Calculation of mass transfer process in vertical sedimentation tank and construction of CFD model

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Abstract. The development of a numerical model of mass transfer in a vertical pion is considered. The reconstruction was carried out in a room with a three-dimensional exchange of contaminants and a potential flow. Clear contrast plans were used for numerical integration. The results of the numerical study are presented in this paper. A quirk of the constructed numerical demonstration is the plausibility of agent-based calculation of structures in three-dimensional space. An auxiliary development of this work should be carried out by creating a mass transfer control model in settling tanks based on the model of a culminating liquid jet in a tornado vortex.

1 Introduction

The world is effectively creating hypothetical strategies for calculating vertical settling tanks. This can be due to the truth that exploratory inquiry in this region requires a parcel of time to set up the exploration, its execution, and the preparation of test information. Other than, when carrying out exploratory considers the utilize costly gear and estimation of parameters of intrigued takes put without "presentation" of the gadget into the stream [1] (for illustration, ADV - Acoustic Doppler Speed estimations, etc.), which not all research facilities can manage. In this association, the physical test cannot serve as a regular instrument for tackling those issues which emerge at the arrangement of planning of developments or their reproduction. One-dimensional kinematic models of poison exchange in structures [5, 6, 7], relapse models [4,], and adjustment models [2, 3] are connected to calculate these structures. These models are practical and straightforward for practical application. For practical application, these models are mild and uncomplicated. However, a real drawback of these collections of models is that they don't account for the geometrical structure of a sedimentation tank or any of its other design elements, like the interior sections of a structure. Calculating settling tanks with complex geometric shapes requires the application of one-dimensional kinematic models, which is impossible. By using 2D or 3D models, the geometrical shape of a settling tank can be considered. The application of multidimensional models necessitates a hydrodynamic solution to the problem of determining the stream speed field inside the settling tank. Overseas, to illuminate the hydrodynamic issue, as a run the show, a gooey liquid model (Navier-Stokes conditions) is utilized. Realizing this CFD demonstration requires the application of a really fine network, which is the reason for the impressive time used for getting the result. Other than that, a strict legitimization of connected turbulence show for calculating this course of streams is essential. It should be noted that the cost of calculating a settling tank based on a specialized code that produces the CFD show is over $20,000 [8]. There aren't really any multidimensional CFD models for calculating vertical settling tanks in Uzbekistan. Developing convincing methods for quickly and inexpensively calculating structures with complex geometrical shapes, such as vertical settling tanks, based on CFD models is a critical issue for this association. This work aims to develop a 3D-CFD demonstration of mass exchange in a vertical settling tank that enables the modeling to consider the settling tank's geometric shape. A 2D-CFD simulation for calculating a vertical settling tank is shown in the works [9, 10, 11].

OBJECTS AND METHODS OF RESEARCH

The three-dimensional admixture transport equation [11] calculates the pollutant transport process in a vertical settling tank.

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\frac{\partial (w-w_s)C}{\partial z}+\sigma C=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu_z\frac{\partial C}{\partial z}\right) \qquad (1)$$

Boundary conditions for the exchange equation

The dividers of the settling tank and different impermeable objects interior it (pipe, perplexes, etc.), define the current's boundaries. The boundary condition of the form is built into the numerical demonstration of these boundaries.

$$\frac{\partial C}{\partial n}=0,$$

where n represents the unit vector of the surface's typical exterior. On the strong level surfaces of the settling tank, the numerical demonstration actualizes the boundary condition of "retention" of the poison. At the channel boundary (the boundary of the wastewater stream channel into the settling tank), the condition is set:

$$C_{bolder}=C_E,$$

where C_E is could be known esteem of toxin concentration. At the output boundary of the computational space, within the numerical demonstration, a "cyclic" (delicate) boundary condition of the form

$$C(i+1,j,k)=C(i,j,k),$$

where i,j,k are the number of distinction cells at the toxin dissemination within the settling tank, which are unraveled to set up the arrangement.

Demonstrate of hydrodynamics The arrangement of the contaminant transport condition interior of the sedimentation tank (1) is conceivable if the stream speed field within the vertical sedimentation tank is known. Hence, to calculate the transport of toxins within the settling tank, it is fundamental to unravel the hydrodynamic issue and decide on this speed field. To unravel this hydrodynamic issue, a 3D potential stream demonstration is utilized. In this case, the modeling condition has the frame [12]

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}+\frac{\partial^2 P}{\partial z^2}=0, \qquad (2)$$

where P is the speed potential.

