Study on influencing factors of hydraulic efficiency of the clearwell

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Abstract. The clearwell has the dual function of hydraulic regulation and disinfection contact. Improving hydraulic efficiency is an important measure to reduce the amount of disinfection by-products. The example of the clearwell was modeled as a whole. Then the influence of the main geometric dimensions on the hydraulic efficiency of the clearwell were studied by two-dimensional numerical simulation method, and the rationality of the design scheme was verified. The results showed that the length-width ratio had the most obvious influence on hydraulic efficiency, but the trend of t_{10}/T increasing was slowing down.The t_{10}/T value could be increased by reducing the number and width of bends and increasing the diameter of inlet pipe. The Pe under each working condition was greater than one, so the particle translation with the water flow was the main factor of mass transfer. The length-width ratio of the clearwell was 38 and the t_{10}/T was 0.54 which would meet the design requirement of not less than 0.5.

Keywords: Clearwell, CFD, t_{10}/T, length-width ratio, inlet.

1 Introduction

In all drinking water plants, the clearwell is an indispensable structure, which has the dual role of hydraulic regulation and disinfection contact. Reasonable design of clearwell is an important guarantee to ensure disinfection and reduce the amount of disinfection by-products [1]. There were obvious backflow phenomena on the back side of the diversion plate and the wall area of the clearwell, and these flow dead zones would seriously affect the disinfection efficiency [2]. Optimizing the hydraulic conditions of the clearwell could make the flow state in the clearwell as close as possible to the ideal push flow. The optimization of the inner structure could improve the hydraulic efficiency of the high clearwell [3,4]. The Surface Water Treatment Law of the United States adopts traditional CT value as a practical control parameter to predict the disinfection effect. Thus the t_{10}/T becomes an indicator to evaluate the hydraulic efficiency of a clearwell, reflecting the degree of short flow. The closer the value is to 1.0, the closer the flow state of a clearwell is to the push flow. The flow state would be better and the t_{10}/T would be higher.

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Traditionally, tracer methods have been used to determine the relationship between the hydraulic efficiency of clearwells and the internal structure of clearwells [5]. In recent years, some scholars have conducted researches using NaCl as tracers in pilot tests. However, the determination of the clearwell time distribution function by tracer tests would be time-consuming and may not be possible due to field conditions. Computational fluid dynamics (CFD) simulation could easily, accurately and intuitively obtain the distribution of water flow state and velocity in a clearwell [6]. Therefore, based on CFD, the influencing factors such as the geometric structure, length-width ratio and the number of partitions were studied to provide technical methods for the transformation, construction and design of the clearwell.

2 CFD parameter

2.1 Grid

The quadrilateral grid in map format was divided by Gambit into 35,000 to 51,000. Both the side grid spacing and the surface grid spacing were taken as 0.25m, and the minimum volume 1.56E-02 was greater than zero.

2.2 Model Parameters

In fluent simulation, the water surface of a clearwell was regarded as a plane [7], so two-dimensional CFD modeling (no depth dimension) was conducted. The inlet was set to velocity inlet and the outlet was set to pressure outlet. The RNG k-ε turbulent flow model was used for the aqueous phase, and the Euler-Lagrange dispersive phase model was used for the granular phase. One thousand particles were loaded for tracking with the Discrete Phase Model (DPM).

2.3 Influencing Factor

The actual clearwell was 50m long, 48m wide, 4m deep and the volume was 10,000m^3. The corridor was 8m wide, and the bend was 4m wide. The inlet and outlet pipes were DN1000. Structure factors such as the setting of baffle, inlet and outlet conditions, and corridor angle had a great influence on t_{10}/T [8].

3 Results and discussion

3.1 Length-width Ratio

Different number of partitions would produce different length-width ratios. The hydraulic efficiency t_{10}/T could increase with the rise of length-width ratio, as shown in Figure 1.

