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ANALYSIS OF FLOW AND SEDIMENTATION PROCESSES IN SECONDARY SEDIMENTATION TANK

[1]Jaroslav HRUDKA, [2]Štefan STANKO, [3]Michal HOLUBEC

Department of Sanitary and Environmental Engineering, Faculty of Civil Engineering,
Slovak University of Technology in Bratislava, e-mail: [1]jaroslav.hrudka@stuba.sk,
[2]stefan.stanko@stuba.sk, [3]michal.holubec@stuba.sk

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Abstract: In the process of design and operation of sewerage system are used empirical formulas, which are in many cases, become obsolete and unusable when somebody can use nowadays modern technologies and materials. Therefore there is the possibility of using the mathematical models enormous importance for the enhanced environmental protection with the lowest operating and investment costs. In this modern method of analyzing of sewers has been designated as the first object, the object sedimentation tank. The purpose of the primary and secondary settling tank is to ensure the reduction of concentration the floating solids.

For the solution of research work has been chosen, after consultations with representatives of the Western Slovakia Water Company as interesting object of sedimentation tank located on the waste water treatment plant Nitra - Dolné Krškany.

Measurements on the object settlement tank situated at waste water treatment plant Nitra confirmed the expected speed parameters of the sewage in the tank. The velocity of wastewater is in the most cases very low, and even insignificant. However, finding that the sludge cloud has a non-standard form of a double wave gives the opportunity to optimize the operation of facilities sedimentation tank. The measured parameters are used as calibration parameters to input to the mathematical simulations, which are created by software ANSYS fluent.

Keywords: Sludge, Flow rate, Sedimentation tank

1. Introduction

The purpose of the primary and secondary settling tank is to ensure the reduction of concentration the floating solids. Generally it can say that reductive process can reach by three methods: sedimentation, flotation and filtration. In the sedimentation tank can be generally achieved the first method or a combination of sedimentation and flotation. Sedimentation and flotation uses the same principle that is different mass of the liquids and solids. In terms of hydrodynamics, these tanks are characterized by unstable turbulent flow, complex geometry, and the presence of multiple phases and the strong influence of buoyancy and shear forces. From physical point of view sedimentation tanks are based on sedimentation phenomena: flotation, buoyancy and friction [1].

2. Methodology

For the solution of research work has been chosen, after consultations with representatives of the Western Slovakia Water Company as interesting object of sedimentation tank located on the Waste Water Treatment Plant (WWTP) Nitra - Dolné Krškany. WWTP capacity is 212,000 population equivalents. The river Nitra will adopt approximately 13,249 500 m³/year of treated wastewater. The tank parameters are described in *Table I* and *Fig. 1*.

Table I

The description of WWTP

Parameters	Unit	WWTP Dolné Krškany
Population equivalent		212000
Secondary sedimentation tank type		circular
Diameter	[m]	40
Depth of outer wall	[m]	3,55
Bottom slope	[%]	10
Centre wall depth	[m]	5,63
Sludge removal mechanism		scraper

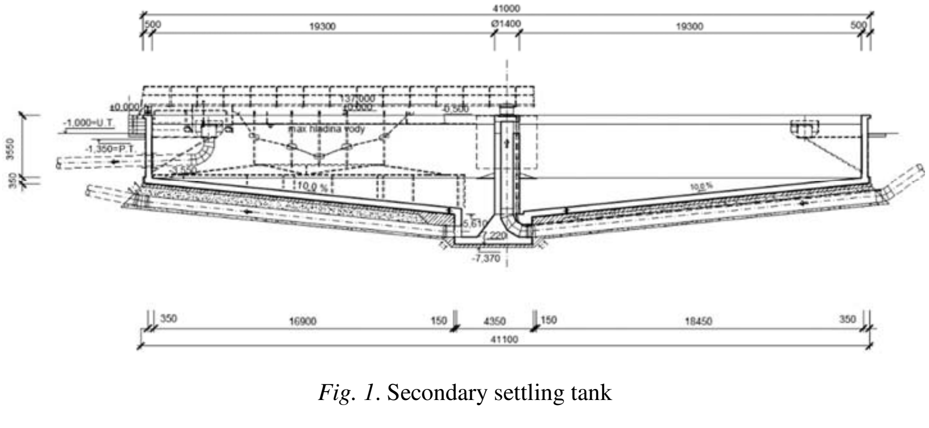

Fig. 1. Secondary settling tank

3. Measurement

Field measurements in the object sedimentation tank were divided into three measurement days. Before the start of each measurement cycles it was necessary that each machine must be calibrated in the calibration bucket. It was also necessary to degrease all probes. On the first day of measurements 13.07.2015 the object was divided into eight measurement cross-sections from ‘A’ to ‘H’ (*Fig. 2*). As the first luminous profile ‘A’ was selected.

