The reliability evaluation of reclaimed water reused in power plant project

Jie Yang¹,*, Ru-sheng Jia¹, Yu-lan Gao¹, Wan-fen Wang¹, Peng-qiang Cao²

¹Department of Architecture and Civil Engineering, West Anhui University, Lu’an, 237012, China;
²Anhui & Huai River Institute of Hydraulic Research, Bengbu, 233000, China

*Corresponding author: E-mail: yangjie6363@163.com.

Abstract. The reuse of reclaimed water has become one of the important measures to solve the shortage of water resources in many cities. But there is no unified way to evaluate the engineering. Concerning this issue, it took Wanneng power plant project in Huai city as an example, analyzed the reliability of wastewater reuse from the aspects of quality in reclaimed water, water quality of sewage plant, the present sewage quantity in the city and forecast of reclaimed water yield, in particular, it was necessary to make a correction to the actual operation flow rate of the sewage plant. The results showed that on the context of the fluctuation of inlet water quality, the outlet water quality of sewage treatment plants is basically stable, and it can meet the requirement of circulating cooling water, but suspended solids (SS) and total hardness in boiler water exceed the limit, and some advanced treatment should be carried out. In addition, the total sewage discharge will reach 13.91×10⁴ m³/day and 14.21×10⁴ m³/day respectively in the two planning level years of the project. They are greater than the normal collection capacity of the sewage system which is 12.0×10⁴ m³/day, and the reclaimed water yield can reach 10.74×10⁴ m³/day, which is greater than the actual needed quantity 8.25×10⁴ m³/day of the power plant, so the wastewater reuse of this sewage plant are feasible and reliable to the power plant in view of engineering.

1. Introduction

In recent years, with the increasing contradiction between water supply and demand, people have paid more and more attention to the recycling of water resources, the reclaimed water is an important aspect of which has become an integral part of the water resources system in many countries around the world. For example, the amount of the water resource occupation per capita of Israel was just 476 m³, its main responses were water-saving in agriculture and reuse of reclaimed water in city, for now, the 100% of the sanitary sewage and 70% of the urban sewage had been reused; Japan had started to use the reclaimed water in 1960s, and the recovery utilization rate of the industrial wastewater kept at 78%, more than 50% of the rural areas had built wastewater treatment facilities; The United States was also one of the earliest countries in the world to adopt the reclaimed water, it had begun using the membrane bioreactor for wastewater treatment in the late 1960s, and more than 300 cities had been able to recycle treated wastewater; In the late 1990s, China had began to use the reclaimed water technology, which started late, but developed quickly, and a series of reclaimed water project [1,2] had been completed in cities such as Beijing, Tianjin, Qingdao, Taiyuan and Shenzhen, where the reclaimed water is included in the overall planning of the city. There are all indications that the reclaimed water will become the second water resources in the city.
construction projects which requires lower water quality, taking the reclaimed water as water supply sources will get good economic and environmental benefits.

For the research on the reclaimed water, there are a lot of relevant literatures at home and abroad, such as, Wang et al. [3] summarized the typical processing technique for the reclaimed water and put forward several modes, she also analyzed the wastewater reuse in technical and economic view. Chen et al. [4] analyzed the current situation of circulating cooling water of some gas thermal power plants in Beijing urban areas, and he put forward the countermeasures of reclaimed water treatment according to the characteristics of secondary treatment water quality in sewage plant. Xin [5] proposed the idea of park sprinkler irrigation planning from the perspective of experiment and application, and he also analyzed the engineering and economics of the reclaimed water reuse as the main water supply source for irrigation. Lim [6] evaluated the positive and negative effects of excessive water reuse on the environmental and economic performance of a water network system and gave some feasible suggestions. Hlavinek [7] proposed to introduce optimization techniques into the treatment facility of reclaimed water, and used the genetic algorithm to optimize the device model. The above research were analyzed from the perspective of engineering design, treatment process, model optimization and wastewater quality analysis [8-13], however, there is no unified method for evaluating the reliability of reclaimed water resources in practical engineering. This article takes a power plant construction project in Huai city as an example, and discusses the feasibility and reliability of the utilization of reclaimed water resources in water quality and water quantity.

