Economic Analysis of Wastewater Treatment Plant in Xi'an Siyuan University

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Abstract: To facilitate the transformation of long-term operational experience into application, and guarantee this MBR technology reaching market, an economic analysis of 4000 m³/day A^2/O-MBR wastewater treatment plant in Xi'an Siyuan University has been conducted. The wastewater treatment and reuse system in Xi'an Siyuan University includes campus' wastewater collection, treatment into reclaimed water in line with national recycling standards, and reuse. The capital cost of the system is 22.3813-million-yuan RMB, the unit capital investment is 5595.33-yuanRMB/m³/day. According to the relevant 10 years data analysis of Xi'an Siyuan University, the first to fifth years, including all depreciations and amortization, the unit reuse water cost is 3.29 to 3.75-yuan RMB/m³. The sixth to tenth year, including three depreciations of main project, equipment, and reuse pipe-pump system, the unit reuse water cost is 2.58~3.00-yuan RMB/m³. So far, 6.7 million m^3 of campus' wastewater and raining has been treated, and 4.4 million m^3 of reclaimed water has been produced and reused. For a sustainable transition in MBR wastewater treatment at several thousand cubic meter per day scale, the reclaimed capacity and reusing destination, as well as membrane's longevity must be given special attention.

Keywords: Wastewater treatment; Reclaimed water reuse; Capital cost; Operation costs; Economic benefits.

I. INTRODUCTION

Comparing with carbon emissions exchanges, the environment and green development in China are facing two practical problems: insufficient infrastructure funds and resource investment and insufficient sewage treatment deep processing capacity in urban wastewater [1, 2]. A total of 2,162 key companies in the power generation industry were included in the first batch of carbon emissions exchanges, covering about 4.5 billion tons of carbon dioxide emissions. At the end of the first day of trading (July 16, 2021), the trading volume reached 4.104 million tons, and the turnover exceeded 210-million-yuan RMB [3-5]. There are many reasons for the gap between water conservation and carbon reduction, and the authors of this article believe that because of the "unclear accounting", wastewater treatment and reclaimed water reuse have not yet entered the market operation in the true sense. According to the primary treatment of wastewater, the upfront investment and operating costs can be accepted, but its water quality cannot meet the increasingly demanding requirements and cannot meet the reuse standards. According to the calculation of advanced wastewater treatment (such as A^2/O-MBR membrane bioreactor), the upfront capital cost and operating costs are very high [6-12]. This paper uses the economic analysis of the wastewater treatment and reclaimed water reuse system of Xi'an Siyuan University as an example to illustrate the A^2/O-MBR long-term stable operation, and the effluent water quality has reached the "Urban Sewage Recycling Landscape Environment Water Quality Standard" (GB/T 18921-2002). It is then further explained that the cost per unit of water production, without calculating taxes and return on investment, considers operating expenses, management fees, and all depreciation costs. The most fundamental purpose is to promote the vigorous participation and investment of government finance, social funds, and public resources, and to achieve the market-oriented operation of multi-channel, multi-subject, and multi-mode urban sewage treatment infrastructure construction.

In 2000, when Xi'an Siyuan University moved from Xi'an City to Bailuyuan, the board of directors have used limited self-owned funds to build a campus wastewater treatment station, including to construct a 4000 m³/day

A^2/O-MBR wastewater treatment plant and its pretreatment system, to lay a dedicated collecting and reusing pipe network and the pump to collect all the water and then reuse. Over the years, we have continuously increased our investment. The school has 5 large and small reclaimed water reservoirs, including a 3500 cubic meter artificial lake, 12 pumps of various types, and 25 kilometers of reclaimed water special pipelines. The reclaimed water is transported back to the campus by lift pump pressurization, which is used to flush more than 1,000 toilets in 32 buildings, to water 480,000 square meters of green land, and to clean all hard concreate pavement inside of campus. Xi'an Siyuan University A^2/O-MBR has been operating for 10 years and has processed 6.7 million m^3 wastewater, output 4.4 million m^3 in line with the national standard reclaimed water and all reused. The complete economic analysis, from capital cost to operation cost, of wastewater treatment plant is carried out in this paper.