The wastewater stream speed vector components are calculated based on the conditions after the speed potential field has been computed [5].

$$u=\frac{\partial P}{\partial x}, \qquad v=\frac{\partial P}{\partial y}, \qquad w=\frac{\partial P}{\partial z}.$$

Numerical strategy for understanding the poison transport equation

A substituting triangular part distinction plot is utilized for numerical integration of the toxin transport condition within the settling tank [13, 14, 15]. A rectangular distinction lattice is used to implement numerical calculations. Within the contrast cell centers, the pollutant concentration value is computed. Let's think about how this contrast conspires for the exchange equation developed.

We should replace the time subordinate with the "in reverse" difference:

$$\frac{\partial C}{\partial t}\approx\frac{C_{i,j,k}^{n+1}-C_{i,j,k}^{n}}{\Delta t}.$$

Let us represent the convective derivatives in the form:

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

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

$$\frac{\partial wC}{\partial z}=\frac{\partial w^+C}{\partial z}+\frac{\partial w^-C}{\partial z},$$

Where $u^+=\frac{u+|u|}{2}$; $u^-=\frac{u-|u|}{2}$; $v^+=\frac{v+|v|}{2}$; $v^-=\frac{v-|v|}{2}$; $w^+=\frac{w+|w|}{2}$; $w^-=\frac{w-|w|}{2}$.

Let us approximate the convective derivatives by dividing differences "against the flow":

$$\frac{\partial u^+C}{\partial x}\approx\frac{u_{i+1,j,k}^{+}C_{i,j,k}^{n+1}-u_{i,j,k}^{+}C_{i-1,j,k}^{n+1}}{\Delta x}=L_x^+C^{n+1},$$

$$\frac{\partial u^-C}{\partial x}\approx\frac{u_{i+1,j,k}^{-}C_{i+1,j,k}^{n+1}-u_{i,j,k}^{-}C_{i,j,k}^{n+1}}{\Delta x}=L_x^-C^{n+1},$$

$$\frac{\partial v^+C}{\partial y}\approx\frac{v_{i,j+1,k}^{+}C_{i,j,k}^{n+1}-v_{i,j,k}^{+}C_{i,j-1,k}^{n+1}}{\Delta y}=L_y^+C^{n+1},$$

$$\frac{\partial v^-C}{\partial y}\approx\frac{v_{i,j+1,k}^{-}C_{i,j+1,k}^{n+1}-v_{i,j,k}^{-}C_{i,j,k}^{n+1}}{\Delta y}=L_y^-C^{n+1},$$

$$\frac{\partial w^+C}{\partial z} \approx \frac{w^+_{i,j,k+1}C^{n+1}_{i,j,k} - w^+_{i,j,k}C^{n+1}_{i,j,k-1}}{\Delta z} = L^+_z C^{n+1},$$

$$\frac{\partial w^-C}{\partial z} \approx \frac{w^-_{i,j,k+1}C^{n+1}_{i,j,k+1} - w^-_{i,j,k}C^{n+1}_{i,j,k}}{\Delta z} = L^-_z C^{n+1}.$$

The second derivatives are approximated as follows:

$$\frac{\partial}{\partial x}\left(\mu_x \frac{\partial C}{\partial x}\right) \approx \tilde{\mu}_x \frac{C^{n+1}_{i+1,j,k} - C^{n+1}_{i,j,k}}{\Delta x^2} - \tilde{\mu}_x \frac{C^{n+1}_{i,j,k} - C^{n+1}_{i,j-1,k}}{\Delta x^2} = M^-_{xx}C^{n+1} + M^+_{xx}C^{n+1},$$

$$\frac{\partial}{\partial y}\left(\mu_y \frac{\partial C}{\partial y}\right) \approx \tilde{\mu}_y \frac{C^{n+1}_{i,j+1,k} - C^{n+1}_{i,j,k}}{\Delta y^2} - \tilde{\mu}_y \frac{C^{n+1}_{i,j,k} - C^{n+1}_{i,j-1,k}}{\Delta y^2} = M^-_{yy}C^{n+1} + M^+_{yy}C^{n+1}.$$