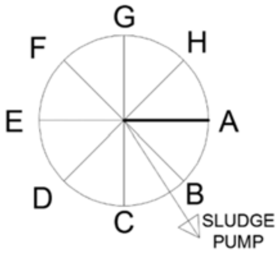

Fig. 2. Scheme of measured profiles

Then this specific profile was divided into smaller measurement cross-sections ‘AA’ to ‘AG’ as it is shown in the *Fig. 3*.

The arrangement of the horizontal measurement cross-sections in all the other measurement cross-sections ‘B’ up to ‘H’ is the same as it is shown in *Fig. 3*.

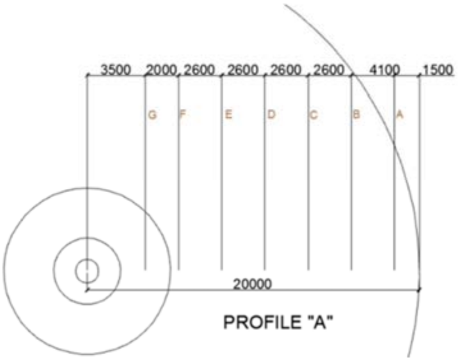

Fig. 3. Identification of the measurement in horizontal profiles- profile ‘A’

Measuring rod consisted of a 5.5 meter rod on which two probes devices Flomate V has been placed. Probe No 1 of device no. 1 was placed 20 cm from the end of the measuring rod. Probe No. 2 was placed 70 cm from the bottom of the measuring rod. At an elevation of 20 cm from the end of the rod a manual probe analyzer of turbidity and suspended solids has been placed (*Fig. 4*).

Fig. 4. Location of individual probes on measuring rod, source: Hrudka Jaroslav, Nitra, 13.7.2015

The actual measurements began in profile ‘AA’ at a depth of 3 m below the surface. At this level the amount of suspended solids, the rate of the waste-water flow direction (from the center to the outside) and the rate of waste water perpendicular to the flow have been measured. All measured values were written to the measurement protocol, which was then evaluated. After the measured parameters at a depth of 3 m, the probe is pulled out to a depth of 2.5 meters, and subsequently held all measurements as in the first specific point. In this way a depth 0.5 m below the surface has been proceeded (*Fig. 5*). Following the complete measuring the profile of ‘AA’ measurements are shifted gradually to the last measurement cross-sections ‘AH’. Since bottom of the tank is inclined in profile ‘H’ is the lowest luminous point at a depth of 4.5 meters.

After completing the measurements on profile ‘A’ the measurement is moved, after running the mobile bridge to the measurement cross-sections ‘E’ where the measurements are repeated as in the case of profile ‘A’. The following day there were measured the remaining profiles, and that has been measured in an identical way as for the measured profiles ‘A’ and ‘B’.

Fig. 5. Measurement of one of vertical profile, source: Hrudka Jaroslav, Nitra, 13.7.2015

4. Evaluation of measurements

The results of field measurements have been recorded in the protocol, part of which is shown in *Table II*. Overall, eight protocols have been developed. They were recorded all the measured parameters, which were subsequently evaluated at 336 charts. One of these charts is as an example shown in *Fig. 6, Fig. 7* and in *Fig. 8*.

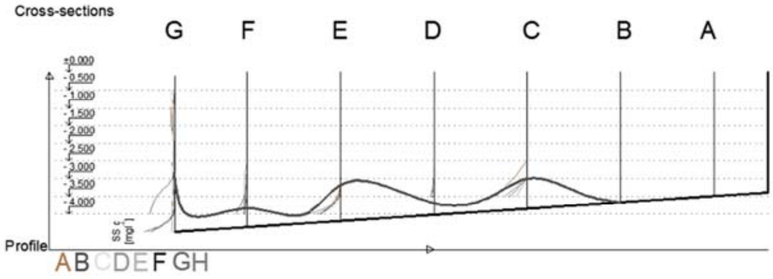

Fig. 6. The concentration of solids in the individual profiles with a curve of sludge wave

