A Study of Water Treatment Clarifier

Rome-Ming Wu*, Tsung-Hao Lee and Wen-Jie Yang

Department of Chemical and Materials Engineering, Tamkang University, Tamsui, Taiwan 251, R.O.C.

Abstract

In this work the geometry of the sludge blanket clarifier was established based on Bansin Water Treatment Plant, Taiwan. The meshes of the clarifier were constructed, and the boundary conditions were set, then the velocity field of the clarifier was calculated. Two models were computed individually: 1. the fluid in the whole clarifier is pure water – a test for obtaining the flow pattern; 2. the flow field contains a homogeneous blanket of permeability k and pure water – a test modeling the sludge blanket as a homogeneous porous medium.

The results showed that when the inlet velocity decreased from υ_x = 0.3 m/s to 0.1 m/s, the effect of channel flow or break-through of blanket decreased. Decreasing of the rotation velocity of the impeller could decrease the effect of the reversed flow in the secondary reactor. In the case of a uniform blanket on the bottom of the clarifier, the high permeability of the blanket indicates the similar velocity field with those of pure water. While the clarifier with a low permeability blanket, the rebound of the blanket becomes seriously.

***Key Words*:** Clarifier, 3D Simulation, Sludge, Blanket, Water Treatment

1. Introduction

Flocculation clarifier has been widely used for clean water production since its first introduction in 1930's. Owing to the more efficient flocculation and better chance to solid contacts, the flocculation clarifiers could have a surface loading two to three times higher than the conventional coagulation-sedimentation basins [1–4]. The Taiwan Water Supply Corporation (TWSC) installed flocculation clarifiers for drinking water production since early 1990's. Flocculation clarifiers supply over 50% drinking water to the Taiwan's public. The floc blanket functions as a particle coagulator as well as a filter. The existence of a floc blanket in clarifiers is thereby essential to produce quality drinking water. The settling velocity of the coagulated flocs and the upflow velocity control the stability of the blanket [5,6]. Stringent operational control is required for preventing sludge washout from the clarifiers [7].

The Bansin Water Treatment Plant in Banchiao City, Taipei County, Taiwan, takes raw water from Yuanshanyan (Yuanshan weir) and Shihmen Reservoir at a rate of about 1,200,000 m^3/day with polyaluminum chloride (PACl) as the coagulant. The turbidity of raw water exhibits a "two-state" characteristic. Under normal weather condition the raw water turbidity is commonly less than 10 NTU, referred to as the "low-turbidity period". In summer, tropical storms frequently hit Taiwan, which produce heavy showers and serious flooding. The turbidity of raw water could increase to 10000 to 30000 NTU in one day, and remain higher than 100 NTU over the next 2–3 weeks. This is referred to the "high-turbidity period". The typhoons inflicting heavy losses on Taiwan during 2000–2005 are listed in Table 1. Pre-sedimentation followed by conventional coagulation and flocculation with filter aid is proposed for treating high turbidity water [8–12].

The Works conventionally adopted 16 high-speed solid contact clarifiers (referred to as the "single-stage process") to treat its raw water. The floc blanket is noted

*Corresponding author. E-mail: romeman@mail.tku.edu.tw

Table 1. The typhoons inflict heavy losses on Taiwan during 2000–2005

2000.08.22	BILIS
2000.11.01	XANGSANE
2001.07.30	TORAJI
2001.09.10	NARI
2004.07.01	MINDULLE
2004.08.25	AERE
2004.09.12	HAIMA
2004.10.25	NOCK-TEN
2005.08.04	MATSA
2005.09.01	TALIM

rather unstable [13]. As Figure 1 shows, about every 20 mins sludge blanket overturns somewhere and solid flux of the effluent increases, making a large loading on the following sand filtration. Moreover, when treating high-turbidity raw water the coagulated solids would rapidly accumulate in the clarifiers and the flocs exhibit very poor settleability. Hence, the Works normally has to reduce its water throughput, for instance, by 30% at the raw water turbidity of 200 NTU, and by 50% at 1,500 NTU. The turbidity of the clarified water is generally too high to produce quality clean water after sand filtering.

