Numerical simulation and field test of double-storey sedimentation tank in potable water treatment

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Abstract. A method combining CFD and field test is applied to study the influence of geometric parameters of double-storey sedimentation tank on hydraulic characteristics. The results show that the flow field of the sedimentation tank is close to the clear water sedimentation tank and the effect of particles on water flow is relatively small. Longer width, longer length, upper and lower stories with comparable depths, and longer sumps are beneficial for reducing the particle concentration at the outlet. The velocity of the bottom is small and the velocity of the upper storey is large. The floc particles in the front section are larger and the sedimentation speed is larger, and the flocs in the rear section are opposite.

1. Introduction
In order to remove low-temperature and turbid raw water, the horizontal flow rate will be reduced and the hydraulic retention time will be prolonged for the advection sedimentation tank. Thus, the floor area will be larger. For saving land, two or even three-storey advection sedimentation tanks have been used in many projects. The design parameters of the sedimentation tank are important factors affecting the sedimentation efficiency. The current researches mostly focus on the secondary sedimentation tank and single-storey advection sedimentation tank [1-3]. There are also laboratory tests [4-6].

Double-storey advection sedimentation tank is a multi-storey sedimentation tank developed based on the theory of shallow ponds [7]. It was first used in the United States in 1993. But there are few research results on the geometric dimensions, the flow distribution of the upper and lower stories, the sediment suspension of the upper and lower stories, and the removal rate of suspended matter. Therefore, it is necessary to numerically simulate the solid-liquid two-phase flow in the two-storey sedimentation tank, evaluate the precipitation effect of the sedimentation tank, and optimize the key parameters affecting the precipitation effect.

2. Experiment method
2.1. Grid model
The front section of the double-storey advection sedimentation tank is divided into upper and lower stories, and the rear section discharges water through three water collecting tanks. Because the width direction of the sedimentation tank is symmetrical and the flow is uniform in the plane direction, the velocity component in the plane direction is relatively small, and the suspended particle distribution is roughly equivalent.
2.2. Multiphase flow model
Due to the relatively low concentration of particles in the sedimentation tank and the lack of clear interphase forces, the Euler two-phase flow model not only has a large amount of calculation, but also has difficulty in achieving the ideal accuracy. After trial calculations of different multiphase flow models, the solid-liquid two-phase flow model is finally determined to adopt a mixture model.

2.3. Boundary conditions
The import is the flow boundary conditions 0.28935 m³/s. The outlet finger weir is a horizontal outlet in a two-dimensional model, so the pressure outlet boundary is used. Free water surface is symmetrical boundary. According to the standard k-epsilon turbulence model, the wall boundary is a standard wall function.

2.4. Flocculation
Ignoring the flocculation process in the sedimentation and setting parameters such as the particle density and diameter of the suspended solids, the settlement and removal effects of the suspended solids in the sedimentation tank are analyzed. The inlet of the sedimentation tank is based on a particle concentration of 10 mg/L, initial concentration 2 mg/L, a density of 1050 kg/m³, and a particle size of 150 μm.

2.5. Scheme
The effluent concentration was used as an indicator to evaluate the sedimentation effect of the sedimentation tank under different geometric sizes, Table 1.

| Sedimentation length(m) | Sedimentation width(m) | Sump length(m) | Upper and lower proportion |
|------------------------|------------------------|----------------|---------------------------|
| 1                      | 55.3                   | 5              | 15.2                      | 2.95:3                    |
| 2                      | 55.3                   | 4              | 10.2                      | 2.08:3.87                |
| 3                      | 55.3                   | 6              | 17.7                      | 3.57:2.38                |
| 4                      | 47.3                   | 5              | 10.2                      | 3.57:2.38                |
| 5                      | 47.3                   | 4              | 17.7                      | 2.95:3                    |
| 6                      | 47.3                   | 6              | 15.2                      | 2.08:3.87                |
| 7                      | 63.3                   | 5              | 17.7                      | 2.08:3.87                |
| 8                      | 63.3                   | 4              | 15.2                      | 3.57:2.38                |
| 9                      | 63.3                   | 6              | 10.2                      | 2.95:3                    |

3. Results and discussion

3.1. Flow field simulation
Due to the low particle concentration, the effect of particles on the water flow was relatively small, and the flow field of the sedimentation tank was close to the clear water sedimentation tank, Figure 1. The suspended particles in the different schemes had the same phase, and the water flow in the sedimentation tank was similar. Only the different shapes cause different flow patterns. The other flow fields were not given here.
3.2. Concentration field simulation

As shown as the particle concentration distribution of T=2h in each scheme, the length of the sedimentation tank, the width of the sedimentation tank, the length of the sump, and the proportion of the upper and lower stories had a significant effect on the sedimentation effect, Table 2.

