Comparative Research to Surface Aeration and Blasting Aeration System Based on LCC Theory

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Abstract. It is difficult to select the suitable aeration system for the designers of wastewater treatment plant (WWTP). In this paper, taking two WWTPs with surface aeration systems and blasting aeration respectively for an example, LCC theory was adapted to analysis the cost of consumption and the environmental impact, which caused by the different aeration system. Research results showed that: (1) In the 20-year life cycle, the LCC mainly depend ed on the cost of energy consumption whatever blasting aeration system o r surface aeration, while the LCC of blasting aeration system affected by the equipment maintenance cost, maintenance cost, economic losses caused by wastewater loss and environmental load in maintenance period. (2) The LCC of blasting aeration system was lower than the surface aeration in general, on the premise of the standard discharge; (3) the blasting aeration system estimated a saving of 60,000 RMB annually in costs compared with the surface aeration.

1. Introduction

The energy consumption of secondary treatment unit was more than 50% compared with that of the total wastewater treatment plant (WWTP) [1-3], the research on the choose of aeration devices has been widely attracted attention [4, 5].

In one WWTP using typical A2/O process, the energy consumption distributions of various units and equipment in the entire wastewater treatment process were analyzed [5]. The methods and solutions of energy saving potential could be put forward, and the importance of the optimal aeration system was also presented. By comparing surface aeration process and blasting aeration process in oxidation ditch WWTP, L G Shao [6] analyzed the treatment effect and energy consumption in 2010(one year) , and the results showed that: surface aeration system paid more cost than the blasting aeration system, that was about 1,300,000RMB one year in 10Wm3/d per day. Another typical example was illustrated by P yang [7], the same results coincided that surface aeration need cost more energy consumption than blasting aeration at the similar circumstance. In addition, Y Liang [8] carried on the research that the variation of energy consumption changed with influence of oxygenation capacity of fine bubble aerator. To reduce energy consumption of WWTP, B Kumar[9], A Thapinta [10], I Lee [11], M Jolly [12] and so on were respectively studied the oxygenation capacity of surface aeration or blasting aeration equipment.

Based on the above analysis, much research had been devoted to the energy consumption of aeration equipment and obtained certain research results. However, the conclusions weren’t considered...
the other economic costs and environmental negative benefits. In other words, they didn’t conclude the costs of surface or blasting aeration in the whole life cycle. In particular, the operation and maintenance of blasting aeration system were difficult, and the average length of 10 years should replace the blasting aeration disc, such as the plug, tear, corrosion, aging and so on, which might bring out more economic consumption and environmental loads than the surface aeration. The principal purpose of this paper was confirmed to concern with this problem.

2. Theory of LCC analysis
The LCC was a methodology for calculating the whole cost of a system or product from inception to disposal. The systems or the products were applicable to long series of industry or production, which could be a building, a equipment, a factory or a power station. So LCC could found its place in calculate the cost of aeration system in WWTP.

Generally, the entire life-cycle of system could be divided into the follows: construction stage(planning and research, investment), operation stage(use or operation, maintenance) and the dismantling stage(disposal), while the total cost also provided a variety in different ways depending on the application filed, the specific content could be changed based on the requirement of the users. For this paper, the purpose of LCC analysis didn’t only make a decision of the total cost, but also compare costs of different alternative system plans between the surface aeration and blasting aeration system. So we could check out which choice would be the most cost efficient, and what caused difference in cost, these would be one of the main benefits of the study and be shown as data. Taking into account the operation stage cost and energy consumption were more than 60% in LCC analysis, so we paid more attention and gave a detailed analysis, so that the conclusion was more in line with the actual situation. The implementation of LCC for aeration system was divided into three parts. First, a specific and representative WWTP was illustrated, which had two treatment systems and distinguished from each other only by the aeration system. Second, the LCC analysis asset list of different aeration system was developed and calculated including the process form inception to disposal. Third, the total cost was calculated and discussed the several alternatives of the efforts to improve efficiency.

3. WWTP introductions: a case study
The investigation was applied to the two WWTPs (defined A and B) located in Guangdong province which were considered a relatively consistent except the aeration system[6]. The capacity for A was 100,000 m$^3$/d operational with A$^2$/O oxidation ditch process, and the aeration system adopted inverted umbrella surface aerators. The costs and energy consumption of A could represent that generated by the surface aerator equipment. The capacity for B was also 100,000 m$^3$/d operational with A$^2$/O oxidation ditch process, and the aeration system adopted rubber membrane middle and fine bubble diffusers as the source of oxygen. At present, there was a large proportion of the WWTP using the aeration of rubber membrane, so the aeration plate material used in B factory could have certain representativeness in china. A and B plant layout plan were shown in figure 1.