2. Simulation Method

2.1 Geometry and Meshes

Figure 2 indicates the geometry of the high speed solid contact clarifier. The clarifier is of size 19 × 19 × 5.5 m^3, with a 16 blades impeller of 3 m diameter in the center and in top of the clarifier. The inlet pipe is of 0.9 m diameter and usually with an inlet water velocity of 0.34 m/s. The inlet pipe is connected to a 2.4 m diameter draft tube, which is the first reaction zone. The second reaction well is 3.7 m high and has upper and lower diameters as 8 and 13 m, respectively. Figure 3 is the corresponding calculation meshes.

2.2 Governing Equations and Boundary Conditions

The governing equation for the fluid velocity $\vec{u}_p$ within the porous sludge blanket taking into account the viscous effect is stated as follows:

$$\mathrm{Re}\,\vec{u}_p^{*2} = -\beta^2\vec{u}_p^* - Eu\,\mathrm{Re}\,\nabla P^* \tag{1}$$

Where $Eu = P_o/\rho V^2$ (Euler number), $\mathrm{Re} = d_f \rho V/2$ (Reynolds number), $\beta = d_f/2k^{0.5}$, $P^* = p/P_o$ and $\vec{u}_p^* = \vec{u}_p / V$. The two terms in the right-hand-side of eq. (1) is the Darcy's law. The left-hand-side is attributed to the momentum sink, a modification version of Darcy's law.

For the surrounding Newtonian fluid field in the clarifier, the governing equations are the steady-state Na-

Figure 1. Overturns of the blanket.

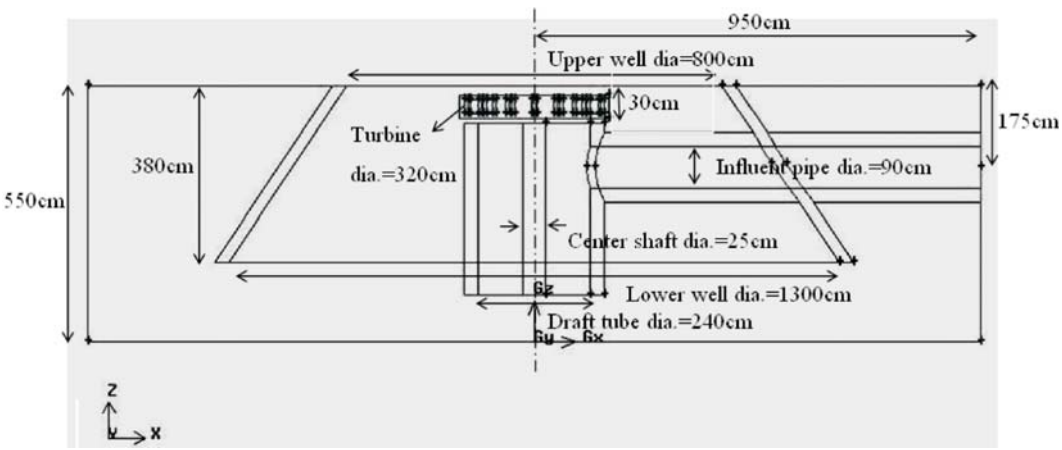

Figure 2. Geometry of the clarifier.

