

CFD-mass transfer model process in a vertical sedimentation tank

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Abstract. Currently, the world is actively developing a logical course to create hypothetical strategies for the calculation of tanks for sewage sump. At the same time, engineers usually use balance models and one-dimensional kinematic models. These models do not take into account the hydrodynamics of the flow inside the sump and its complex geometric shape. This can be a serious deterrent to the widespread use of Navier-Stokes conditions when refining a regular plan. The use of CFD models based on the formulation of Navier-Stokes conditions requires the use of a really thin network, which leads to critical computer time spent on obtaining predictive information. To this conclusion, it is fundamental to form an successful CFD show to think about the method of wastewater treatment in vertical settling tanks, taking into consideration their geometric shape and plan highlights. The plans of individual parts, carried out by the strategy of the current count, are used. A 2-D-CFD demo was created that allows a vertical settler to be calculated in a few seconds, taking into account its geometric shape, the proximity of the central pipe, its parameters, and the proximity of a divider that has recently exited the pipe. The application of the strategy for checking the calculated space in the constructed show makes it possible to carry out coordinate numerical simulation of the flow hydrodynamics and mass transfer in settling tanks without limiting their shape. Creation of CFD models that allow, on the one hand, to require into consideration the geometric shape of the sump, the most physical forms of mass exchange within the structure, and on the other hand - requiring small time to get comes about. The created CFD demonstrate and the code based on it permit, with a little consumption of computer time - approximately the same as when calculating a one-dimensional demonstrate, to illuminate complex multiparametric issues that emerge at the plan arrange of vertical settling tanks, considering their shape and design features.

1 Introduction

Settling tanks of wastewater transfer frameworks are one of the foremost vital components within the framework of wastewater treatment offices. These offices decide, to an expansive degree, the productivity of the working of the complex of treatment offices as a entirety. In expansion, it must be borne in intellect that after auxiliary settling tanks,

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wastewater containing a certain extent of suspended solids is released into the store. Subsequently, guaranteeing effective water decontamination at auxiliary settling tanks is the foremost critical implies of securing surface waters from contamination by suspended solids.

Vertical settling tanks are presently broadly utilized within the advancement of water decontamination frameworks for little ventures. Assessing the effectiveness of these settling tanks at the plan organize of a complex of treatment offices could be a complex and dependable errand. The operational arrangement of this issue, when different variations of settling tanks are considered, their plan, measurements, etc. change, is conceivable by calculation – based on the strategy of numerical modeling [1-3]. To date, most of the connected strategies for calculating vertical sedimentation tanks are based on the utilize of one-dimensional kinematic models of toxin transport in sedimentation tanks or on the use of zero-dimensional (adjust) models. These models don't permit taking into consideration the pressure driven mode of operation of the sump and its geometric shape. Subsequently, an pressing assignment is to form numerical models of the operation of vertical settling tanks, which would permit the creator to expeditiously get the vital educate, taking into consideration the shape of the treatment offices, the characteristics of mass exchange, and their working mode.

2 Objects and methods of research

In particular, when designing sumps, engineers mainly use correction models [4, 11-13] and one-dimensional volumetric models [8, 10, 14-16, 18-20]. Adjustment models allow you to quickly calculate the productivity of water disinfection in the office, but have a number of limitations:– the geometric shape of the sump isn't taken under consideration within the models;

- the scheme for supplying wastewater to the sump and the discharge of wastewater from it are not taken into account in the models;

- the flow velocity inside the sump and its internal part of the structure is not taken into account;

- Models do not take into account the propagation handle. Numerical models of sedimentation tanks based on solving the one-dimensional poison exchange condition allow expanding the possibilities of designers by taking into account those variables that are not taken into account in zero-dimensional models. Dynamic improvement of one-dimensional models is associated with a combination of a number of circumstances:

- these models take into account such vital components as convection, diffusion;

- building these models is much easier than building 2D or 3D CFD models;

- development of a code (program) for the numerical integration of a one-dimensional kinematic exchange condition, which is simpler than for performing a 2- or 3-dimensional numerical model;

The use of CFD models based on the arrangement of conditions for liquid elements makes it possible to subjectively simulate the preparation of indications in a sump at the modern level [17, 21, 22]. But it should be noted that when using the thick fluid model (the Navier-Stokes condition), a very thin lattice is required, which leads to significant computer time spent on obtaining estimated information. This can be a significant deterrent to the widespread use of Navier-Stokes conditions when refining plans. The extension requires a reasonable choice of turbulence show for the flow lesson below thought. It is important to note here that the use of numerical 3-D-CFD models based on the display of thick liquid is also extremely expensive in practical use.