Plant A: There were three anaerobic tanks and one blenders installed per tank for favoring P removal, two anoxic tanks per tank were employed and two anoxic blenders installed using for nitrate supplied by the internal recirculation. There were 6 sets of inverted umbrella surface aerator installed in aerobic tank and each 3 units (dual-use option). Each surface aerator impeller adopted turbo type with 8 blades and actual rotational velocity was 35/26rpm, the power of electric machine was 150kW and rotational velocity was 900/740rpm.

Plant B: The layout of the plant B were exactly similar with A, except 4 sets of underwater impellers and 3 units high-speed single-stage centrifugal blasting aerator (two in service one standby).The power of blasting aerator was 250kW and maximizes air volume was 10,200 m$^3$/h. The diameter of micro-porous aeration diffuser disc was 230mm and total amounts were 8160.
4. **LCC analysis of aeration system**

4.1. **LCC-oriented range definition of aeration system**

Minimum LCC of aeration system was the most straightforward and easy-to-interpret measure defined from the user's point of view, so life-cycle range was focus on equipment purchases, installed, operational, removal costs and environmental load brought in the process. The consumption of various raw materials and the environment load caused by mining, processing and removal were not taken into account.

Based on the life-cycle range of aeration system, the required data in the LCC list were determined and operational cost was paid more attention because of its high proportion in total cost. The details were shown in figure 2.

4.2. **LCC analysis of aeration system**

4.2.1. **Covers area analysis.** The surface aeration system (A) and the blasting aeration system (B) resembled one another in the scale, including the influent quality, the effluent quality, the process with modified A₂/O, and also had many features similar in volume of secondary sedimentation tank, the grit clarifier as well as other process units. The significant difference was aeration equipment and came with the covers area of oxidation ditch which induced by different aeration system. Therefore, it was reasonable that only design parameters of biological treatment stage made a statistics and analysis in oxidation ditch. The details about the parameters of oxidation ditch were shown in table 1.

| Items (unit/m²)                        | A       | B       |
|---------------------------------------|---------|---------|
| Affective volume of anaerobic zone     | 3177×2  | 3330×2  |
| Affective volume of anoxic zone        | 5678×2  | 5210×2  |
| Affective volume of aerobic zone       | 16500×2 | 14600×2 |
| Available water depth                  | 4.9     | 5.25    |

Generally, the immersion depth of surface aeration equipment was from 10 to 100mm under the water surface in operating, principle of operation were as followed: firstly, high-speed-working impellers splash the water into the air; secondly, these splashing water mixed the oxygen in the air drops into the water surface, then the content of dissolved oxygen in wastewater would be increased. The oxygen transfer mainly occurred at the air-water surface, which limited the depth of oxidation ditch to achieve the effluent quality standards. The depth of oxidation ditch usually was 3 to 4 meters; the deepest was less than 5 meters, and more deeper more energy consumption. Blasting aeration utilized a bottom-up method for continuous creation of foams comprising of air micro-bubbles, that was, the oxygen transfer not only came on the air-water surface but also in the depths of wastewater. Therefore, it could save a certain construction area because the oxidation ditch with blasting aeration...
was deeper than surface aeration’s. According to the volume and the depth shown in table 1, the construction areas of the aeration system were approximate calculated, as shown in figure 3.

Figure 3. Construction area of different aeration system

As shown by the data in figure 3, the construction areas of surface aeration system and blasting aeration system were about 10348.98m² and 7822 m², respectively. This brought about 2500m² construction areas economized if blasting aeration system was applied. However, it should be noted that some auxiliary facilities such as blower room for blasting aeration also needed to be built, so the construction area was less than 2500m². The costs were calculated at current price 500,000 RMB /mu, there was a difference about 1870,000 RMB between surface aeration system and blasting aeration system.

4.2.2. Analysis of equipment list in aeration stage. The equipments for surface aeration system (A) and the blasting aeration system (B) in oxidation ditch were confirmed and formed a statistical list, which was showed in table 2.

Table 2. The number of equipment and the power of biological treatment stage

| Equipment                              | Surface aeration system (A) | Total Power |
|----------------------------------------|-----------------------------|-------------|
| Blender for anaerobic(T1)              | 6                           | 1086kW      |
| Blender for anoxic zone(T2)            | 4                           | 30          |
| Surface aerator (T3)                   | 6                           | 150         |
| **Blasting aeration system (B)**       |                             |             |
| Propeller for anaerobic(T4)            | 4                           | 2.3         |
| Propeller for anoxic(T5)               | 4                           | 4.3         |
| Propeller for aerobic(T6)              | 12                          | 4.3         |
| Blasting aerator(T7)                   | 3                           | 250         |

Due to the different selling price for various brands, as a representative, the equipments with the medium-price were chosen for a substitute. The quantity and the unit-price of aeration system were shown in table 3.