2. Materials and methods

2.1. Study area

Huai city is a new energy industrial city dominated by coal and electricity in East China, The Wanneng Power Plant is part of construction project of city's large coal-fired power base, which plan to assemble the supercritical coal-fired unit with the capacity of 4*600 MW, the total investment is about 10 billion yuan, and the project will be implemented in two phases, the first one was completed and put into production in 2010, and the later with the capacity of 2*600MW will be completed in 2018, The maximum water requirement for the project is 8.05×10^4 m^3/d. The water for production of the project will be supplied by the reclaimed water of the municipal sewage treatment plant which mainly deals with the domestic and industrial wastewater from the urban areas, the designed capacity of Sewage treatment is 12×10^4 m^3/d, and the total length of the pipe network is 98.9km, The processing capacity of completed project is 8×10^4 m^3/d, and the late expansion project will be put into production at the end of 2018, then the capacity of sewage treatment will reach to the designed scale. Due to the guaranteed rate of water supply of power plant must reach to 97% [14], the reliability of water supply will be a key factor in the project establishment.

2.2. The evaluation of reclaimed water quality

2.2.1. The water quality of municipal sewage. The main source of sewage in Huai city is urban sewage, but some industrial wastewater, such as light and textile industry, are also accounts for a large proportion, so the pollutants in sewage are more complex, but the main contamination index are COD, BOD₅, NH₃-N, total phosphorus (TP), suspended solids (SS) and sulfide which exceeds the standard occasionally.

2.2.2. The water quality of inlets and outlets with sewage plant. According to the main pollution indicators of sewage, the sewage treatment plant uses the carrousel 2000 oxidation ditch technology which is good for removal of BOD₅, COD and NH₃-N, it can also removal of TP. In order to check the operational effect of sewage plant, in March 2015, the municipal drainage management office had been monitor the total discharge with index values A, and the environmental protection monitoring station monitored it with index values B in September of the same year (Table 1). Besides, in January
2016 to June, the monitoring station also continued to monitor the water quality in the enters and exports of sewage plants, the test results for major indexes are shown in Figures 1.

### Table 1. The monitoring results of outfall in sewage treatment plant (2015).

| Indexes                | Index values A | Index values B |
|------------------------|----------------|----------------|
| PH                     | 8.75           | 7.36           |
| SS (mg/L)              | <5             | 9.5            |
| BOD₅ (mg/L)            | 10.2           | 6.7            |
| COD (mg/L)             | 37             | 51             |
| Chlorides (mg/L)       | 136            | 129            |
| Total hardness (mg/L)  | 375            | 438            |
| Iron (mg/L)            | 0.11           | 0.23           |
| Manganese (mg/L)       | 0.07           | 0.15           |
| Turbidity (mg/L)       | 6.8            | 9.2            |
| TP (mg/L)              | 0.12           | 0.31           |
| NH₃-N (mg/L)           | 2.4            | 1.7            |
| Total alkalinity (mg/L)| 12.8           | 9.6            |

![Fig.1. Compared the influent and effluent water quality with COD, BOD₅, NH₃-N and TP (2016).](image)

Above tests showed that although the inlet water quality had some fluctuation, the outlet water quality in sewage plant was roughly stable. Even under the most polluted circumstance, the outlet water could still meet the water quality control index of recycled water used for industry and cooling according to Code for Design of Wastewater Reclamation and Reuse (GB50335-2002), and also satisfied the secondary standard according to the Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002). Based on current processes and operational parameters, when the inlet water quality of the sewage plant is stable or better than current situation, the outlets one will keep or be better than current situation too.

2.2.3. Evaluation of water quality in industry. The requirement of specific user for water quality is another important part of reclaimed water quality assessment. In the project of Wanneng Power Plant, the utilization mode and availability level of reclaimed water need to be identified further by evaluating the quality of industrial water which including boiler water and loop cooling water evaluation. The total hardness and SS are seriously exceeds the standard in the part of boiler water used which should carry out necessary treatment before it enter into the boiler. The loop cooling water basically meet the water quality requirements. In summary, reclaimed water produced by sewage
treatment plant can basically meet the water quality requirements of power plant project. The advanced treatment needs to be applied to boiler water.