The reason of this work is to create a 2–D numerical show of mass exchange in a vertical sump, which permits taking under consideration the geometric shape of the sump

amid modeling and calculating the speed field and the mass exchange handle within the sump.

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial (v-w)C}{\partial y} + kC = \text{div}(\mu \text{grad}C) \quad (1)$$

where C is the concentration of the pollutant in the wastewater;

u, v are the components of the flow velocity vector;

$\mu = (\mu_x, \mu_y)$ – diffusion coefficients;

w is the settling rate of the pollutant;

t – time;

k can be a factor that takes into consideration the shapes of biochemical acidification in the sedimentation tank. The taking after boundary conditions are set for the exchange condition (1). On strong boundaries (the form of the sump, the central pipe, different impediments interior it) realizing a strong surface. At the entryway border (the savage stream's entrance border in the sims), a requirement is set:

$$C_{border} = C_E,$$

where C_E is the known esteem of the concentration of the contamination. At the yield boundary of the computational space, a "cyclical" (delicate) boundary condition of the frame is set within the numerical model:

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

where $i+1, j$ is the number of the difference cell at the exit from the calculated area (settling tank).

At the beginning of time, $C = 0$ is assumed in the computational domain. The assignment of transporting the poison within the sump is fathomed by setting up a arrangement. At the lower boundary of the structure, the condition of "precipitation" of the poison from the wastewater stream at a speed w is realized. That's, the contaminant, having come to the lower surface of the sump, "clears out" the arrangement.

To unravel the mass exchange condition within the sump, it is vital to calculate the stream speed field interior the structure. It is vital that the components u, v of the wastewater stream speed vector included in condition (1) must fulfill the progression condition. To illuminate this hydrodynamic issue, a 2-D demonstrate of potential stream is utilized in this work. In this case, the modeling condition has the shape [6]:

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} = 0 \quad (9)$$

where P is the speed potential.

For this condition, the taking after boundary conditions are set [6]:

– on the strong dividers of the sedimentation tank, the pipe interior it: $\frac{\partial P}{\partial n} = 0$, where n is the unit vector of the outside ordinary to the strong boundary;

– at the entrance boundary (the range of wastewater stream into the sedimentation tank):

$\frac{\partial P}{\partial n} = V_n$, where V_n is the known esteem of the stream rate;

– at the yield boundary of the calculated region (the region of the clarified water outlet from the sump) $P = P_0 = \text{const}$.

After calculating the speed potential field, the component vector of the wastewater stream speed is calculated based on known conditions [9].

$$u = \frac{\partial P}{\partial x}, \quad v = \frac{\partial P}{\partial y}.$$

The calculated value of the components of the wastewater flow velocity vector is used in another modeling method to illuminate the issue of mass transfer of the toxin in the sump.

Numerical integration of the display conditions is carried out using the strategy of limited contrast on a rectangular difference lattice. The velocity potential and toxin concentration are determined at the center of the difference cells, and the components of the flow velocity vector are determined at the sides of the contrast cells. For the numerical integration of condition (2), the strategy of determining the location in time is used. Then the development frame state is numerically integrated:

$$\frac{\partial P}{\partial t} = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} \quad (3)$$

where t is a fictitious time.

For numerical integration of condition (3), a verifiable add up to guess conspire is utilized [9]. In this case, the difference equations at each fractional step have the form:

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

$$\frac{P_{i,j}^{n+1} - P_{i,j}^{n+\frac{1}{2}}}{\Delta t} = \left[\frac{P_{i+1,j}^{n+1} - P_{i,j}^{n+1}}{\Delta x^2} \right] + \left[\frac{P_{i,j+1}^{n+1} - P_{i,j}^{n+1}}{\Delta x^2} \right].$$

Note that the value of the velocity potential $P_{(i,j)}$ at the center of each difference cell at each step of partitioning this difference scheme is determined by an explicit formula, the running count method [9].