Table 3. Price of major equipments

| Equipment                              | Surface aeration system (A) | Blasting aeration system (B) |
|----------------------------------------|-----------------------------|-----------------------------|
| T1                                     | 6                           | 53000                       |
| T2                                     | 4                           | 93000                       |
| T3                                     | 6                           | 500000                      |
| T4                                     | 4                           | 53000                       |
| T5                                     | 4                           | 58000                       |
| T6                                     | 12                          | 58000                       |
| T7                                     | 3                           | 720000                      |
| T8                                     | 500000                      |                             |

T8 (in table 3) referred to the assistive devices such as diffuser disc, gas pipeline and so on, which
were necessary for blasting aeration system, but surface aeration system were not. As shown by the data in table 3, total cost of surface aeration was 3702,000 RMB and blasting aeration was 3800,000 RMB, the difference between two aeration systems was about 98,000 RMB.

4.3. Inventory and cost analysis in operation stage

4.3.1. Inventory analysis. Operation experience based on the WWTP proved that most of the WWTPs need be conducted technical modification or equipment revamping for 15 to 20 years guaranteeing to satisfy the development of wastewater treatment technology, the increasing amount of wastewater and the improvement of the water discharge requirements, etc.

In the paper, the energy consumption was evaluated in terms of 20-year life cycles. Factoring the costs of operation and maintenance stage was in closing of 60% to total costs, the following sections explained the costs of these in more detail. Item lists in operation and maintenance stage were shown in table 4:

| Number | Item list                      |
|--------|--------------------------------|
| 1      | Equipment maintenance          |
| 2      | Update of aerator              |
| 3      | Economic losses                |
| 4      | Environmental load             |
| 5      | Energy consumption(Electricity)|

The costs of day upkeep and repair projects for the blasting and surface aeration system were roughly similar every year, thus daily maintenance costs were ignored and not covered in item lists.

4.3.2. LCC analysis in operational stage. Based on the practical experience of the WWT and the data in table 4, the consumption in the operational stage was divided into three parts:

1) Maintenance and repair list during operations. Basically, it was not necessary for surface aerators to require massive overhaul in 20 years of operation, involved only routine maintenance. As there was no significant difference between surface aeration and diffused aeration in terms of routine maintenance costs, so this part of cost could be neglected. Currently, combined with practical engineering, rubber was mainly used for gas distribution membrane in micro-porous aeration system. In contrast to micro-porous aeration with the titanium or ceramic plate, they could effectively avoid the blockage. However, rubber had a certain degree of flexibility; it was prone to causing breakage, tearing, corrosion or decline of gas distribution membrane. These damages on the aeration tray might greatly reduce the oxygenation efficiency of the diffused aeration system, and might affect the treatment effect of wastewater treatment plants. Therefore, LCC of the diffused aeration system was closely related with the service life of the aeration tray. With the increase of operation time, it could cause a significant reduction in oxygenation power efficiency, due to the lack of timely replacement and maintenance. Therefore, it was necessary to pay close attention to the changes of effluent quality and conduct timely contrast with the historical data. On the premise of the influent quality unchanged and blasting aerator fault excluded, only by extending the aeration time could meet the discharge standard, it would be considered that there was something wrong with diffusers. In this situation, they had to be repaired or replaced. To obtain better economic costing, the diffusers should be replaced by a certain year. The optimal option was about 10 years. There was a large price volatile because of different manufacturers, to make the results representative we assumed that the price of aeration diffusers was taken as 150RMB and the life-cycle was 10 years, it arrived at the conclusion that the diffusers should be replaced twice within a 20-year life cycle, ignored the labor costs and ancillary expenses because of a small proportion.

2) Maintenance and repair based on sensitivity analysis. As a comparison, the present value method (formula 1, 2) was adopted to convert the cost into the base year, due to the replacement time of the diffusers different.
\[ PCOST = COST \times PW \] (1)

\[ PW = \left(1 + i\right)^n \] (2)

Where PCOST was the present value convert to base year (RMB), COST referred to cost present value (RMB), PW was the present value factor, I was the bank interest rates, I=0.05.

Based on the formula (1) and (2) for calculation, the replacement cost of the aeration plate in the air blasting aeration system during the operation period of 20 years was 751,000 RMB (P1) (in the 10th) and 461,000 RMB P2 (in the 20th) respectively, therefore the total costs were P1+P2=1,212,000 RMB.