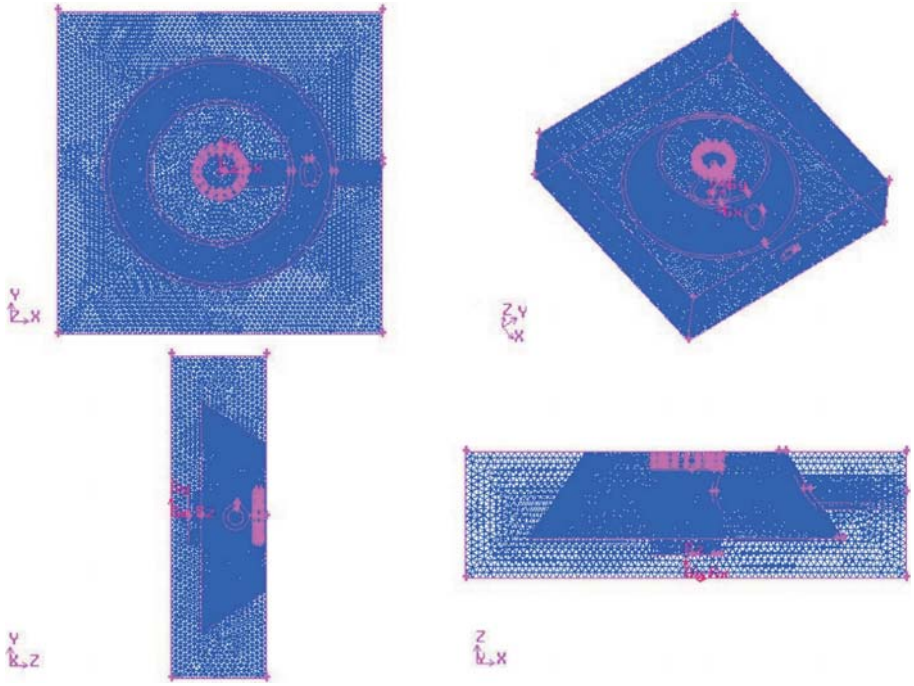

Figure 3. Meshes of the clarifier.

vier-Stokes equations, which can be stated as follows:

$$(\vec{u}_f^* \bullet \nabla)\vec{u}_f^* + Eu\nabla P^* = \frac{1}{\mathrm{Re}}\nabla^2\vec{u}_f^* \tag{2}$$

where $\vec{u}_f$ is the fluid velocity. The first and the second terms of the left-hand-side of eq. (2) correspond to the inertial and pressure effect, respectively; while the right-hand-side, the viscous effect.

The boundary conditions are as follows:

$$\vec{u}_f = \vec{V}, \ @\, r \to \infty \tag{3a}$$

$$\vec{u}_p = \vec{u}_f, \ @ \text{ blanket's surface} \tag{3b}$$

$$\nabla\vec{u}_p = \nabla\vec{u}_f, \ @ \text{ blanket's surface} \tag{3c}$$

$$P = 0, \ @ \text{ water surface} \tag{3d}$$

Equation (3a) states that the inlet fluid is moving at a constant speed. Equations (3b) and (3c) are the continuation conditions of fluid velocity and shear stress across the sludge blanket. Eq. (3d) describes the gauge pressure at the water surface (top of the clarifier) is zero.

The computational fluid dynamics program FLUENT 6.1 (Fluent Inc., USA) solved the governing equations, eqs. (1) and (2), together with the associated boundary conditions eqs. (3a)–(3d), using hybrid mesh volumes. The numbers of mesh volumes in the fluid side and within the sludge blanket are about 2,000,000 and 500,000, respectively. The calculations were carried out with maximum relative error of 10^{-4} in fluid velocity evaluation. The maximum relative errors for velocity at elevation z = 2.2 m are less than 5% when compared with Water Works.

3. Results and Disscussion

Figure 4 plots the velocity vector of clean water in the clarifier. When inlet water is flowing into the draft tube, it is sucked to the top of the clarifier, owing to the rotating impeller. Then it goes down along the inside of the well and separates into two streams. One of the stream inside the well makes a strong cycling flow in the reaction well, and the other stream goes up along the wall of the clarifier, to the effluent surface, and goes down along the outside of the reaction well, making another weaker cycling flow. It is suggested if there is a dilute, weak blanket in the bottom of the clarifier, the flocs may be elutriated by the cycling flow outside the reaction well, leading to an average 20 mins overturn as shown in Figure 1. A naturally thinking is to treat the flocs into a