To use the boundary condition $\partial P / \partial n = 0$ (n can be a unit vector of the outer ordinal to the wall) on strong separators, the invented difference cells are used in the numerical representation. To start the calculation according to the Liebman strategy, it is necessary to set the "initial" value of the velocity potential in the calculation space, for example: $P_{(i,j)} = 0$. When performing sequential calculations, the velocity potential field, determined numerically for one task, can be used as an "input" in the calculation of the next one in order to reduce the computer time in the calculation. The calculation ends when the condition is met:

$$|P_{i,j}^{n+1} - P_{i,j}^n| \leq \varepsilon, \quad (4)$$

where ε is a small number (for example, $\varepsilon = 0.001$); n is the iteration number.

After deciding the speed potential field, the speed vector component is calculated utilizing the equations:

$$u_{ij} = \frac{P_{i,j} - P_{i-1,j}}{\Delta x}, \quad v_{ij} = \frac{P_{i,j} - P_{i-1,j}}{\Delta y}, \quad (5)$$

When understanding the developmental condition (3), the speed potential field is given for the "starting" minute of imaginary time. Method is also used for numerical integration of the Laplace equation [9]. In this case, the approximating equation has the form:

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

Then the unknown value of the potential in the center of the difference cell is defined as:

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

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

Within the created code, the calculation by the Liebman strategy is actualized in a isolated subroutine. For numerical integration of the pollutant transport condition within the sump, an on the other hand triangular understood contrast plot is utilized [5]. This distinction conspire is based on part the initial differential condition. The distinction relations of this conspire, for each step of part, are composed in administrator shape as takes after [5]:

in the first step of splitting: $k = n + \frac{1}{4}$;

$$\frac{C_{i,j}^k - C_{i,j}^n}{\Delta t} + \frac{1}{2}(L_x^+ C^k + L_y^+ C^k) = \frac{1}{4}(M_{xx}^+ C^k + M_{xx}^- C^k + M_{yy}^+ C^n + M_{yy}^- C^n);$$

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

$$\frac{C_{i,j}^k - C_{i,j}^c}{\Delta t} + \frac{1}{2}(L_x^- C^k + L_y^- C^k) = \frac{1}{4}(M_{xx}^- C^k + M_{xx}^+ C^k + M_{yy}^- C^k + M_{yy}^+ C^c);$$

in the fourth step of splitting: $k = n + 1$; $k = n + \frac{3}{4}$;

$$\frac{C_{i,j}^k - C_{i,j}^c}{\Delta t} + \frac{1}{2}(L_x^- C^k + L_y^+ C^k) = \frac{1}{4}(M_{xx}^- C^k + M_{xx}^+ C^c + M_{yy}^- C^c + M_{yy}^+ C^k);$$

The following notation of difference operators is used in these expressions:

$$\begin{aligned} \frac{\partial u^+ C}{\partial x} &\approx \frac{u_{i+1,j}^+ C_{i,j}^{n+1} - u_{i+1,j}^+ C_{i-1,j}^{n+1}}{\Delta x} = L_x^+ C^{n+1}, \\ \frac{\partial u^- C}{\partial x} &\approx \frac{u_{i+1,j}^- C_{i+1,j}^{n+1} - u_{i+1,j}^- C_{i,j}^{n+1}}{\Delta x} = L_x^- C^{n+1}, \\ \frac{\partial v^+ C}{\partial y} &\approx \frac{v_{i+1,j}^+ C_{i,j}^{n+1} - v_{i,j}^- C_{i,j}^{n+1}}{\Delta x} = L_y^+ C^{n+1}, \\ \frac{\partial v^- C}{\partial y} &\approx \frac{v_{i+1,j}^- C_{i,j}^{n+1} - v_{i,j}^- C_{i,j}^{n+1}}{\Delta x} = L_y^- C^{n+1}, \\ \frac{\partial}{\partial x} \left(\mu_x \frac{\partial C}{\partial x} \right) &\approx \tilde{\mu}_x \frac{C_{i+1,j}^{n+1} - C_{i,j}^{n+1}}{\Delta x^2} - \tilde{\mu}_x \frac{C_{i,j}^{n+1} - C_{i-1,j}^{n+1}}{\Delta x^2} = M_{xx}^- C^{n+1} + M_{xx}^+ C^{n+1} \end{aligned}$$

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

A point by point clarification of these contrast administrators is displayed in [5]. The obscure esteem of the poison concentration at each step of part is decided by an express "running check" equation. The considered distinction part plot is completely steady at each step of part and has the property of conservativeness – which is greatly vital when tackling mass exchange issues [7]. At these calculations step, the change in the concentration of the pollutant due to its gravitational subsidence is calculated according to the following formula:

$$\frac{C_{i,j}^{n+1} - C_{i,j}^n}{\Delta t} - \frac{w(C_{i,j}^{n+1} - C_{i,j}^n)}{\Delta y} = 0.$$

The calculated conditions at each part step are executed within the created code as a partitioned subroutine. The code was made on the premise of the built CFD show. FORTRAN was utilized for programming. Confirmation of the created CFD demonstrate was carried out on the illustration of fathoming a set of test issues with an correct (expository) arrangement, examined tentatively or unraveled by other analysts utilizing other numerical methods.