2.3. The evaluation of the yield of reclaimed water

2.3.1. Current situation on wastewater production. Sewage collection system in Huai city which can be divided into eight collection areas, the total catchment area is 37.14 km², the designed volume of daily collection sewage is $18 \times 10^4$ m³/d, and the maximum wastewater yield is $22.5 \times 10^4$ m³/d, as is shown in Table 2.

| Catchment section       | Catchment area (km²) | Wastewater yield ($10^4$ m³/d) |
|-------------------------|----------------------|---------------------------------|
| Old city                | 4.55                 | 3.68                            |
| Development zone        | 2.95                 | 2.66                            |
| Xianyang pumping station| 7.47                 | 3.2                             |
| Nanhu pumping station   | 1.68                 | 0.77                            |
| Dongshan pumping station| 3.79                 | 3.20                            |
| Renwei pumping station  | 5.96                 | 2.60                            |
| Xishan pumping station  | 3.67                 | 2.30                            |
| others regions          | 7.07                 | 4.09                            |

Due to relevant sewage collection system is not perfect enough, sewage treatment capacity is lower than $6.5 \times 10^4$ m³/d now. In order to make sure the amount of wastewater in current situation, municipal hydrographic office monitored the flow in sewage plants’ inlets and outlets for 24 hours continuous from October 7 to 8 in 2016, and it also has flowmeter in the entrance of sewage plant, the relevant discharge process is shown in Figures 2.

![Fig.2. The influent and effluent flow procedure of sewage treatment plant (2016).](image)

According to the results of hydrologic survey, the loss rate of water $\alpha$ in sewage treatment plant can be calculated as follows,

$$\alpha = \frac{(Q_{w1} - Q_{w2})}{Q_{w1}}$$  \hspace{1cm} (1)

where $Q_{w1}$ is the average flow of inlet by hydrologic survey, $Q_{w1}=57381$ m³/d, $Q_{w2}$ is the average flow of outlet by hydrologic survey, $Q_{w2}=51343$ m³/d, so $\alpha=10.5\%$.

This test that the flow in outlet is about $5.7 \times 10^4$ m³/d, compared with the inlet flow of hydrologic survey, the flow rate of the sewage plant is systematic bias of $\beta$ which is the correction factor of the data recorded by the flowmeter,

$$\beta = \frac{(Q_{w3} - Q_{w1})}{Q_{w1}}$$  \hspace{1cm} (2)

where $Q_{w3}$ is the average flow of inlet by flowmeter of sewage plant, $Q_{w3}=60840$ m³/d, so $\beta=6\%$.

The sewage treatment plant is running normally from 2013 to 2015, according to the flowmeter, the monthly average sewage treatment capacity in 2015 was shown in Table 3. It can be seen that the
average amount of daily sewage, which recorded by the flowmeter is \( Q_j \), the treated wastewater quantity in sewage plant with normal condition is \( Q_n \).

\[
Q_n = Q_j (1-\beta)
\]  

(3)

where \( Q_j \) is the average quantity of daily sewage, \( Q_j = 63778 \text{ m}^3/\text{d} \); so \( Q_n = 59951 \text{ m}^3/\text{d} \).

Based on the above analysis, the reclaimed water yield \( Q_z \) in sewage plant can be obtained combined the water loss rate \( \alpha \) and \( Q_n \), it can be calculated as follows,

\[
Q_z = Q_n (1-\alpha)
\]  

(4)

where \( Q_n = 59951 \text{ m}^3/\text{d} \), so \( Q_z = 53656 \text{ m}^3/\text{d} \).

**Table 3.** The flow of water inlet in sewage treatment plant (2015).

| Month | Flow (m³/d) | Month | Flow (m³/d) |
|-------|-------------|-------|-------------|
| 1     | 60024       | 7     | 60116       |
| 2     | 68976       | 8     | 55732       |
| 3     | 80465       | 9     | 54983       |
| 4     | 78504       | 10    | 58879       |
| 5     | 73405       | 11    | 59365       |
| 6     | 58363       | 12    | 56525       |

2.3.2. *The prediction of reclaimed water yield.* Under the premise of certain designed collection capacity, the amount of sewage that can be formed within the catchment area will affect the final quantity which is pass into the sewage treatment plant, and the amount of sewage within a certain range is determined by the amount of water used. The planning years for Wanneng power plant are 2018 and 2020 in the water resources evaluation, with the total amount of the designed sewage from five sewage pumping stations in the city is \( 12\times10^4 \text{ m}^3/\text{d} \), and the prediction of water yield in study area mainly includes two parts: domestic and industrial water. In domestic water aspect: the urban population was about 350 thousand in 2015, according to The Recent Construction Plan for Huai City (2016-2020), the growth rate of population is 1.6%, Thus, the each population of urban districts is about 367 thousand and 379 thousand in 2018 and 2020. In recent years, the water supply of urban is \( 6.0 \sim 7.0\times10^4 \text{ m}^3/\text{d} \). It is predicted that the water consumption quota for 2020 will be 195 L/(cap.d), so the amount of daily drinking water will be \( 7.16\times10^4 \text{ m}^3/\text{d} \) and \( 7.39\times10^4 \text{ m}^3/\text{d} \) respectively in 2018 and 2020, as is shown in Figure3. In industrial water aspect: according to the prediction of the Water Resource Planning in Huai City (2012), the increasing rate of the industrial water is 0.7%, so the industrial water consumption in the target area will reach to \( 11.69\times10^4 \text{ m}^3/\text{d} \) in 2018 and \( 11.86 \times10^4 \text{ m}^3/\text{d} \) in 2020.