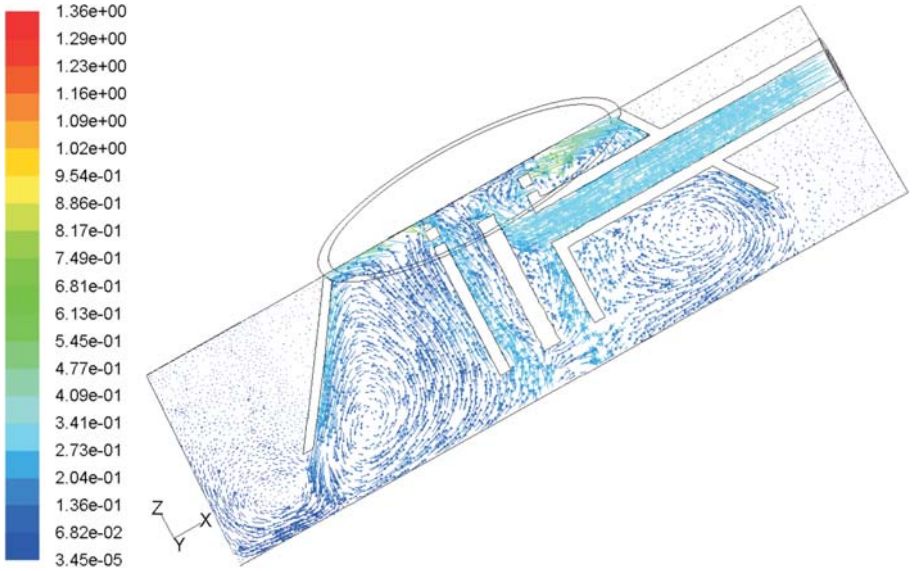

Figure 4. Velocity vector of water flows (inlet velocity = 0.1 m/s, impeller rotation speed ω = 0.9 rad/s)

strong and dense blanket.

Figure 5 depicts the velocity contour of the central cross surface (x = 0, y = 0) of the clarifier, with sludge blanket permeability of 4×10^{-2} m^2. Figures 6, 7, and 8 are the velocity counters with permeability of 4×10^{-4}, 4×10^{-6}, 4×10^{-8} m^2, respectively. The colors shown in these figures indicate the velocities are all larger than 4.2×10^{-4} m/s, which is a break-through velocity offered by

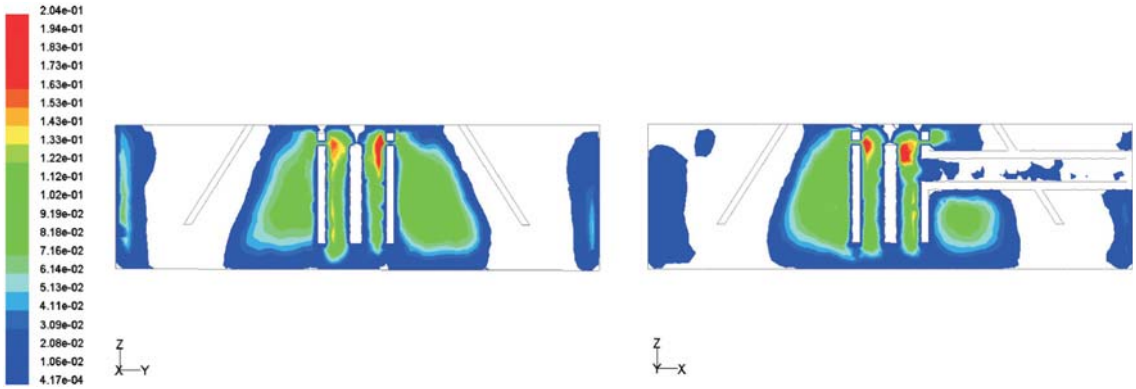

Figure 5. Velocity counter ($k = 4 \times 10^{-2}$ m^2).

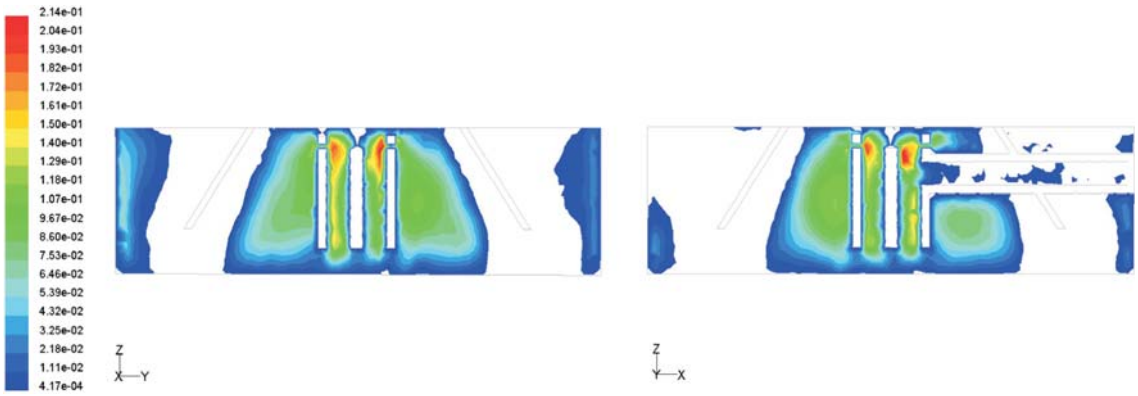

Figure 6. Velocity counter ($k = 4 \times 10^{-4}$ m^2).