It ought to be famous that the calculation of mass exchange in vertical settling tanks is carried out within the region of a complex geometric shape, which greatly complicates the method of building a numerical demonstrate of the structure. In this paper, the arrangement of the geometric shape of the sump on a rectangular distinction network is carried out utilizing the checking strategy [5]. This makes it conceivable to quickly form any geometric shape of the sump within the source data file, without any limitations on its appearance, and, most vitally, not to form any changes to the calculation code.

Calculation for tackling the issue of poison transport in a vertical sump. The arrangement of the issue of transport of the toxin within the sump is carried out within the following sequence:

1. The client enters the introductory data within the introductory information record (DAT record) around the treatment office: the geometric shape of the sump, its measurements, the position of the openings for the section and exit of wastewater, the position of the central pipe or other components of the structure, the concentration of the poison within the wastewater stream entering the sump, etc. The arrangement of the sort of the calculation zone is carried out utilizing markers. The client can moreover alter the estimate of the contrast grid.

2. The numerical integration of the equation for the velocity potential is launched. The velocity potential field is printed after a certain number of completed integrations. The computer program monitors the procedure for calculating the velocity potential and stops this calculation if the condition of the form (4) is met. The velocity potential field is printed.

3. The calculation of the component vector of the wastewater flow rate in the sump is performed according to the dependencies of the form (5).

4. The schedules of numerical integration of the condition of transport of the toxin within the sump are being propelled. The field of the concentration of the toxin within the sump is printed after a indicated number of time steps.

5. The reenactment comes about are entered into a DAT-type calculation information record.

6. The examination of the concentration field of the poison within the sump and, to begin with of all, at the outlet from it is carried out, since it is this data that decides the proficiency of the treatment plant.

Hence, by going through (calculating) the different plan alternatives of the sump, the client can decide the foremost sound alternative for particular conditions. Considering that it takes a brief time (on the arrange of many seconds) to calculate the settling tank based on the CFD demonstrate built, it'll take a brief period of time satisfactory to the creator to select the ideal development alternative.

3 Results and their discussion

Practical realization of the model. The results of the practical use of the developed CFD demo are shown below. The modeling of the mass transfer handle in a vertical sump with a central pipe is considered. A divider is found close the outlet of the pipe (in Fig. 1 – this is a triangle). The outlet from the sump is conventionally indicated by the letters **R** (right) and **L** (left). The computational experiment was carried out with the following parameters: the flow rate at the inlet to the sump is 21.7 m/h and 11 m/h; the diffusion coefficient is 0.7 m²/h. The value of the deposition rate of the pollutant is: $w = 2.5$ m/h and $w = 1.6$ m/h; the coefficient of biochemical oxidation $k = 0$; the length of the sump is 8 m; the depth is 3.6 m. The concentration of the pollutant in the stream entering the sump is 100 units (in dimensionless form).

The purpose of the simulation is to evaluate the efficiency of wastewater treatment in a sump with given initial data. Let's consider the comes about of a computational test. Figure 1-3 appears the calculated values of the concentration of the toxin within the sump with diverse values of the rate of section of the wastewater stream into the sump and diverse rates of sedimentation of the poison. In these figures, the concentration esteem is appeared in dimensionless shape: each number is the concentration esteem as a rate of the input concentration esteem.

It ought to be famous here that the printing of the calculation comes about in these figures was carried out agreeing to the organize of printing "entire" numbers, i.e. the fragmentary portion of the number isn't printed. This implies that in case, for case, at a few point the calculated concentration esteem is "7.36%" of the concentration at the channel to the sump, at that point "7" will be printed. In addition, if the concentration estimate is less than 1%, "0" is printed at this point. The choice of this approach is explained by the fact that it allows you to quickly analyze the feasibility of water filtration in any zone of the sump. In the created code, when performing calculations, the concentration value is printed in parallel, which allows organizing "real" numbers in any zone of interest.

