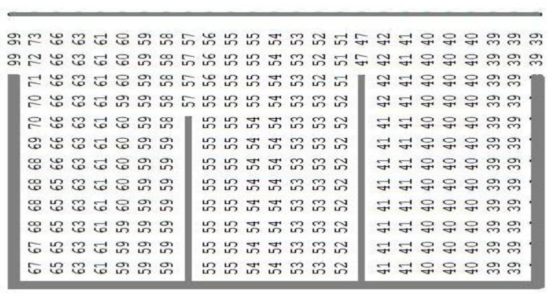

Fig. 5. Concentration field
in the horizontal settler with two vertical plates

In Fig. 5 the concentration field in the settler is shown. The concentration is presented using «Integer» form of number. Every number shows the percentage of the concentration in the computa-

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tional cell. The maximum concentration is at the inlet cell (it's equal to «99») and the smallest concentration is in the outlet cell. This concentration shows the efficiency of the settler.

The computational time was 5 min to solve the fluid dynamics problem and mass transfer using the developed numerical model.

Originality and practical value

Results of physical experiments are presented in the paper. These results show the peculiarities of sludge sedimentation in horizontal settler with additional plates.

A new approach to investigate the mass transfer process in horizontal settler was proposed. This approach is based on the developed CFD model. The fluid dynamics model was used for the numerical investigation of flows in the settler. These models use the rectangular grid and porosity technique to create the form of the settler in the numerical model. The developed models have more capacity than the existing models in Ukraine. The developed models allow to compute quickly the efficiency of water purification in settlers. The models are not computationally expensive.

Conclusions

The experiments which were carried out in hydraulic laboratory confirm the idea that the additional plates in the horizontal settler can increase the efficiency of water purification.

The CFD model was developed to compute the flow field in horizontal settler. This model is based on the equations of viscous flow. The process of mass transfer in the horizontal settlers is simulated using convection-diffusing equation. Numerical study based on the developed models was carried out. Results illustrate that the developed models can be used to simulate the process of water purification for settlers having comprehensive geometrical form.

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ДОСЛІДЖЕННЯ ОСАДЖЕННЯ ДОМІШОК У ГОРИЗОНТАЛЬНОМУ ВІДСТІЙНИКУ

Мета. Осадження домішок є найбільш простим та широковживаним методом механічної очистки природних або стічних вод. Цей процес реалізується, зокрема, в горизонтальних відстійниках, які є одним із найважливіших елементів у технологічній схемі очищення води. Їх застосування пов’язано з можливістю пропуску досить великих обсягів води. В цих спорудах вода, що очищується, рухається з невеликою швидкістю, що дозволяє домішці осісти. Пошук нових методів для розрахунку горизонтальних відстійників та підвищення їх ефективності є метою багатьох теоретичних, експериментальних та чисельних досліджень. Проте моделі та методики, які в даний час використовуються для розв’язання поставленої задачі, не дозволяють врахувати форму відстійника і різні конструктивні особливості. Метою роботи є побудова чисельної моделі для оцінки ефективності горизонтального відстійника з вертикальними пластинами і проведення експерименту для візуалізації процесу осадження домішки в горизонтальному відстійнику з набором пластин. **Методика.** Основою моделі є: 1) вихровий рух реальної рідини (рівняння Нав’є-Стокса); 2) рівняння масопереносу. Для чисельного розв’язку рівнянь використовуються різницеві схеми. Чисельний розрахунок здійснюється на прямокутній різницевій сітці. Для формування виду розрахункової області та виділення її особливостей застосовується метод маркування. **Результати.** Розроблена чисельна модель дозволяє розрахувати процес освітлення води в горизонтальних відстійниках різної форми і з різними конфігураціями пластин. **Наукова новизна.** Автором представлено новий підхід у дослідженні та розрахунку роботи горизонтальних відстійників різної конфігурації. Даний підхід ґрунтується на чисельному інтегруванні рівнянь руху рідини і масопереносу домішки. **Практична значимість.** Розроблена чисельна модель розрахунку роботи горизонтальних відстійників пред’являє невеликі вимоги до потужності комп’ютерної техніки. Час розрахунку одного варіанта завдання становить кілька хвилин.

Ключові слова: чисельна модель; горизонтальний відстійник; очистка води; фізичний експеримент

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ИССЛЕДОВАНИЕ ОСАЖДЕНИЯ ПРИМЕСЕЙ В ГОРИЗОНТАЛЬНОМ ОТСТОЙНИКЕ

Цель. Осаждение примесей является наиболее простым и широкоиспользуемым методом механической очистки природных или сточных вод. Этот процесс реализуется, в частности, в горизонтальных отстойниках, которые являются одним из важнейших элементов в технологической схеме очистки воды. Их использование связано с пропуском достаточно большого количества воды. В этих сооружениях очищаемая вода движется с небольшой скоростью, что позволяет примесям осесть. Поиск новых методов для расчета горизонтальных отстойников и повышения эффективности их работы является целью многих теоретических, экспериментальных и численных исследований. Но модели и методики, которые сейчас используются для решения поставленной задачи, не позволяют учесть форму отстойника и различные конструктивные особенности. Целью работы является построение численной модели для оценки эффективности горизонтального отстойника с вертикальными пластинами и проведение эксперимента для визуализации процесса осаждения примесей в горизонтальном отстойнике с набором пластин. **Методика.** В основу модели положено:

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1) вихревое движение реальной жидкости (уравнения Навье-Стокса); 2) уравнение массопереноса. Для численного моделирования моделирующих уравнений используются разностные схемы. Численный расчет осуществляется на прямоугольной разностной сетке. Для формирования вида расчетной области и выделения ее особенностей применяется метод маркирования. **Результаты.** Разработанная численная модель позволяет рассчитать процесс осветления воды в горизонтальных отстойниках различной формы и с различными конфигурациями пластин. **Научная новизна.** Автором представлен новый подход в исследовании и расчете работы горизонтальных отстойников различной конфигурации. Данный подход основывается на численном интегрировании уравнений движения жидкости и массопереноса примеси. **Практическая ценность.** Разработанная численная модель расчета работы горизонтальных отстойников предъявляет небольшие требования к мощности компьютерной техники. Время расчета одного варианта задачи составляет несколько минут.

Ключевые слова: численная модель; горизонтальный отстойник; очистка воды; физический эксперимент

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