**Fig.3.** The water consumption quantity during 2005 to 2020 (the values of 2018 and 2020 are predicted)

When the water consumption can be certain, the key factor that affects the forecast of sewage quantity is the production capacity of the sewage plant [15], which is closely related to the reduction factor of wastewater. The reduction factor of the domestic water and the industrial water in the target area are \( \lambda_1 \) and \( \lambda_2 \) respectively [16]. Therefore, the amount of sewage that will be formed at different level years are \( Q_{w2018} \) and \( Q_{w2020} \).
where $Q_{s1}$ and $Q_{s2}$ are the amount of daily drinking water in 2018 and 2020, $Q_{s1} = 7.16 \times 10^4 m^3/d$, $Q_{s2} = 7.39 \times 10^4 m^3/d$, $Q_{i1}$ and $Q_{i2}$ are the amount of industrial water consumption in 2018 and 2020, $Q_{i1} = 11.69 \times 10^4 m^3/d$, $Q_{i2} = 11.86 \times 10^4 m^3/d$, $\lambda_1$ and $\lambda_2$ are the reduction factor of the domestic water and the industrial water, $\lambda_1 = 0.8$, $\lambda_2 = 0.7$, so $Q_{w2018} = 13.91 \times 10^4 m^3/d$, $Q_{w2020} = 14.21 \times 10^4 m^3/d$.

According to above calculation, the total sewage in the area will be $13.91 \times 10^4 m^3/d$ in 2018 and $14.21 \times 10^4 m^3/d$ in 2020, which are greater than the normal collection capacity of $12 \times 10^4 m^3/d$ in the sewage system, as a result, the wastewater that enters into the sewage plant is measured by the maximum daily treatment capacity of $12 \times 10^4 m^3/d$, so the amount of reclaimed water that can be produced by sewage treatment plants in 2018 and 2020 is $Q_{z1}$:

$$Q_{z1} = Q_{w0} \times (1-\alpha)$$

where $Q_{w0}$ is the maximum of daily treatment capacity, $Q_{w0} = 12 \times 10^4 m^3/d$, so $Q_{z1} = 10.74 \times 10^4 m^3/d$.

There are three parts of the production water supply for the power plant project: chemistry supplement water which is main for boiler supplement, water supply for circulating cooling and the other industry water. This project only perform advanced treatment to chemistry supplement water whose loss rate is $\varepsilon$, So the required reclaimed water quantity is $Q_{z2}$:

$$Q_{z2} = Q_{1} + Q_{2} / (1-\varepsilon) + Q_{3}$$

where $Q_{1}$ is water supply for circulating cooling, $Q_{1} = 6.5 \times 10^4 m^3/d$, $Q_{2}$ is water for boiler supplement, $Q_{2} = 0.6 \times 10^4 m^3/d$, $Q_{3}$ is the other water used for industry, $Q_{3} = 0.95 \times 10^4 m^3/d$, $\varepsilon$ is loss rate of advanced treatment, $\varepsilon = 25\%$, so $Q_{z2} = 8.25 \times 10^4 m^3/d$.

3. Discussion and Conclusions

The reclaimed water is an important aspect of the recycling of urban wastewater which is a major measure to realize the sustainable development of urban water resources. This article combines with Wanneng power plant project, tries to evaluate the reliability of reclaimed water resource in Huai city, and one can draw a conclusion as following:

(1) Though the inlet water quality of sewage plant fluctuates sometimes, the outlet one is basically stable, it can meet the demands of circulating cooling water. In this process, SS and total hardness in boiler water exceed standards, so the corresponding depth treatment process is needed. In a word, the reclaimed water in sewage treatment plant shall meet the water quality requirements for the project.