In the used expressions $L^+_x, L^-_x, M^+_{xx}, M^-_{xx}$ etc. are notations of different operators. Taking these notations into account, the difference analog of the admixture transfer equation will have the form:

$$\frac{C^{n+1}_{i,j,k} - C^{n}_{i,j,k}}{\Delta t} + L^+_x C^{n+1} + L^-_x C^{n+1} + L^+_y C^{n+1} + L^-_y C^{n+1} + L^+_z C^{n+1} + L^-_z C^{n+1} + \sigma C^{n+1}_{i,j,k}$$
$$= \left(M^+_{xx}C^{n+1} + M^-_{xx}C^{n+1} + M^+_{yy}C^{n+1} + M^-_{yy}C^{n+1} + M^+_{zz}C^{n+1} + M^-_{zz}C^{n+1}\right).$$

Let us decompose the solution of this difference equation when integrating over the time interval ∂t as follows:

first step $k = \frac{1}{4}$:

$$\frac{C^{n+1}_{i,j,} - C^{n}_{i,j,}}{\Delta t} + \frac{1}{2}\left(L^+_x C^k + L^+_y C^k + L^+_z C^k\right) + \frac{\sigma}{4} C^k_{i,j,k} =$$
$$= \frac{1}{4}\left(M^+_{xx}C^k + M^-_{xx}C^n + M^+_{yy}C^k + M^-_{yy}C^n + M^+_{zz}C^k + M^-_{zz}C^n\right). \quad (3)$$

in the second step $k = n + \frac{1}{2}$; $c = n + \frac{1}{4}$:

$$\frac{C^{k}_{i,j,k} - C^{c}_{i,j,k}}{\Delta t} + \frac{1}{2}\left(L^-_x C^k + L^-_y C^k + L^-_z C^k\right) + \frac{\sigma}{4} C^k_{i,j,} =$$
$$= \frac{1}{4}\left(M^-_{xx}C^k + M^+_{xx}C^c + M^-_{yy}C^k + M^+_{yy}C^c + M^-_{zz}C^k + M^+_{zz}C^c\right). \quad (4)$$

in the third step, $k = n + \frac{3}{4}$; $c = n + \frac{1}{2}$ use the formula (4);
in the fourth step, $k = n + 1$; $c = n + \frac{3}{4}$ use the formula (3).
In the notation adopted $w = w - w_s$.
The obscure esteem of toxin concentration at each part step is decided by an unequivocal "running check" equation.

Numerical integration of the condition for the speed potential

The Liebman strategy is utilized for the numerical integration of condition (2) [15]. In this case, the approximating condition has the form:

$$\frac{P_{i+1,j,k} - 2P_{i,j,k} + P_{i-1,j,k}}{\Delta x^2} + \frac{P_{i,j+1,k} - 2P_{i,j,k} + P_{i,j-1,k}}{\Delta y^2} + \frac{P_{i,j,k+1} - 2P_{i,j,k} + P_{i,j,k-1}}{\Delta z^2} = 0.$$

On the premise of this reliance, we get an equation for deciding the esteem of the speed potential within the center of the contrast cell

$$P_{i,j,k} = \frac{\left[\frac{P_{i+1,j,k} - P_{i-1,j,k}}{\Delta x^2} + \frac{P_{i,j+1,k} - P_{i,j-1,k}}{\Delta y^2} + \frac{P_{i,j,k+1} - P_{i,j,k-1}}{\Delta z^2}\right]}{A},$$

Where $A = \left(\frac{2}{\Delta x^2} + \frac{2}{\Delta y^2} + \frac{2}{\Delta z^2}\right)$.

Utilized is the speed potential's calculated field to decide the components of the following equations to the faces of the control volumes (distinction cells) for the speed vector.

$$u_{i,j,k} = \frac{P_{i,j,k} - P_{i-1,j,k}}{\Delta x},$$

$$v_{i,j,k} = \frac{P_{i,j,k} - P_{i,j-1,k}}{\Delta y},$$

$$w_{i,j,k} = \frac{P_{i,j,k} - P_{i,j,k-1}}{\Delta z}.$$

It is possible to develop a traditionalist distinction conspire for the toxin transport condition inside the settling tank by calculating the stream speed vector components on the faces of the distinction cells. Numerical calculation of the speed field and the poison transport prepared in vertical settling tanks is carried out within the range of complex geometric shapes. Arrangement of the geometric shape of the settling tank on a rectangular contrast network is carried out by implies of the checking strategy [16, 17, 18]. This approach permits the client to rapidly frame any geometric shape of the settling tank without any limitations forced on it.