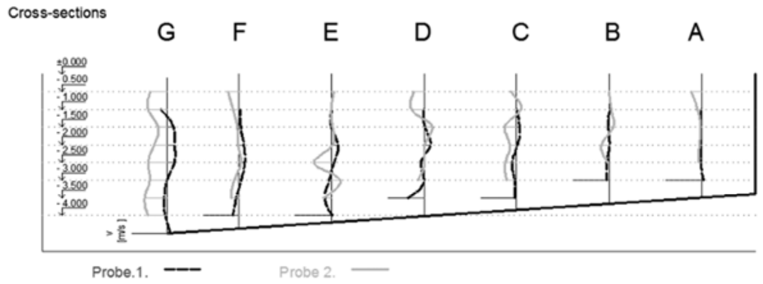

Fig. 7. The speed in cross-sections of the profile ‘B’ in flow direction

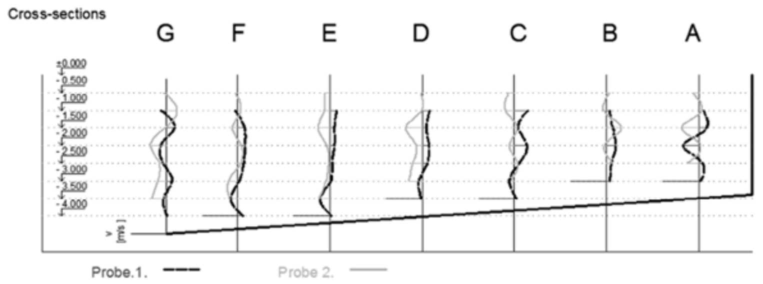

Fig. 8. The speed in cross-sections of the profile ‘B’ in perpendicular to the flow direction

Table II

Part of the protocol from the specific profile ‘B’

Measurements on the object sedimentation tank									
Day: 14.07.2015							Location: WWTP Nitra - Dolné Krškany		
Start: 14:00		Temperature of WW: 20.70°C			Atmospheric temperature: 26°C			wind: /	
Profile	Mark	Depth above w. lvl [m]	Speed perpendicu. to the flow [mm/s]		Speed in the flow direction [mm/s]		SP [mg/l]	Time	Length of measurement
			Probe 1	Probe 2	Probe 1	Probe 2			
a	1	0.5		-0.018		-0.009	0	14:08	6 min
	2	1	0.02	-0.014	0	-0.055	0		
	3	1.5	0.015	0.015	0.002	-0.028	0		
	4	2	0.018	0.014	0.01	-0.009	0.001		
	5	2.5	0.027	0.004	0	-0.1	0.001		
	6	3	0.019		0		0.002	14:02	
b	1	0.5		-0.024		-0.016	0	14:15	5 min
	2	1	0.008	-0.006	0.006	-0.028	0		
	3	1.5	0.009	-0.016	-0.008	-0.026	0		
	4	2	0.034	-0.03	0.007	-0.05	0		
	5	2.5	0.013	-0.036	0.009	-0.024	0.01		
	6	3	0.009		0.022		0.01	14:10	
f	1	0.5		0		-0.013	0	14:53	10 min
	2	1	0.014	0	0.002	-0.017	0		
	3	1.5	0.015	0.003	-0.016	-0.017	0		
	4	2	0.013	-0.011	-0.014	-0.026	0		
	5	2.5	0.01	0.001	-0.006	-0.02	0		
	6	3	0.002	-0.011	0.016	0.008	0.21		
	7	3.5	-0.013	-0.018	0.022	0.003	0.61		
	8	4	0.001		0.001		9.03	14:43	
g	1	0.5		0.014		0.054	0	15:08	13 min
	2	1	-0.011	-0.013	-0.008	-0.02	0.06		
	3	1.5	0.029	-0.024	-0.025	-0.029	0.01		
	4	2	0.021	-0.009	-0.018	-0.025	0.19		
	5	2.5	0.01	-0.006	0.004	-0.015	0.19		
	6	3	-0.043	-0.027	-0.004	0.006	0.54		
	7	3.5	-0.012	-0.026	-0.011	-0.003	0.95		
	8	4	0.005	0.001	-0.01	-0.021	2.26		
	9	4.5	0.003		0		5.67	14:55	

5. Modeling

During this study the hydraulic Computational Fluid Dynamics (CFD) modeling began with the definition of the settling tank geometry. Secondly, fluid characteristics and boundary conditions were defined. The momentum balance, including the turbulence model and continuity equations, was then solved numerically for the tank using the finite volume method. Finally, the obtained solution was post-processed to be properly visualized. Common mathematical hydraulic model equations used for CFD modeling include the momentum balances for a non-compressible viscous media and the continuity equation [2],

$$\rho \frac{\partial \boldsymbol{U}}{\partial t} - \nabla \left[\left(\mu + \rho C_\mu \frac{k^2}{\varepsilon} \right) \left(\nabla \cdot \boldsymbol{U} + (\nabla \cdot \boldsymbol{U})^T \right) \right] + \rho \boldsymbol{U}\, \nabla \cdot \boldsymbol{U} + \nabla P = \boldsymbol{F}, \tag{1}$$

$$\nabla \cdot \boldsymbol{U} = 0, \tag{2}$$

where ρ is the density [kg/m^3]; $\boldsymbol{U}$ is the average flow velocity vector [m/s]; t is the time [sec]; μ is the molecular viscosity [Pa.s]; C_μ is the model constant; k is the turbulent kinetic energy [m^2/s^2]; ε is the dissipation of turbulent energy [m^2/s^3]; P is average pressure [Pa], $\boldsymbol{F}$ is volume force term [N/m^3] which is zero in both the x and y directions.