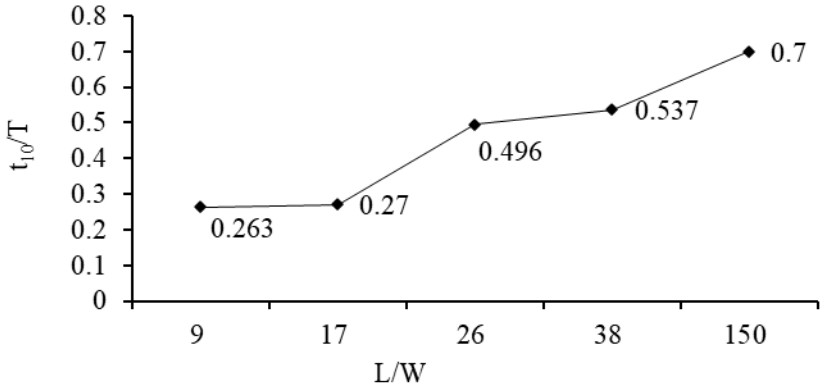

Fig. 1. Hydraulic efficiency at different length-width ratios.

As the length-width ratio increases to more than 26, the growth of hydraulic efficiency would slow down significantly, Figure 1. Measured by the t_{10}/T of 0.5, according to the simulation trend line method, the length-width ratio should be 26 or more.

The residence time of particles was affected by the actual hydraulic conditions and often deviates from the theoretical residence time [9]. With the increase of length-width ratio, the W(t) curve became steeper and the particles flowed out more and more in a short time. When the length-width ratio was 150, particles were concentrated in the 2000s to 4000s, and the time of concentrated outflow was significantly shortened, as shown in Figure 2.

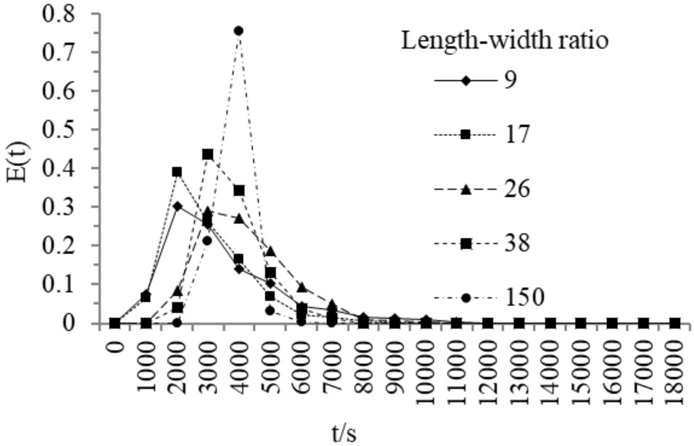

Fig. 2. Residence time distribution of different length-width ratios.

3.2 Inlet

The influence of different inlet on hydraulic efficiency was obvious because the initial velocity distribution was important. The difference of t_{10}/T between the maximum and minimum values was 0.2, as shown in Figure 3.

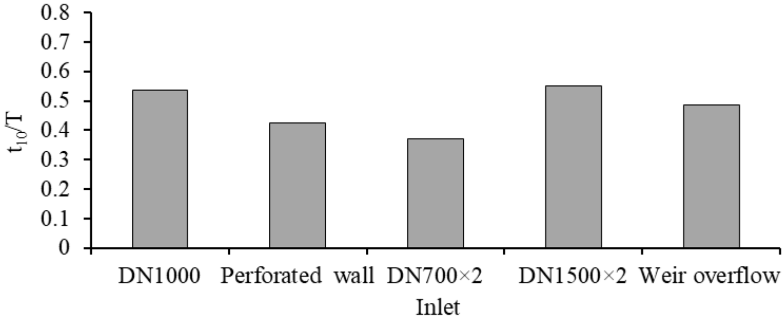

Fig. 3. Residence time distribution of different length-width ratios.

Under the single DN1000, t10/T could be more than under walls or spills. Under the DN1500, t_{10}/T was slightly better than under the DN1000 which was more economical. The hydraulic efficiency would decrease after the addition of the perforated wall, because the flow velocity through the perforated wall orifice was 0.14 m/s and the distance from the water intake was not far enough. The flow rate of two DN700 tubes was the same as that of single DN1000 tubes, but the t_{10}/T was low.

Among all working conditions, DN1500 had the longest t_{10}, as shown in Figure 4. For the single DN1000, the residence time density was concentrated.

3.3 Turning width

When the width of the bend was increased to 8 m, the number of 3000s to 4000s particles concentrated in the outflow was about 120, which slightly reduced than that in the 4m bend.

When the curve was 4m, the hydraulic efficiency was 0.537, and the t_{10}/T would decrease to 0.444 after the curve was expanded to 8 m.