RESULTS AND THEIR DISCUSSION

The specialized code "Settler-3D" was created based on the built CFD model. FORTRAN was utilized for programming. The developed numerical demonstration was utilized to reenact the method of mass exchange in a vertical settling tank with a segment (Fig. 1) [2]. The reason for the computational exploration was to assess the effectiveness of water filtration within the sedimentation tank of the considered sort at the distinctive settling speed of the poison ws and at the diverse situation of the astound interior of the settling tank[19, 20]. The computational exploration was conducted with the taking after parameters: length of the settling tank - 6 m; width, 5 m; profundity, 3.34 m; stream speed at the channel to the settling tank, 12 m/h; dissemination coefficient in all arrange headings, 0.7 m^2/h; w_s=1.6 m/h and w_s=0.5 m/h; k =0. The concentration of poison within the approaching stream into the settling tank is 100 units (dimensionless). The length of the baffle is 1.66 m.

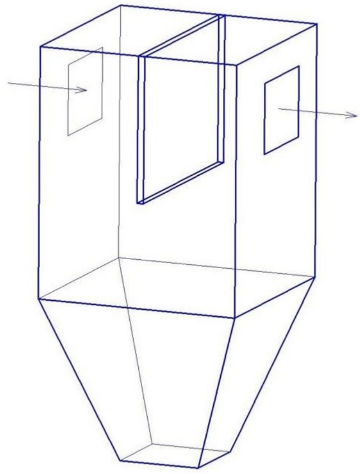

Fig. 1. Schematic of upright sedimentation tank with area

Let's consider the comes about of the computational test. Fig. 2 appears the dissemination of the toxin concentration esteem within the settling tank (side see) within the segment y = 2.25 m, w_s= 1.2 m/h. In this issue variation, the parcel divider is set within the center of the settling tank. This figure is visible where the water enters and leaves the settling tank. Comparatively speaking, Fig. 3, within the same sedimentation tank segment, it appears that it is delivering a toxin concentration., but at poison settling speed w_s=0.5 m/h. It can be seen that at the esteem of w_s=1.2 m/h, the distribution of toxin concentration over the stature of the most toxin mass is "focused" within the slipping portion of the tank. Within the climbing stream, the concentration of the poison is much lower (the contamination zone in this portion of the tank is as on the off chance that "thin").

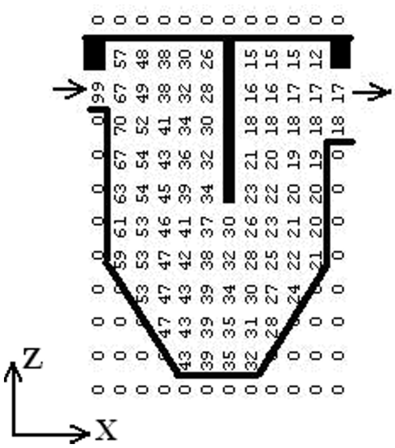

Fig. 2. Distribution of concentration of contaminant in upright septic tank with partition (side view, cross-section y = 2.25 m, w_s = 1.2 m/h, C_{max} =100)

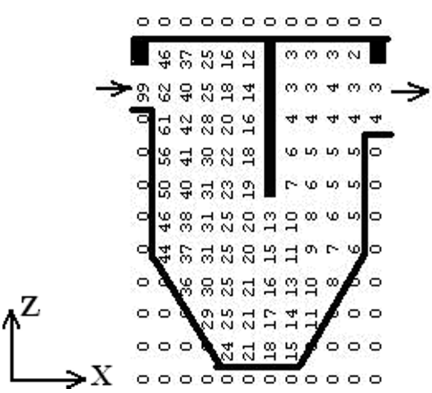

Fig. 3. Distribution of concentration of contaminant in upright septic tank with partition (side view, cross-section y = 2.25 m, w_s = 0.5 m/h, C_{max} =100)

At esteem w_s = 0.5 m/h, the conveyance of toxin concentration in this segment is distinctive and more uniform, which clearly shows that the water filtration preparation is less viable. The taking after figures (Fig. 4, 5) appear the conveyance of poison concentration in totally different segments of the settling tank at the esteem of parameter w_s= 1.2 m/h. These details enable us to evaluate the effectiveness of the settling tank's various filtration systems. Fig. When the perplex is moved closer to the structure's outlet, as shown in Figure 6, the conveyance of toxin concentration within the settling tank appears to vary. It should be emphasized that within the over figures, the concentration esteem is displayed in a dimensionless shape. Each number is the concentration esteem as a rate of the greatest concentration esteem in this segment. Subsequently, data around the esteem of this greatest concentration for this segment is given beneath each figure. Such representation of the comes about of computational exploration makes it conceivable to rapidly analyze the data on evaluating the esteem of concentration in any portion of the settling tank. It ought to be famous that the comes about of calculations are printed out concurring to the organization of "entire" numbers, i.e., the fragmentary part of a number isn't printed out. This means that in case, for case, The number "1" will be printed if the calculated concentration value is ever "1.85 percent" of the concentration at the settling tank inlet. The number "1" will be printed out if the calculated concentration value is ever "1.85 percent" of the concentration at the settling tank inlet. It is productive for clump calculations when "attempting" diverse variations in arrange to select the foremost ideal structure plan. For the nitty gritty examination of calculation information, the created code yields the concentration esteem agreeing to the arrange of "genuine" numbers, i.e., with sparing the esteem of fragmentary portion of the number.