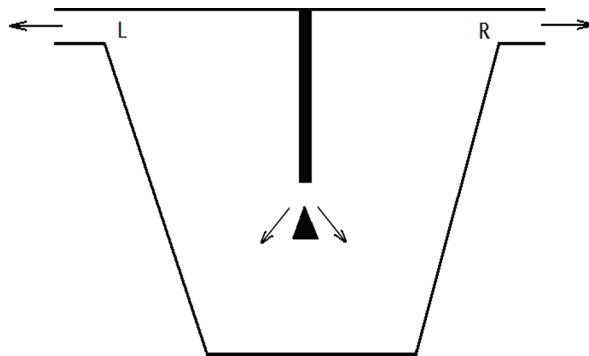


Fig. 1. Diagram of a vertical sedimentation tank with a middle tube.

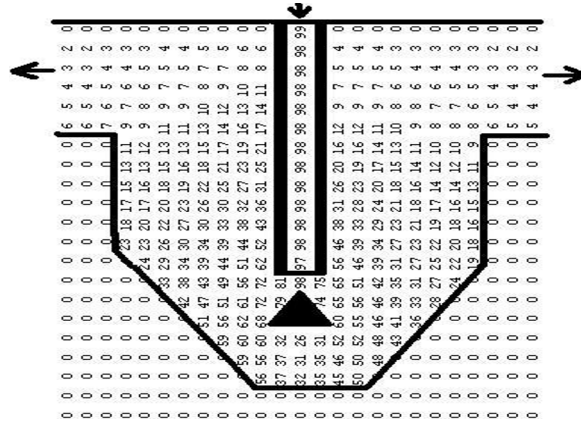


Fig. 2. Distribution of the concentrations of contaminants in a vertical jump using a center tube.

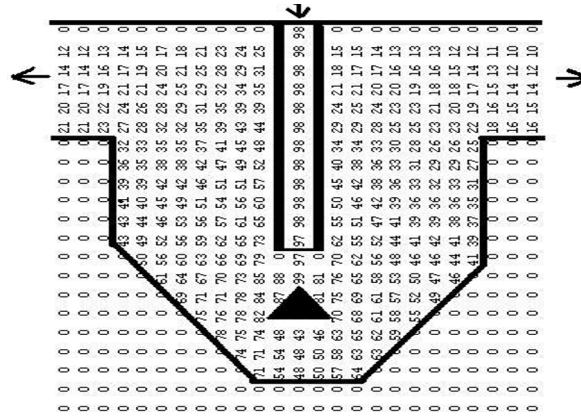


Fig. 3. Distribution of the concentration of the contaminant in a vertical jump with a vertical partitioning and a vertical lamina (the length of the vertical partition is 2.4 m, the length of the vertical plate is 0.8 m, $w = 0.02$ m/h)

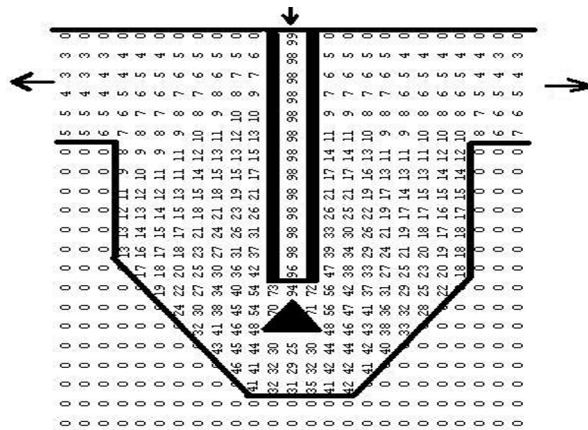


Fig. 4. Distribution of the contaminant concentration in a vertical jump by means of horizontal and transverse lamellae (the length of the vertical partition is 2.4 m, the length of the horizontal plate is 1.08 m, the length of the vertical plate is 0.8 m, $w = 0.2$ m/h)

As anticipated, a diminish within the testimony rate of the toxin leads to a diminish within the effectiveness of water refinement within the sump. In conclusion, we note that it took 5 seconds of computer time to calculate the variation of the issue.

4 Conclusions

The paper provides a compelling CFD demonstration to reflect on the preparation of mass transfer in sewage vertical sumps with complex geometric shapes. The created code allows, with minimal time, to solve complex multi-parameter issues that arise when planning the installation of vertical settling tanks. The auxiliary section of this work should be done as part of a three-dimensional demonstration of the handle of mass transfer in sedimentation tanks.

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