A CFD-based simulation study of a double-storey sedimentation tank for drinking water treatment

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Abstract. CFD is applied to study the effects of geometric factors and particle concentration of double-storey advection sedimentation tank on hydraulic state and particle removal for low turbidity raw water. The results show that the width has a great influence on the particle concentration at the outlet. When the width is 5m, the effluent turbidity can basically meet the design. The impact of hydraulic load on the weir about 3L/s/m on the particle concentration at the outlet is small. When the water depth is shallow, the particle concentration at the outlet increases significantly.

1. Introduction

The advection sedimentation tank, as the main structure of the conventional water treatment plant of the drinking water treatment plant, has excellent treatment effect [1-2], but covers a large area. In recent years, thanks to the bottom scraper, potable water plants have begun to use double-storey sedimentation tanks based on shallow pond theory in North China to treat low temperature and low turbidity water.

For many years, the research on sedimentation tanks has focused on the numerical simulation and laboratory test of secondary sedimentation tanks and advection sedimentation tanks [3-5]. The research on the multi-storey advection sedimentation tank only is about the form of catchment [6]. At present, in-depth research on double advection sedimentation tanks is little.

In order to optimize the design scheme, the numerical simulation of a double-storey advection sedimentation tank used by a drinking water plant in Northwest China reveals the influence of geometric factors on hydraulic conditions and particle removal effects, and optimizes the design scheme.

2. CFD method

2.1. CFD

The standard κ-ε turbulence model was used to simulate the advection secondary sedimentation tank [7], and the velocity distribution and the sludge particle mass concentration distribution were analysed. The calculation uses an unsteady solid-liquid two-phase flow mixture model with a time step of 5s and a total time of 4h. The velocity field and concentration field of the two-dimensional model are in good agreement with the three-dimensional model, so the two-dimensional model is used to speed up the simulation. The software is Fluent.

2.2. Suspended particles

The density of suspended particles is 1050kg/m³, the particle size is 150μm, and the inlet concentration is 10mg/L.
2.3. Sedimentation tank
The inlet flow is 100,000 m³/d. The length of the double-storey advection sedimentation tank is 55.3m, the upper water level is 2.95m, and the lower water depth is 3m.

3. Results and discussion

3.1. Clear water
In order to analyse the flow pattern of the sedimentation tank and study the effect of the solid-liquid two-phase flow on the flow, the numerical calculation in the state of clear water is performed.

![Figure 1. Flow pattern of clear water](image)

The flow pattern of the upper and lower layers is more uniform, and the overall flow pattern is good. There is a stagnant area in the exit section affected by the outflow conditions. The flow ratio of the upper and lower storeys is 0.91, which is mainly due to the small differences in the different areas and the impact of the exit boundary.

3.2. Width
The widths of the sedimentation tanks of Scheme 1, Scheme 2 and Scheme 3 are 5m, 4m and 6m, respectively. The velocity field of each scheme is relatively uniform, and the flow ratio of each scheme is basically the same.

![Figure 2. Flow field evolution of scheme 1](image)

![Figure 3. Concentration field in scheme 1](image)

![Figure 4. Concentration field in scheme 2](image)

When the width of the sedimentation tank is reduced, the flow velocity in the tank increases, and the particle concentration at the outlet increases. When the width of the sedimentation tank is increased, the flow velocity in the tank is reduced, and the particle concentration at the outlet is reduced, and the precipitation effect is enhanced. But increasing the width of the sedimentation tank increases the cost of the project. When the width of the sedimentation tank is 5m, the particle concentration at the outlet is relatively low, which can basically meet the design requirements.
At T = 4h, the outlet particle concentrations of scheme 2 and scheme 3 were 13.4 mg/L and 0.9 mg/L, respectively.

Table 1. Outlet concentration of sedimentation tank

| Width (m) | Import concentration (mg/L) | T=0 concentration in the tank (mg/L) | T=4h outlet concentration (mg/L) |
|----------|-----------------------------|-------------------------------------|---------------------------------|
| 1        | 5                           | 100                                 | 10                              | 5.7                             |
| 2        | 4                           | 100                                 | 10                              | 13.4                            |
| 3        | 6                           | 100                                 | 10                              | 0.9                             |

3.3. Sump length

The lengths of the sump of schemes 1, 4 and 5 are 15.2m, 10.2m and 20.2m respectively. The flow velocity field of each scheme is relatively uniform, the water flow is straight, the flow velocity is small, and the flow rate of the upper storey and the lower storey is basically the same. When T=4h, the flow ratios of the upper and lower layers of scheme 4 and scheme 5 are 0.70 and 0.69 respectively.

The hydraulic load on the catchment weir is changed with the length change of the catchment weir. The length of the total weir is according to the three finger weirs.

Table 2. Hydraulic load of sump

| Sump length (m) | Weir total length (mg) | Hydraulic load (L/s/m) |
|-----------------|------------------------|------------------------|
| 1               | 15.2                   | 91.2                   | 3.17                   |
| 4               | 10.2                   | 61.2                   | 4.73                   |
| 5               | 20.2                   | 121.2                  | 2.39                   |

At T=4h, the particle concentration at the outlet of scheme 4 is 8.79 mg/L. The particle concentration at the outlet of scheme 1 is similar to that of scheme 5, which is 3.70 mg/L and 3.19 mg/L respectively. When the length of the sump is short, the hydraulic load on the weir is relatively large, which tends to cause the outlet flow rate to be too fast, the hydraulic residence time is slightly shorter, and the outlet concentration increases accordingly, which affects the precipitation effect. When the length of the sump is longer, the hydraulic load on the weir gradually decreases, and the outlet concentration decreases accordingly, but the project cost increases appropriately. Comprehensively considering the influence of the water collection tank on the sedimentation effect, the hydraulic load on the weir meets the design requirements and engineering cost, the length of the sump 15.2m has basically met the sedimentation effect.
3.4. Tank depth
The depths of the tank in scheme 1 and scheme 6 are 6.3m and 4.3m, respectively. The flow velocity distribution of the upper storey and lower storey in the two schemes are relatively uniform, the flow is straight, and the flow velocity is small. The flow ratio of the two schemes is basically the same. When \( T=4h \), the flow ratio of the upper and lower layers of scheme 6 is 0.85.

![Figure 8. Concentration field in scheme 6](image)

When the water depth is small, the particle concentration at the outlet increases significantly. When \( T=4h \), the particle concentration at the outlet of scheme 6 is 34.5mg/L. When the depth is 6.3m, the outlet particle concentration is 5.7 mg/L, and the precipitation effect is good, which can basically meet the design.

4. Conclusions
The width of the double-storey sedimentation tank has a greater effect on the particle concentration at the outlet, while the weir length has a smaller effect. In order to avoid sinking mud into the water, the depth needs to be large.

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