In the settling model an additional scalar equation was added to include the concentration of the solids. This convection-diffusion equation is as follows:

$$\rho \frac{\partial C}{\partial t} + \frac{\partial \rho (U + U_S) C}{\partial x_i} = \rho \frac{\partial}{\partial x_i} \left(\frac{\nu_t}{\sigma_C} \frac{\partial C}{\partial x_i} \right), \tag{3}$$

where C is the concentration of solids [mg/l]; $U = |\boldsymbol{U}|$ is the absolute value of the velocity [m/s]; U_S is the amplitude of the settling velocity [m/s]; ν_t is the turbulent viscosity [Pa.s]; σ_c is the Schmidt number (0.7).

The settling velocity was modeled using the Takács exponential settling function [3], this expression being introduced in the resolution of the concentration equation,

$$\boldsymbol{U}_S = \boldsymbol{U}_{S0} \cdot \exp[-r_h (C - C_{ns})] - \boldsymbol{U}_{S0} \cdot \exp[-r_p (C - C_{ns})] \ , \tag{4}$$

where r_h, and r_p induce the domination of the first and the second term, for the falling and the rising part [-], $\boldsymbol{U}_{s0}$ is reference settling velocity [m/s] and C_{ns} is the non-settleable concentration [mg/l].

The standard k-ε eddy-viscosity model was used to account for the turbulent effects. The turbulent viscosity was defined as a function of the turbulent kinetic energy k and its dissipation rate ε by the equation [4]:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}, \tag{5}$$

where μ_t is turbulent viscosity [Pa.s].

The distributions of k and ε were determined from the following transport equations [5]:

$$\frac{\partial \rho k}{\partial t} + \frac{\partial k}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left((\mu + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_i}\right) + G_k + G_b - \rho\varepsilon - Y_M + S_k, \tag{6}$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial k}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left((\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_i}\right) + C_k \frac{\varepsilon}{k}(G_k + C_{SC}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon. \tag{7}$$

The model constants (C_μ, $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, σ_k, σ_ε) in the above equations have been determined from experimental data and are set to the standard parameters [4]:
$C_\mu = 0.09$, $C_{1\varepsilon} = 0.1256$, $C_{2\varepsilon} = 1.92$, $\sigma_k = 0.9$, $\sigma_\varepsilon = 1.3$.

G_b describes the influence of the buoyancy effects and is defined as a function of the suspended solids concentration gradient [6]:

$$G_b = \beta g \frac{\nu_t}{\sigma_\varepsilon}\frac{\partial C}{\partial x} = \frac{\rho_p - \rho_w}{\rho_p \rho_w} g \frac{\nu_t}{\sigma_\varepsilon}\frac{\partial C}{\partial x}, \tag{8}$$

where ρ_p is the particle density [kg.m^{-3}]; ρ_w is water density [kg.m^{-3}]; σ_k is the model constant = 0.9 [-]; σ_ε is the model constant =1.3 [-].

The concentration gradient, which reaches maximum values at the interface between the clear fluid and the sludge blanket, hinders turbulence. The source term G_b introduced in the turbulence equation addresses this matter.

The later expression yields values close to a unity for the unstable areas, and tends towards zero for the stratified sedimentation. A Boussinesq-type approach also implies that the effect of sludge gravity is introduced implicitly as a function of the concentration of suspended solids. Its implementation in the momentum equations is carried out by means of the source terms [7]:

$$g(\rho_p - \rho_w) = gC\frac{\rho_p - \rho_w}{\rho_p}. \tag{9}$$

The dependence of the viscosity on the concentration is empirically input at different concentration ranges. The effect of the scraper blades has been usually either neglected or introduced as uniform constant sources, especially in the modeling of a circular sedimentation tank. However, due to the significance of the scraper system for a circular sedimentation tank, an additional sub-model was incorporated to better model the effects of the transport of solids. The conveying force exerted on the fluid was approximated as a function of fluid velocity, including a flow regime dependent drag coefficient:

$$F_D = C_D \frac{1}{2} \rho A V_r^2 , \tag{10}$$

where C_D is the drag coefficient; A is the scraper displacement area [m^2].

