MODELING THE EFFECT OF WIND IN RECTANGULAR SETTLING TANKS FOR WATER SUPPLY

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ABSTRACT

Sedimentation is one of the most important treatment processes in conventional Water Treatment Plants and is performed in settling tanks, whose cost usually accounts for almost 30% of the total investment. Subsequently, the determination of the removal efficiency of settling tanks has been the subject of numerous studies, which in the last three decades have focused on the use of CFD (Computational Fluid Dynamics) models. Although it is generally recognized that the removal efficiency of settling tanks is sensitive to wind effects, the latter is usually neglected and there are only a few relevant studies in the literature. In the present work, we apply a 2-D CFD code to model the effect of wind via the modification of the shear stress on the water surface of the tank and draw the following conclusions: (1) When no wind is present, the flow is characterized by a large recirculation region, which forces the flow to exit the tank following a short-circuiting route; this type of flow is characteristic for settling tanks without density effects. When wind is present, a two-layer flow is developed, in which the surface layer follows the direction of the wind. With increasing wind velocity in the downstream direction, the upstream bottom layer directs the incoming jet towards the surface and finally towards the outlet, thus increasing the degree of short-circuiting. When the wind blows in the upstream direction, the incoming flow is directed downstream; thus, short-circuiting decreases with increasing wind velocity. (2) The suspended solids concentration fields depend strongly on the flow fields; in the recirculation area without wind and in the region close to the interface of the two-layer flow when wind is present, mixing is intense and the concentration profiles are approximately uniform. With increasing wind velocity in the downstream direction the iso-concentration contours are shifted towards the water surface being influenced by the upstream bottom current, the outlet concentration increases and the efficiency of the tank is reduced. When wind blows in the upstream direction, the incoming flux of suspended solids is directed downstream, the outlet concentration decreases and the efficiency increases. (3) Without wind the removal efficiency of the tank is calculated equal to 68.1 %, i.e. it is practically equal to the value of 68.4 % determined with 3-D calculations; this very good agreement is observed for all classes of solids. The effect of wind is generally more prominent with decreasing settling velocity. From the practical point of view, efficiencies for all classes decrease by up to 2% and 3% for co-current wind velocities equal to 5.0 and 7.5 m/s, respectively, while the same order of efficiency increase is observed for counter-current wind velocities.

Keywords: wind, settling tank, water treatment plant, CFD modeling, suspended solids, settling efficiency

1. Introduction

Sedimentation is one of the most important treatment processes in conventional Water Treatment Plants (WTP) and is performed in settling tanks, whose investment usually accounts for almost 30% of the total investment. Subsequently, the determination of the removal efficiency of settling tanks has been the subject of numerous studies, which in the last three decades have focused on the use of CFD (Computational Fluid Dynamics) models. CFD models calculate the flow field and mixing regime, the distribution of the suspended solids concentrations and subsequently their removal in the tank. CFD models use as input data the physical characteristics of the solids, e.g. particle size, density and settling velocity taking into account processes, such as flocculation and breakup or re-entrainment of solid particles, and effects, e.g. due to the wind, which can strongly affect the flow field and settling. Although it is generally recognized that the removal efficiency of settling tanks is sensitive to wind effects (Asgharzadeh *et al.* 2012), the latter is usually neglected and there are only a few relevant studies in the literature. Sivakumar & Lowe (1990) investigated the effect of wind on the removal efficiency of a rectangular settling tank using a 2-D model and the k-ε turbulence model; they observed that (i) with increasing wind speed, the re-circulation region in the tank becomes more extended leading to intense mixing and uniform distribution of the suspended solids, and (ii) the wind has a detrimental effect on the distribution of suspended solids and the removal efficiency decreases with increasing wind speed with counter current wind speed being more significant. Khezri *et al*. (2012) performed an experimental study in a pilot sedimentation tank and concluded that (1) the actual efficiency of the tank (61.24%) decreases with co-current wind speeds of 4.5 m/s, 5.5 m/s, and 7.0 m/s to 50.01%, 46.04%, and 45.03%, respectively, (2) for counter current wind speed equal to 2.5 m/s the efficiency increases to 65.00% due to the increase of solids retention time, and (3) when the counter current wind speed increases to 3.5 m/s and 5.0 m/s, the efficiency decreases to 55.07% and 47.00%, respectively, due to re-suspension of solids. Very recently, Stamou and Gkesouli (2015) applied a 3-D CFD model in the settling tanks of the WTP of Aharnes (WTPA), an important component of the water supply system of the greater area of Athens in Greece, and showed that the effect of wind on the flow field and the hydraulic efficiency was strong, with the creation of massive re-circulation areas with intense mixing and high short-circuiting. However, the effect of wind on the settling performance of the tanks was not pronounced; the removal efficiency of the tanks, which was equal to 72.48% in calm conditions, was reduced to 68.07% in windy conditions. Stamou and Gkesouli (2015) modeled the effect of wind by applying a constant horizontal flow velocity equal to 0.50 m/s on the free surface in the flow direction, which was based on a free stream-wind speed of 15 m/s (Tsahalis, 1979).