II. CAPITAL COST

The A^2/O-MBR wastewater treatment plant (simplified as plant from now on) of Xi'an Siyuan University is based on intensive secondary biological treatment technology (anaerobic, anoxic, aerobic) aggregate membrane bioreactor with a focus on phosphorus and nitrogen removal. The biggest advantage of MBR membrane bioreactor is that the effluent water quality is stable and always meets the national water quality standards. The project construction investment includes three parts: the construction cost of the plant, the reclaimed water reuse pipe-pump network of the plant, and the amortization cost.

TABLE 1: Construction cost of the plant

Item	Total price (million yuan)	Depreciation period
C_1	5.88	20
C_2	7.9882	10
C_3	0.48	10
C_4	3.6118	5

Where:

C_1: Concreate construction cost.

C_2: Equipment procurement and installation.

C_3: Air floatation tank.

C_4: MBR membrane module.

Reaching the national standard of miscellaneous water quality for urban sewage recycling or water quality for landscape environment has certain economic value and market competitiveness. Therefore, the sewage treatment subsystem includes pretreatment, biochemical treatment, and membrane bioreactors to ensure that the reclaimed water meets the reuse standard.

B. Capital costs of reuse network

The reclaimed water reuse subsystem in Xi'an Siyuan University consists of 25 km of recycled water pipes, 12 various types of regenerative water pumps and all necessary valves and regulators. The capital cost of the reclaimed water pipe-pump network is calculated according to the equation (1) [14].

$$C_5 = 16.72Q^{0.78}L \quad (1)$$

here,

C_5 is the engineering fee of the reclaimed water pipe-pump network, 0.01-million-yuan RMB.

Q is the reclaimed water reuse water flow, 10,000 m^3/day, according to the scale of reclaimed water reuse of Xi'an Siyuan University 4000m^3/day takes 0.4.

A. Construction costs of plants

The construction cost of the plant is divided into MBR membrane module fee, the main civil engineering (regulation pool, air flotation tank, anaerobic pool, anoxia pool, aerobic pool, membrane pool) construction costs, equipment procurement and installation costs. Classification is based on the depreciation period of different fixed assets in commonly used engineering economies [13], rather than using the basic comprehensive depreciation rate of fixed assets [14]. The specific construction costs are shown in Table 1.

L is the length of the water transmission network, km, according to the length of the reclaimed water reuse supply pipe network of Xi'an Siyuan University, take 25.

Substitute the above data into equation (1) to get C_5 as 2.0454 million yuan. The depreciation period of the reclaimed water pipe network is 20 years [13], which is 0.1023-million- yuan RMB per year.

C. Amortization Expenses

Unlike the A^2/O-MBR wastewater treatment plant in other references, Xi'an Siyuan University also has 15 items that are spent for the construction of the plant but cannot be clearly classified as the three items that have been described, which are recorded as amortization costs. All amortization expenses totaled 2.3759-million-yuan RMB. Although the amortization cost is as many as 15 items, only 5 items account for more than 5%, namely: A_1, outdoor greening fee (1 million, 42.09%); A_2, power expansion fee (0.5 million, 21.04%); A_3, engineering design fee (0.28 million, 11.79%); A_4, environmental supervision fees (0.2 million, 8.42%); and A_5, construction supervision fees (0.13 million, 5.47%）. The remaining 10 items were for A_6, other costs, accounting for 11.28 %. Figure 1 is a pie chart representing the proportion of these items.

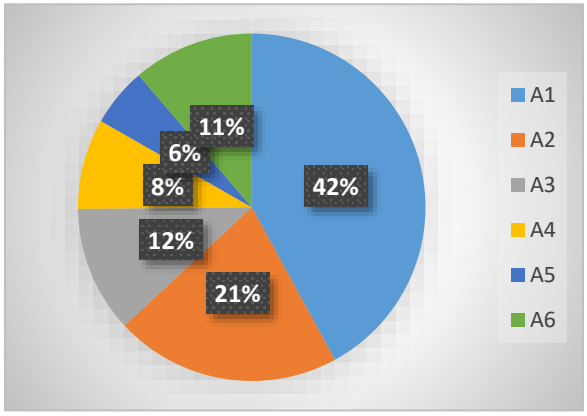

Figure 1: Schematic representation of the amortization expenses.