Models of hydraulic phenomena are closely related to modeling of some form of movement. Fluid motion is related with the solution of various problems that are contained in the physical models:

- Laminar and turbulent flow;
- Compressible and incompressible flow;
- Stationary, non-stationary and transitional flow;
- Heat transfer, natural and mixed convection;
- Transfer of chemicals and chemical reactions;
- Multiphase flow, flow with free surface, flow with field particles, bubbles or drops;
- Porous media flow and others [8].

The mathematical model is based on the definitions of the above problems. Given that this is a planar, two-dimensional, and axially symmetric three-dimensional, time-dependent event. They are described in a system of partial differential equations, which are authorized by numerical methods [9].

It is possible to solve these problems using different commercial software systems such as ANSYS Fluent CFD and more. Constructing a proper calculation model is very important. It contains mathematical, physical and technical principles. For these models, it is necessary to identify all input data of software, which are needed for model. In all phases of the creation of these models is necessary re-check of input data. In these models shall be graded all the information about the geometry (two-dimensionally or three-dimensional units), information about external forces, physical data (information on the flowing medium) [10].

Dynamic modeling is based on determining flow equations, which are based on three basic principles:

- Conservation of weight;
- Conservation of momentum;
- Conservation of energy [11].

These principles are expressed in the form of continuity equation, motion equations and energy equation. They are formulated as a system of partial differential equations (Navier-Stokes equations) [12] (Setup is shown in *Fig. 9*).

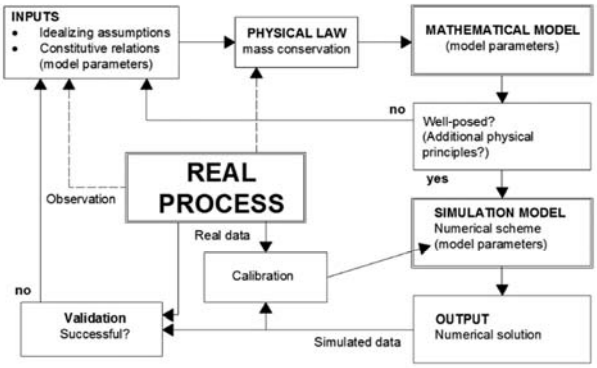

Fig. 9. Schematic overview of the consistent modeling methodology. The dashed arrows indicate the initial observations of the real process. Note that (model parameters) refers to the same set of parameters defined in the constitutive relations [13]

On the central bearing structure we are proposing deflector in the horizontal direction (*Fig. 10*).

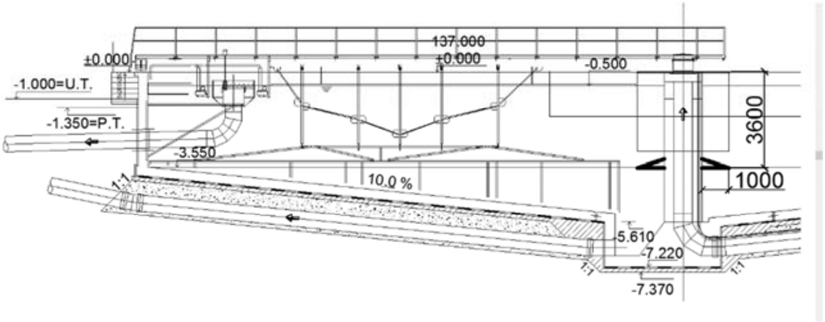

Fig. 10. The proposed new deflector 3, 6 m above water level

6. Conclusion

While this research work was solved, methodology for measuring flow parameters of the property settlement tank was developed. The measurement procedures are set with high efficiency, in view of the quality and speed of measurement. The measured parameters are used as entering into the calibration parameters of the mathematical model.

From the in situ measurements and simulation results it is clear that the hydraulic processes in the sedimentation tank are not ideally. At a distance of 6.8 meters from the center of the tank is starting rinsing of sludge from the bottom of the tank. This process causes a bad sedimentation and a leakage effect of suspended solids. Because of these bad processes in the tank there are proposed constructional adjustments. On the central bearing structure deflector in the horizontal direction is proposed. The proposed deflector can prevent higher flow speed at the bottom of the tank. This process ensures undisturbed process of sedimentation in the lower part of the tank.

The proposal of the horizontal deflector is based only on the evaluation of the measurements is not yet supported by the results of mathematical simulations. The improvement of effectiveness sedimentation through the proposed construction will be possible after verification will be done.

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