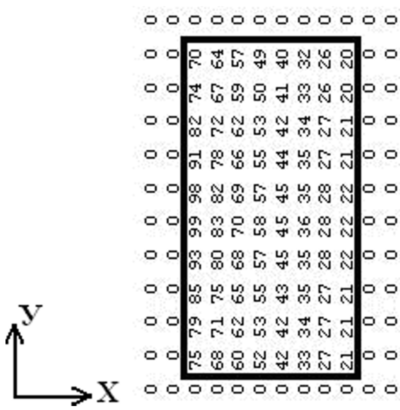

Fig. 4. Distribution of concentration of contaminant in upright septic tank with partition (side view, cross-section) $z = 0.82$ m, $w_s = 1.2$ m/h, $C_{max} = 0.3$)

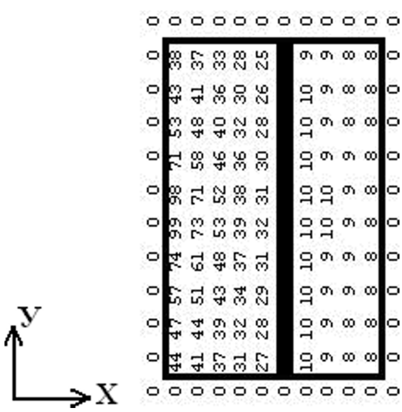

Fig. 5. Distribution of concentration of contaminant in upright septic tank with partition (side view, cross-section) $z = 2.14$ m, $w_s = 1.2$ m/h, $C_{max} = 0.52$)

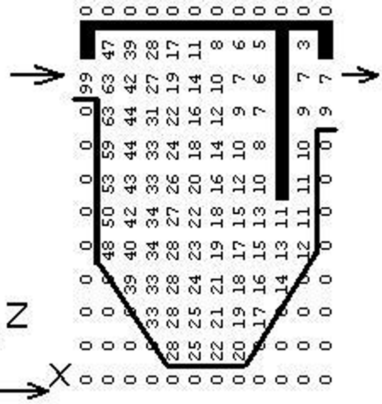

Fig. 6. Distribution of concentration of contaminant in upright septic tank with partition (side view, cross-section) z = 2.25 m, w_s = 1.2 m/h, C_{max} =100)

On the premise of the computational test, we decided the effectiveness of the sedimentation tank. In this way, the esteem of toxin concentration at the outlet of the settling tank (i.e., cleaning effectiveness), at the esteem of the parameter w_s = 1.2 m/h, is: C_b =2 % of the esteem of the toxin concentration at the gulf to the sedimentation tank, and at the esteem of w_s = 0.5 m/h, the poison concentration at the sedimentation tank outlet is C_b=13 - 15 %. Hence, a decrease in the toxin settling rate by almost 2.4 times, driven to the amount of water decontamination inside the settling tank, disintegrated noticeably (roughly 7 times). The concentration of the poison is C_b=3% for the settling tank with a shock moved to the outlet (w_s= 1.2 m/h). In conclusion, we point out that it took the computer about 2 minutes to calculate one problem adaptation. An essential prerequisite for serial calculations in practice is a minute amount of time for computational testing.

CONCLUSIONS

An effective 3D numerical is presented in the paper show to think about the method of mass exchange in vertical settling tanks of complex geometric shapes. The made specialized code can be utilized as an apparatus for fathoming a set of applied issues emerging within the plan and reproduction of vertical settling tanks. A quirk of the built numerical demonstration is the plausibility of agent calculation of structures in three-dimensional space. Assist development of this work ought to be carried out within the course of creating a demonstration of the mass exchange handle in settling tanks on the premise of a demonstration of culminating liquid stream in a tornado vortex.

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