Amortization expense C_6 was 2.3759-million-yuan RMB. According to the usual engineering economic practice, the amortization period is 5 years [13], and the annual amortization cost is 0. 4752-million-yuan RMB. At the time of calculation, the amortization expense is also included in the depreciation expense. This was the amortization cost invested by Xi'an Siyuan University at that time.

D. Accounts

The sum of the above discussed items is obtained from the capital cost of the plant in Xi'an Siyuan University.

$$\text{Capital cost} = C_1+C_2+C_3+C_4+C_5+C_6 \quad (2)$$

$$5.88+7.9882+0.48+3.6118+2.0454+2.3759 = 22.3813\text{-million-yuan RMB.} \quad (3)$$

Xi'an Siyuan University invested a total of 22.3813 million yuan to build a complete system for the reuse of reclaimed water for A^2/O-MBR sewage treatment, including air flotation tanks. Then the plant production is 4000m³ / day, the capital investment of Xi'an Siyuan University is 5595.33-yuan RMB/m³/day. This capital investment is higher than the range of 2000–5000-yuan RMB/m³/day as stated in the original other literature. There are three reasons for the high investment cost of Xi'an Siyuan University:

(1) The 4000m³/day treatment capacity is small.

(2) In the early treatment, the air flotation pool is added; and

(3) The investment cost includes the construction cost and amortization cost of the reclaimed water reuse subsystem.

III. OPERATION COSTS

In the process of operation, fixed assets inevitably occur tangible wear and intangible wear, resulting in the loss of their use value. The value of this loss is transferred to the product in the form of depreciation of fixed assets, constituting the cost of the product. In general, depreciation is generally measured in time, such as the annual depreciation rate. Other consumables, such as raw materials, fuels, pharmaceuticals, etc., are related to the quantity of the product.

The plant operating costs consists of the electricity cost, the chemical cost for membrane pool cleaning and

maintenance, the flocculant cost for air flotation pool, the repair cost involved in the plant, and the labor and welfare costs. The repair cost of the pipe network, pump station and instrument outside the plant is 8-thousand-yuan RMB per km per year [14]. Therefore, the repair cost in Table 3 includes both inside the plant (separately measured accounting) and outside the plant (8-thousand-yuan RMB per km per year).

A. Annual water production rate

The industrial permeability will gradually decay with the increase of the operating years, the annual decay rate of industrial permeability is 4.24% [15-17]. The water production in the first year of the first phase of MBR was 578,500 m³. The 4000m³ of regenerated water was calculated as doubled 1.157 million m³, the annual decay rate is calculated at an annual rate of 4.24%.

B. Annual electricity and chemical costs

These costs are related to the amount of water produced. The actual measurement of electricity and chemical costs of the air flotation tank.

Each air flotation tank equipment consumes 21 kWh and operates 24 hours a day. The efficiency is 75%, the annual working day is 300, and the electricity bill is 0.50-yuan RMB/ kWh.

$$21x\frac{1}{0.75}x24x30x0.5 = 100800 - \text{yuan RMB} \quad (4)$$

Two flocculants are added to the air flotation tank. PAM polyacrylamide. 0.0143kg/h/unit. The unit price is 2400-yuan RMB/ton. PAC polyaluminum chloride. 1.429kg/h/unit. The unit price is 480-yuan RMB/ton. The annual cost of chemicals is 5,000-yuan RMB. The actual measured annual electricity and drug costs of the air flotation pool are 0.1058-million-yuan RMB.

C. Annual repair costs

This cost is related to the amount of water produced.

D. Depreciation expense

Although this cost is not related to the amount of water produced, it is related to the operating life.

From 1~5year, annual depreciation costs include the construction costs of reclaimed water plants (including membrane modules), the construction costs of reclaimed water reuse subsystems, and amortization costs. Table 2 shows the annual depreciation expense and its percentage.

TABLE 2: Annual depreciation expenses and their proportion from 1~5year

item	Annual Depreciation / million-yuan RMB	Percentage/%
B_1	0.294	12.05
B_2	0.84682	34.70
B_3	0.72236	29.60
B_4	0.47518	19.47
B_5	0.1023	4.19
Total	2.44066	100

Here:

B_1: Depreciation of the main project，million-yuan RMB/year.