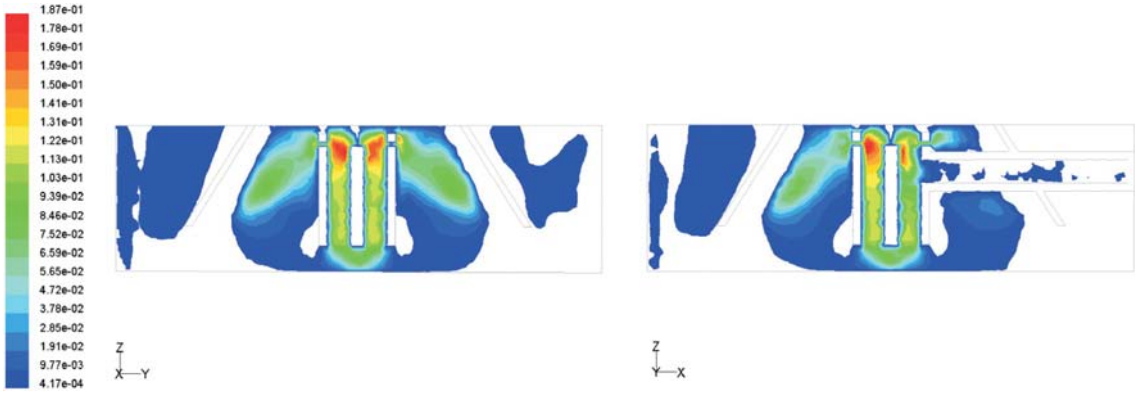

Figure 7. Velocity counter ($k = 4 \times 10^{-6}$ m^2).

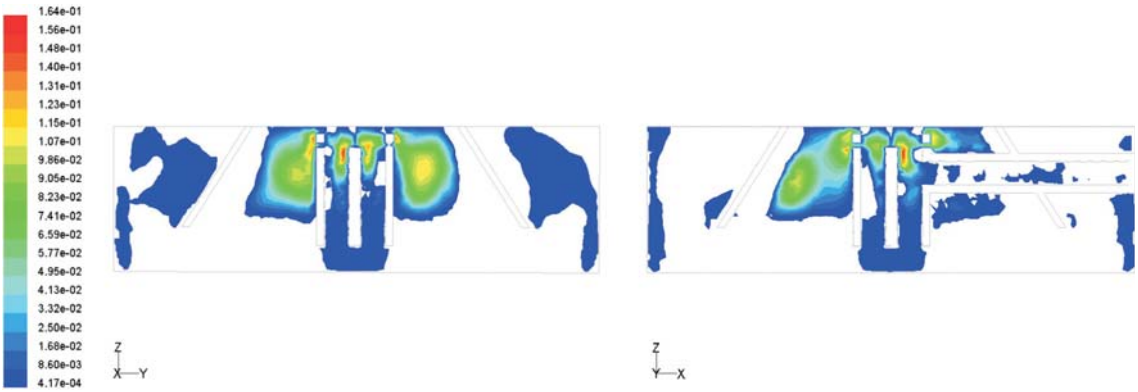

Figure 8. Velocity counter ($k = 4 \times 10^{-8}$ m^2).

Water Works. The velocities are large in the reaction well, owing to the cycling flow as mentioned in the above paragraph.

Due to very low permeability in Figure 8, there is no flow (less than 4.2×10^{-4} m/s) at the bottom of the well. It is shown as Figure 5 that the velocity is larger than that at the clarifier wall, indicating an up flow and finally a complete cycle. Owing to vary large permeability of the blanket at the bottom, the result is similar to Figure 4, only clean water in the clarifier. Figure 6 and 7 indicate the zones of backflow inside the reaction well is getting smaller. This is because the permeability decreases, the resistance increases and water flows less easily through the blanket.