(2) In the two planning level years of the project, the total sewage discharge will reach $13.91 \times 10^4 m^3/d$ and $14.21 \times 10^4 m^3/d$ respectively, which are greater than the normal collection capacity of $12 \times 10^4 m^3/d$ in sewage system, and the yield of reclaimed water can reach $10.74 \times 10^4 m^3/d$, it is greater than the actual needed quantity $8.25 \times 10^4 m^3/d$ of the power plant, meanwhile, the water consumption of industrial water is stable, therefore, it is reliable to use reclaimed water as a source of water.

(3) The key factors that affects the reclaimed water quality are the composition of urban sewage and the treatment process of sewage plant and so on. The main factors that affect the amount of reclaimed water are the scale of urban water, the form users in certain area, the water collection capacity of the sewage pipe network, and the wastewater conversion rate which is from the sewage to reclaimed water.

(4) According to the relevant provisions of the Water Resource Evaluation Guide (SL/T238-1999), it is necessary to check the water quantity of sewage treatment plant. In the paper, the inlet flow rate of the sewage plant is reviewed by the hydrological department based on the actual data, and the flow rate of the sewage plant is systematic bias of $\beta$ which is $6\%$, this check is of great importance in the exact prediction of the amount of sewage in the planning level years, and it also affects the evaluation of reclaimed water yield.
Acknowledgments
This work was partly supported by the key project of Natural Science Foundation of Anhui (Grant No. KJ2017A409) and Natural Science Foundation of West Anhui University (Grant No. WXZR201618).

References
[1] Paul P, Peter J D, Karen E B, et al. (2007). Water quality effects on clogging rates during reclaimed water ASR in a carbonate aquifer. Journal of Hydrology, 334,1-16.
[2] Zhang Q, Meng De J. (2007). The analysis and assessment of processes for treating reclaimed water in China. Environmental Engineering, (1),37-39.
[3] Wang X Q, Wang Q S, Li J H, et al. (2006). Technological and economic analyses of different reclaimed water reuse. China Water & Wastewater, 22(16), 73-76.
[4] Chen Z L, Zhang H T, He B, et al. (2016). Research on status and countermeasures of reclaimed water reused for circulating cooling system of gas thermal power plants in Beijing. Water & Wastewater Engineering, 42(9), 64-67.
[5] Xin H Y, Wang C P, Cai K X. (2008). Discussion on application of reclaimed water in park lawn sprinkler irrigation system. Water & Wastewater Engineering, 24(10), 75-77.
[6] Lim S R, Park J M. (2011). Positive and negative effects of excessive water reuse to be considered in water network synthesis. Korean J. Chem. Eng, 28(2), 511-518.
[7] Hlavinek P, Kubik J. (2007). Optimization of treatment train for water reuse schemes in the Czech Republic. Wastewater Reuse-Risk Assessment, Decision-Making and Environmental Security, 103-108.
[8] Ma Y X, Liu Z N, Zhang W. (2009). Application prospect of biological aerated filter in water reuse. Safety and Environmental Engineering, 16(3), 50-53.
[9] Yin Q Q, Wang L, Jiao Y Y, et al. (2008). The concept and method of health risk assessment for urban wastewater reuse. Journal of Shandong Jian Zhu University, 23(2), 141-144.
[10] Yu Z H, Xu Y P, Zhang Y, et al. (2014). Assessment of urban river health based on entropy weight and matter element model: a case study in Huzhou City at different stages of urbanization. Acta Scientiae Circumstantiae, 34(12), 3188-3193.
[11] Yu Y L, Song X F, Zhang H Y, et al. (2014). Water quality of reclaimed water from treated urban wastewater in Chaobai River Basin, North China. Chinese Journal of Population Resources and Environment, 12(2),103-109.
[12] Barringer J. (2014). Urban domestic and commercial water reuse in Pune and its influence on the present water crisis. Water Qual Expo Health, 6, 35-38.
[13] Guo M T, Hang J J, Hu H Y, et al. (2011). Growth and repair potential of three species of bacteria in reclaimed wastewater after UV disinfection. Biomed Environ Sci, 24(4), 400-407.
[14] National Development and Reform Commission. (2006). DL/T 5339-2006, Code for hydraulic design of fossil fuel power plants. Beijing: China Electric Power Press.
[15] Hernández F, Urkiaga A, et al. (2006). Feasibility studies for water reuse projects: an economical approach. Desalination, 187,253-261.
[16] Ministry of Construction. (2006). GB50013-2006, Code for design of outdoor water supply engineering. Beijing: China Planning Press.