3.4 Number of turns

If the clearwell plane was changed from 50 m and 48 m to 100 m and 24 m, the number of curves was reduced from 5 to 2. The number of particles increased by about 40 when the outflow was concentrated at 3000s to 4000s. As a result, hydraulic efficiency had increased. When the plane was 50 m and 48 m, the hydraulic efficiency was 0.537. The t_{10}/T would slightly increase to 0.561 after it was changed to 100 m and 24 m. The influence of the number of bends was significantly smaller than that of the length-width ratio, which indicated that the number of bends was not the most critical factor affecting the hydraulic efficiency.

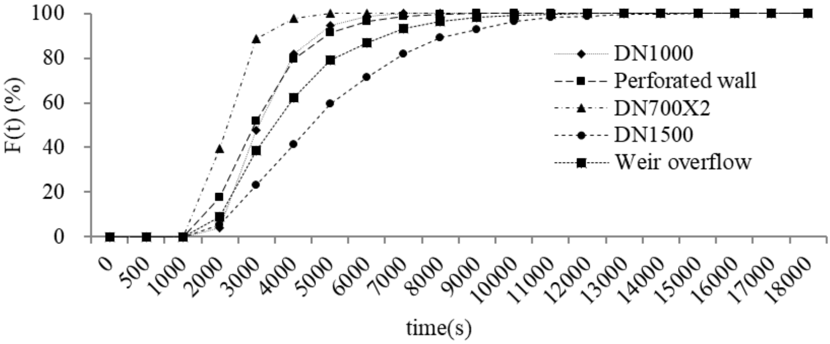

Fig. 4. Cumulative residence time distribution function under different import modes.

3.5 Hydraulic efficiency

The length-width ratio had the most obvious influence on the hydraulic efficiency, and the length-width ratio of working condition 10 was as high as 150, and the t_{10}/T also could reach the good evaluation standard 0.7. When the number of partitions was less than 3, the hydraulic efficiency was obviously less than 0.30. Changing the total plane size of the clearwell, reducing the number of turns, and increasing the diameter of the inlet pipe also had a certain effect on improving the hydraulic efficiency. Thus the hydraulic efficiency of working conditions 11 and 7 was higher than that of the design working condition 4. For the design condition 4, the t_{10}/T was higher than 0.5, and similar to the condition 11 and 7. This effect was also acceptable in the water plant project.

3.6 Mass transfer parameters

The Pe of each working condition was greater than one, so the particle translation with the water flow was the main factor of mass transfer. With the increase of length-width ratio, Pe value would increase and d would decrease, so the dispersion degree in the clearwell was weakened. The dispersion number of each working condition was much lower than 0.05, which indicated that even if the length-width ratio was less than 9, the axial dispersion degree was still low.

The length-width ratio had significant influence on MDI, volume efficiency and short circuit index. When the number of partitions increased, the volume efficiency would increase and the t_{10}/T would also increase. When the length-width ratio of working condition 10 was as high as 150, the t_{10}/T could reach 0.7. The volume efficiency was as high as 78%, and the short circuit index was about 0.6. This indicated that the working condition was close to the ideal thrust flow reactor, and the volume utilization was full.

Under the condition with fewer partition walls, the volume efficiency was lower than 0.5 and the t1/T was small. The clearwell was close to the complete mixed reactor. For example, when the number of partitions was less than 3, the hydraulic efficiency was significantly less than 0.30. Under design condition 4, t_{10}/T was higher than 0.5, and the volume efficiency was 50%. And t_1/T was 0.38. The any MDI of operating conditions 4, 6, 10 and 11 was not greater than 2. According to the standards of the EPA, the clearwell was a flat thrust flow reactor with good efficiency.

4 Conclusion

Among the main influencing factors, the length-width ratio has the most obvious influence on the hydraulic efficiency, while the width and number of bends and the water inlet mode were not the most important factors affecting t_{10}/T.

(1) The t_{10}/T increased with the increase of L/W, but the increase slowed down. The length-width ratio of the clearwell example was 38, and the t_{10}/T was 0.54, which could meet the design requirement of t10/T not less than 0.5.

(2) Reducing the number of bends and increasing the diameter of the inlet pipe could increase the t_{10}/T, but the increase amplitude and effect were not obvious.

(3) The any Pe was greater than 1.0 and the dispersion number was lower than 0.05. The length-width ratio had significant influence on MDI, volume efficiency and short circuit index.

Acknowledgments

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