Somewhat different results from the above naturally thinking are shown in Figure 7. Due to the increasing of the resistance in sludge blanket, the fluid could not pass through easily. While some fluid passes through the sludge blanket, some fluid rebounds from the bottom of reaction well, making a zone of large velocity outside the reaction well and above the sludge blanket. On the contrary, dense blanket increases the turbidity of the effluent flow. This may be the reason of the unstability of the blanket in the Water Works.

4. Conclusion

The Bansin Water Works of Taiwan Water Supply Corporation (TWSC) adopt sixteen solid contact type floc blanket clarifiers to produce drinking water using polyaluminum chloride as a coagulant. The blankets in the clarifiers experienced frequent overturn, which seriously threatened the quality of drinking water. According to the simulation results, the Works has to cut down its water supply for dealing with high-turbidity storm water.

Nomenclature

β: dimensionless permeability, (-)
μ: viscosity of fluid, (kg/m-s)
ρ: density of fluid, (kg/m^3)
d_f : diameter of inlet pipe, (m)

Eu: Euler number, (-)
k: permeability, (m^2)
NTU: Nephelometric turbidity unit, (-)
Re: Reynolds number, (-)
$\vec{u}_f$: fluid velocity in clarifier, (m/s)
$\vec{u}_f^{\,*}$: dimensionless fluid velocity in clarifier, (-)
$\vec{u}_p$: fluid velocity in porous medium, (m/s)
$\vec{u}_p^{\,*}$: dimensionless fluid velocity in porous medium, (-)
V: inflow velocity, (m/s)

Acknowledgment

The authors would like to acknowledge the financial support received from the National Science Council of Republic of China.

References

[1] Kawamura, S., *Integrated Design of Water Treatment Facilities,* John Wiley & Sons, N.Y., U.S.A. (1991).
[2] Masschelein, W. J., *Unit Processes in Drinking Water Treatment,* Marcel Dekker, N.Y., U.S.A. (1992).
[3] Stevenson, D. G., *Water Treatment Unit Process,* Imperial College Press (1997).
[4] Edzwald, J. K., Ives, K. J., Janssens, J. G., McEwen, J. B. and Wiesner, M. R., *Treatment Process Selection for Particle Removal,* Chap. 5, AWWRF/IWSA, N.Y., U.S.A. (1999).
[5] Gregory, R., Head, R. and Graham, N. J. D., "Blanket Solids Concentration in Floc Blanket Clarifiers," *Proc. Gothenburg Symp.,* Edinburgh (1996).
[6] Head, R., Hart, J. and Graham, N. J. D., "Simulating the Effect of Blanket Characteristics on the Floc Blanket Clarification Process," *Water Sci. Tech.,* Vol. 36, pp. 77–82 (1997).
[7] AWWA/ASCE, *Water Treatment Plant Design,* Chap. 7, McGraw-Hill, N.Y., U.S.A. (1990).
[8] Li, G. and Gregory, J., "Flocculation and Sedimentation of High-Turbidity Waters," *Water Res.,* Vol. 25, pp. 1137–1143 (1991).
[9] Cotton, A. P., Elis, K. V. and Khowaja, M. A., "Some Options for Water Treatment in Disaster Situations," *J. Water SRT-Aqua,* Vol. 43, pp. 303–310 (1994).
[10] Heinzmann, B., "Coagulation and Flocculation of Stormwaer from a Separate Seer System-A New Possibility for Enhanced Treatment," *Water Sci. Technol.,* Vol. 29, pp. 267–278 (1994).
[11] Zhu, H., Smith, D. W., Zhou, H. and Stanley, S. J., "Improving Removal of Turbidity Causing Materials by Using Polymers as Filter Aid," *Water Res.,* Vol. 30, pp. 103–114 (1996).
[12] Janssens, J. G. and Buekens, A., "Assessment of Process Selection for Particle Removal in Surface Water Treatment," *J. Water SRT-Aqua,* Vol. 42, pp. 279–288 (1993).
[13] Chen, L. C., Sung, S. S., Lin, W. W., Lee, D. J., Huang, C., Juang, R. S. and Chang, H. L., "Observations of Blanket Characteristics in Full-Scale Floc Blanket Clarifiers," *Proc. IWA Conf. Asian Environmental Technologies (AET 2001),* (2001).

Manuscript Received: May. 1, 2006
Accepted: Jun. 7, 2006