B_2: Equipment depreciation，million-yuan RMB/year.

B_3: Membrane depreciation， million-yuan RMB/year.

B_4: Amortization expenses， million-yuan RMB/year.

B_5: Reclaimed water reuse pipe depreciation， million-yuan RMB/year.

An annual depreciation expense of 1~5 year is represented schematically in Figure 2.

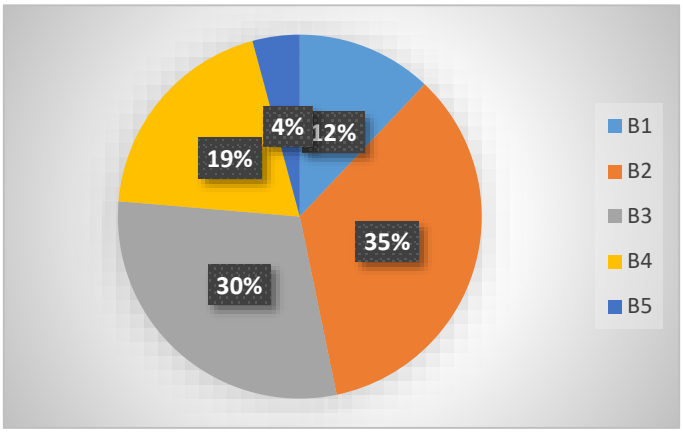

Figure 2: An annual depreciation expense of 1~5 year

If after five years, the membrane module, although attenuated, still does not need to be replaced, and can be used for another 5 years. Then from the 6-10year, because the depreciation of membrane modules and amortization costs has been fully discounted, the depreciations only include the construction cost of the reclaimed water plant (excluding the membrane module) and the construction cost of the reclaimed water reuse subsystem. Under this condition, table 3 shows depreciation expense from the sixth to tenth years and its share.

TABLE 3: Annual depreciation expenses for the 6~10year

item	Annual depreciation / million yuan	Percentage/%
B_1	0.294	23.65
B_2	0.84682	68.12
B_5	0.1023	8.23
Total	1.24312	100

An annual depreciation expense of 6~10 year is represented schematically in Figure 3.

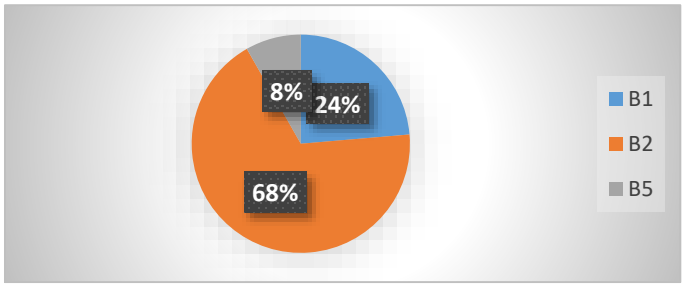

Figure 3: An annual depreciation expense of 6~10 year

The A^2/O-MBR process is a combination of secondary biochemical treatment and membrane depth treatment processes, so it has the advantage of better effluent quality than other processes (effluent can be guaranteed to meet the standard of reclaimed water reuse) and a small footprint. As can be seen from the depreciation cost comparison in Tables 2 and 3, the maximum binding condition of the MBR process is the service life of the membrane. Membrane service life is not only an economic problem, but also a technical problem, involving membrane flux design, membrane pool operating conditions, membrane pool pretreatment process, membrane cleaning and maintenance.

E. Unit water cost

Costing includes operating expenses, depreciation, management fees, taxes, and return on investment. Because it is difficult to calculate the tax and investment return on the sewage treatment and reclaimed water reuse system of the university, it is generally not included in the cost accounting. Table 4 shows the cost per unit of water production from the first to the 10th year. All additional notes are expressed in the relevant paragraphs above.