In the present work we perform calculations in the settling tanks of the WTPA using a 2-D CFD model, in which the effect of the wind is taken into account via the modification of the shear stress on the water surface of the tank.

2. Mathematical model

We performed calculations with the CFD code FLOW-3D v.11 (Flow Science Inc., 2014). The continuity and momentum equations are solved to determine the 2-D flow field in the tank, in which the turbulence is described via the renormalization-group (RNG) model and the free surface is determined with the Volume of Fluid (VOF) method. The concentrations of all the classes of the suspended solids are calculated by solving transport equations, which are transported by advection along with the water and may settle depending on their settling velocity; settled solids are packed remaining static in the computational domain and can only move when they erode due to re-suspension and start to move as bed or suspended load. The effect of the wind is taken into account via the modification of the shear stress on the water surface, which is written as follows

$$\tau = \rho_{\alpha} C W \sqrt{W^2} \qquad (1)$$

where ρ_a is the air density, W is the wind velocity at height 10 m and C is the drag coefficient, whose values were obtained by Hervouet (2007).

3. Characteristics of the settling tank

The real 3-D tanks have length equal to 73.2 m, width equal to 14.4 m, and an average water depth equal to 3.5 m; water from flocculation tanks enters into the settling tanks via four inlet openings, which are located near the bottom of the tanks, and exits via a series of V-notch weirs installed at three outlet channels. In the present calculations the geometry of the tank is approximated as 2-D; the water enters the tank via a slot opening equal to 0.15 m with a velocity equal to 0.12 m/s and exits via the outlet weir that is located in the beginning of the 3-D outlet region (x=63.3 m); the flow rate that is equal to 0.26 m^3/s corresponds to an overflow rate equal to 1.02 m/h and a theoretical detention time of 3.4 h. The characteristics of the suspended solids at the inlet of the tank are shown in Table 1 together with the calculated removal efficiencies, R, using the 3-D model (Stamou and Gkesouli, 2015) and the theory of ideal settling.

Table 1: Characteristics of the suspended solids at the inlet of the tank.

Class (-)	Fraction (%)	Inlet concentration (mg/L)	Settling Velocity (m/h)	Hazen number (-)	Ideal settling R (%)	3-D model R (%)
C1	45	3.17	5.80	5.67	100.0	99.2
C2	36	2.53	0.96	0.94	92.7	59.4
C3	4	0..27	0.31	0.30	30.2	25.9
C4	15	1.05	0.09	0.09	9.2	9.1
Sum	100	7.02	-	-	81.0	68.4

4. Calculations, discussion and conclusions

Calculations have been performed for 7 values of wind velocities equal to W=5, 7.5, 10.0, -5, -7.5 and -10.0 m/s using a numerical grid consisting of 633X81 elements and the boundary conditions that are summarized in Table 2.

Table 2: Boundary conditions.

Location	Boundary condition
Surface	VOF
Bottom	No slip wall
Side walls	Symmetry
Inlet	Velocity=0.12 m/s and total solids concentration=7.02 mg/L
Outlet	Specified pressure and water height

In Figure 1 the velocity vectors of the flow field and the suspended solids iso-concentration contours for class C3 are shown for all scenarios, while in Table 3 the calculated removal efficiencies are depicted.

Figure 1 shows that when no wind is present, the flow is characterized by a relatively large recirculation region above the inlet jet, which forces the flow to exit the tank following a short-circuiting route; this type of flow is characteristic for settling tanks without density effects (Stamou *et al*., 1989). When wind is present, a two-layer flow is developed whose surface layer follows the direction of the wind. With increasing wind velocity in the downstream direction, the upstream bottom layer suppresses the incoming jet and directs it towards the surface and finally towards the outlet, thus increasing the degree of short-circuiting. When the wind blows upstream, the incoming flow is directed downstream; thus, short-circuiting decreases with increasing wind velocity.

The suspended solids iso-concentration contours of Figure 1 show that the concentration fields depend strongly on the flow fields; in the main recirculation area without wind and in the region close to the interface of the two-layer flow when wind is present, where mixing is intense, the concentration profiles are approximately uniform. As expected, with increasing wind velocity in the downstream direction the iso-concentration contours are shifted upwards, towards the water surface, after being influenced by the upstream bottom current; thus, the outlet concentration increases and the efficiency of the tank is reduced. Moreover, when the wind blows in the upstream direction, the incoming flux of solids is directed downstream by the flow and therefore the outlet concentration decreases and the efficiency increases. Without wind the removal efficiency of the tank is calculated equal to 68.1 %, i.e. it is practically equal to the value of 68.4 % determined via 3-D calculations (Stamou and Gkesouli, 2015) that are depicted in Table 1; this very good agreement is observed for all classes of solids. As expected, Table 1 shows that the effect of wind is generally more prominent with decreasing settling velocity; however, not all calculations verified this behavior, mainly these for W=10 m/s, whose results are not shown in Table 1. From the practical point of view, efficiencies for all classes decrease by up to 2% and 3% for co-current winds equal to 5.0 and 7.5 m/s, respectively, while the same order of efficiency increase is observed for counter-current wind velocities.