Table 2. Outlet concentration of sedimentation tank

| Length (m) | Width (m) | Sump length (m) | Proportion | Import (mg/L) | Initial (mg/L) | Outlet (mg/L) |
|-----------|-----------|-----------------|------------|---------------|---------------|---------------|
| 1         | 55.3      | 5               | 15.2       | 2.95:3        | 10            | 2             | 0.305         |
| 2         | 55.3      | 4               | 10.2       | 2.08:3.87     | 10            | 2             | 2.693         |
| 3         | 55.3      | 6               | 17.7       | 3.57:2.38     | 10            | 2             | 0.407         |
| 4         | 47.3      | 5               | 10.2       | 3.57:2.38     | 10            | 2             | 0.991         |
| 5         | 47.3      | 4               | 17.7       | 2.95:3        | 10            | 2             | 2.631         |
| 6         | 47.3      | 6               | 15.2       | 2.08:3.87     | 10            | 2             | 0.476         |
| 7         | 63.3      | 5               | 17.7       | 2.08:3.87     | 10            | 2             | 0.231         |
| 8         | 63.3      | 4               | 15.2       | 3.57:2.38     | 10            | 2             | 2.293         |
| 9         | 63.3      | 6               | 10.2       | 2.95:3        | 10            | 2             | 0.007         |

Among the influencing factors of the sedimentation tank, the width of the sedimentation tank had a significant effect on the particle concentration at the outlet. When the width of the sedimentation tank was 4m, the particle concentration at the outlet increases significantly, and the particle removal rate was relatively low. When the length of the sedimentation tank was long, the particle concentration at the outlet was relatively small. When the proportion of the upper and lower stories of the sedimentation tank was equal, it was beneficial to reduce the particle concentration at the outlet. When the length of the water collecting tank was long, it was beneficial to the particle concentration at the outlet.

3.3. Flow field test

According to the layout characteristics of the sedimentation tank and field test conditions, the middle section of upper storey was measured in the flow field test. Sedimentation tank flow rate was measured with ADV three-dimensional flow meter. The flow velocity Vx and Vy in the plane direction of the sedimentation tank were synthesized, Figure 2. Both the field test results and the calculation results had the same tendency that the flow velocity at the bottom was small and the flow velocity at the upper storey was large. The magnitudes of the speeds were equivalent, both between 0 and 15 mm/s. In the field test, affected by the two mud pumps at the inlet of the sedimentation tank, the velocity values between 1m and 1.5m were small, which was quite different from the results under the uniform inflow in the calculation.

Affected by the inlet boundary of the sedimentation tank and two mud pumps, the velocity field was not uniform in the width direction. After the water flow had diffused for a period of time, the velocity distribution in the width direction of the sedimentation tank was gradually uniform. As a result, the area of the velocity envelope in the test data varied.

3.4. Concentration field test

In the field test, five typical measuring points in the sedimentation tank were sampled, and the floc characteristics in the sedimentation tank were measured, including floc particle distribution, floc strength, and floc sedimentation speed, Table 3. The sedimentation velocity of the floc in the front
section of the sedimentation tank was large, and the sedimentation velocity of the floc in the rear section was small. The floc particles in the front section were larger and the floc particles in the rear section were smaller. The middle finger has a particle size between 1220 and 1380 μm, which indicates that the floc structure is significantly larger than the suspended particles, and the flocculation effect is obvious.

Table 3. Outlet concentration of sedimentation tank

| Mid depth of         | D₁₀(μm) | D₅₀(μm) | D₉₀(μm) | Floc strength | Flocculation velocity(mm) |
|---------------------|---------|---------|---------|--------------|---------------------------|
| Mid depth of upper entrance | 1075.4  | 1379.1  | 1692.4  | 1.771         | 0.98                      |
| Mid depth of upper middle | 61.1    | 1308.3  | 1695.8  | 1.737         | 0.55                      |
| Mid depth of upper exit | 27.7    | 1227.4  | 1626.3  | 1.807         | 0.23                      |
| Mid depth of lower entrance | 898.9   | 1338.4  | 1792.9  | 1.723         | 0.93                      |
| Mid depth of lower exit | 46.0    | 1254.7  | 1622.4  | 1.815         | 0.25                      |

From the inlet to the outlet of the sedimentation tank, the particle concentration gradually decreased, and the particle sedimentation effect was obvious. The particle concentration at the outlet of the sedimentation tank was relatively low. With the passage of time, the particle concentration at the rear of the sedimentation tank would increase slowly after a period of time which was mainly caused by the mud hopper at the bottom of the lower part of the rear part of the sedimentation tank and the disturbance of high-concentration suspended particles.

4. Conclusions
The recommended solution was that the total length of the sedimentation tank was 55.30m, the water depth was 6.30m, the width of each cell was 5.00m, the water depth of the upper storey was 2.95m, and the water depth of the lower storey was 3.00m. Under low turbidity raw water, the particle concentration of the sedimentation tank decreased significantly.

Acknowledgments
The authors would like to acknowledge the financial support by the key Special Program on the S&T for the Pollution Control and Treatment of Water Bodies (No.2017ZX07501001-05).

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