TABLE 4: Unit water production costs from the first year to the 10th year

year	D_1	D_2	D_3	D_4	Volume	Cost/yuan/m³
1	0.7454	0.4609	2.4407	0.16	1.1570	3.29
2	0.7138	0.4414	2.4407	0.16	1.1079	3.39
3	0.6822	0.4218	2.4407	0.16	1.0589	3.50
4	0.6506	0.4023	2.4407	0.16	1.0098	3.62
5	0.6190	0.3827	2.4407	0.16	0.9608	3.75
6	0.5874	0.3632	1.2431	0.16	0.9117	2.58
7	0.5558	0.3436	1.2431	0.16	0.8627	2.67
8	0.5242	0.3241	1.2431	0.16	0.8136	2.77
9	0.4926	0.3046	1.2431	0.16	0.7645	2.88
10	0.4610	0.2850	1.2431	0.16	0.7155	3.00

Were

D_1: Electricity, medicine, million-yuan RMB

D_2: Repair costs, million-yuan RMB

D_3: Depreciation expense, million-yuan RMB

D_4: Labor and welfare, million-yuan RMB

Volume: Water production, million m³

From the first to the fifth year, the unit water cost expense (including membrane depreciation period and amortization fee) excluding taxes and asset returns was 3.29 to 3.75 yuan / m³. The contributions made by each of these accounts are shown in Figure 5.

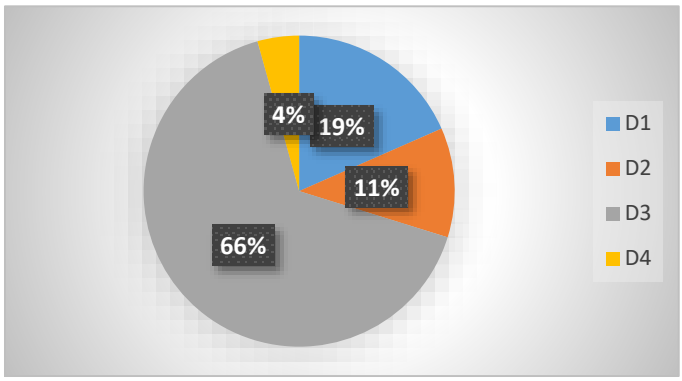

Figure 5: The proportion of each item when the unit water production cost from the first year to the fifth year is 3.29 to 3.75 yuan/m³

In the absence of membrane replacement, the unit water cost (completion of membrane depreciation period, amortization fee) from the sixth to tenth year excluding taxes and returns on assets is 2 58~3.00 yuan/m³. The contributions made by each of these proportions are shown in Figure 6.

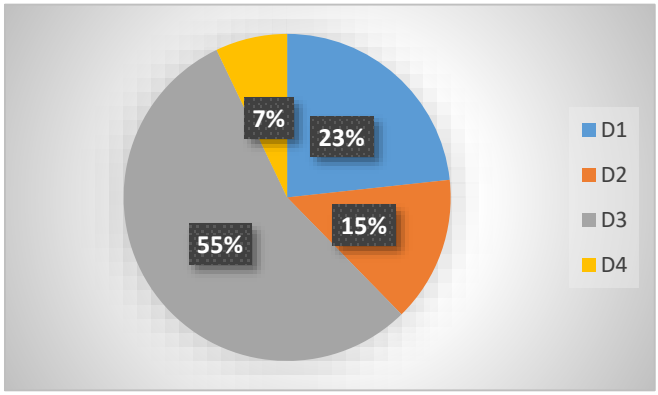

Figure 6: The proportion of each item when the unit water production cost from the sixth to tenth years is 2.58 to 3.00 yuan/m³

IV. CONCLUSIONS

The sewage treatment reclaimed water reuse project of Xi'an Siyuan University is a complete system from raw materials (sewage collection and treatment) to qualified products (reclaimed water in line with national recycling standards) to circulate into commodities (reclaimed water reuse). The project includes subsystems such as pretreatment, A^2/O-MBR sewage treatment, and reclaimed water reuse on campus. The total construction cost was 22.3813 million yuan. The unit investment fee is 5595.33 yuan / m³ / day.

According to the relevant data analysis of Xi'an Siyuan College for 10 years A^2/O-MBR, the first to fifth years include the film depreciation period and the amortization fee The unit reuse water cost is 3.29~3.75 yuan/m³. In the absence of membrane replacement, the sixth to tenth year of depreciation of membrane depreciation and amortization expense is completed, and the unit recycled water cost is 2.58~3.00 yuan/m³.

So far, 6.7 million m^3 of sewage has been treated, and 4.4 million m^3 of recycled water in line with national standards has been produced and all recycled.

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