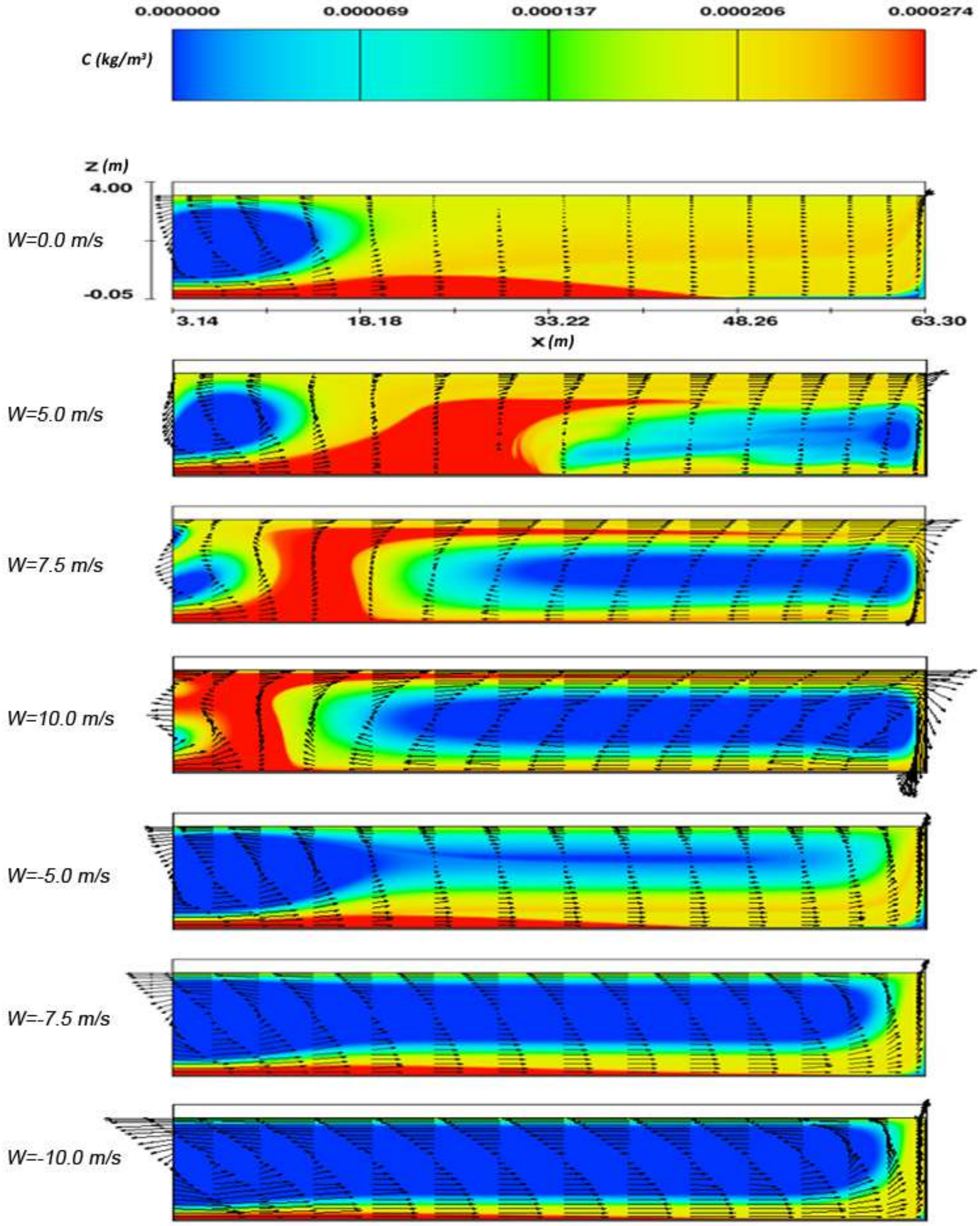

Figure 1: Calculated flow field vectors and concentrations for the 3rd class.

Table 3: Calculated differences in removal efficiencies for various wind velocities.

Wind	7.5 m/s	5.0 m/s	No wind (%)	-5.0 m/s	-7.5 m/s	-10.0 m/s
ClassC1	+0.0	+0.0	100.0	+0.0	+0.0	+0.0
ClassC2	-0.8	-0.5	58.1	+0.6	+1.5	+2.8
ClassC3	-2.9	-1.8	25.4	+1.9	+2.3	+3.0
Class C4	-2.2	-1.3	9.0	+1.8	+2.8	+3.8
Average	-0.7	-0.4	68.1	+0.7	+1.3	+1.9

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