(3) Economic loss cost in the repair process. In the replacement of diffusers of blasting aeration system, two ways was adopted to dispose wastewater: (1) supposed that other WWTP or backup systems could have a capacity to disposal the wastewater, the government can carry out the deployment of the pumping station to accept the wastewater during the diffusers replacement days.(2) Supposed that no other WWTP or backup systems could receive a large volume of waste water, with approval of authority, the WWTP could only declare parking maintenance and the wastewater could be directly discharged without treatment. The economic loss caused by first method was wastewater quantity loss. There were two classes of loss caused by the second method: wastewater quantity loss of WWTP and serious damage to the environment which might cause a series of chain reactions. Therefore, wastewater quantity loss and environmental load were taken into consideration during calculation.

1) Cost of wastewater quantity loss. The replacement of 8160 aeration disc generally required 3 days under full preparations. During this period, wastewater wasn’t disposal, thus causing cost of wastewater quantity loss than they otherwise would have. At current prices for wastewater (0.9 RMB /ton) in the domestic market, the wastewater loss in 3 days was 10Wm³×3day×water price. The entire aeration disc should be replaced 2 times in the 20-year lifecycle. The cost caused by replaced of aeration disc calculated with the present value method, that was 166,000 RMB (P3), 102,000 RMB (P4) the 10th year and the 20th year respectively. So the total cost brought out by replacement of disc was P3+P4=268,000 RMB.

2) Environmental load cost. If the wastewater was discharged to other WWTP or backup systems under the coordination of the government, loads would not excessively generated to the environment during the replacement of diffusers. The environmental load cost under this circumstance (denoted as T1) was negligible. If the wastewater was directly discharged into the natural environment (denoted as T2), pollutants containing in the untreated wastewater entered into the environment, which caused serious damage to the natural environment such as rivers and lakes and so on. The environmental load cost caused by the equipment replacement was calculated according to COD emission reduction. The actual annual influent COD concentration of plant B was 157mg/L, and the annual effluent COD concentration was 23mg/L. The environmental load generated from COD replacement was W= (157-23)g/m³×3days×10³m³. Calculated as the COD emission trading price of 5,034,000RMB /ton provided in Literature [11], the environmental load cost generated in the 10th and the 20th year converted to the base year was 1,240,000 RMB (P5) and 763,000 RMB (P6) respectively. Therefore, within the life cycle of 20 years, the economic loss converted by environmental load generated from the COD emission reduction was P5+P6=2,003,000 RMB.

3) Energy efficiency costs. The oxygenation capacity of the micro porous aeration device for the blasting aeration system would be gradually decreased with the accumulation of being operated years. In order to meet the wastewater discharge standard, the WWTP increased the air volume of blasting aeration system so as to achieve the required treatment effect. Therefore, the operating cost of the blasting aeration system increased year by year, and the actual energy efficiency costs. In Literature [12], the oxygen transfer efficiency and the increased power of blasting system of a new aeration and an old one operating for years had been contrasted and examined. The power of new one was 969.438kW, and the old one was about 1077.15kW. Total power of the aeration system increased by 11% in ten years. Based on this, the power of the blasting aeration system in plant B was 828kW at the
beginning, the power of the blower would change into 919.1kW during the replacement of the new aeration plate at the tenth years, under the circumstance of normal discharge standards. In order to simplify the calculation, the average value of 873.5kW was taken as the total installed power of blasting aeration system. Considering the cost sensitivity, the energy cost of the blasting system converted to the base year according to formula (3) and (4) was 65,225,000 RMB

\[
PCOST = TP \times UPC \times 24 \times 365 \times PW 
\]

Where PCOST was the present value of total operating cost (RMB). TP was the power of blasting aeration system (kW). PW was the present value coefficient. UPC was the unit electric charge (RMB/kWh). n was operation time of aeration equipment (year). I was interest rate, which was taken as 0.05. Refer to the national general industrial electricity prices, and set UPC as 0.684 RMB/kWh.

The energy costs for blasting aeration system were 65,225,000 RMB based on Formula (3) and (4). For the surface aeration system; the power of the whole life cycle was basically unchanged. According to Formula (3) and (4), the total costs of energy consumption converted to the base year were 81,093,000 RMB.

4.3.3. The stage of demolition. The costs of aeration system in demolition stage were largely depended on the considered elements. However, WWTP as an important public infrastructure would not be dismantled after ending the lifecycle, but another beginning of the WWTP lifetime, so the costs in demolition stage were not a consideration.

5. Comprehensive compare of LCC

5.1. Economic consumption comparison within life-cycle
In dismantling stage, the economic consumptions of A and B were basically the same, thus the comparison calculation wasn’t carried out in total cost. Normal maintenance and maintenance wouldn’t significantly different for the two aeration systems. Therefore, the analysis hadn’t concentrated on normal maintenance cost of the two aeration systems. The comprehensive comparison results of surface and blasting aeration systems energy consumptions in various stages were shown as table 5.

| Item(unit/thousand RMB )         | A       | B (T1)  | B (T2)  |
|----------------------------------|---------|---------|---------|
| Energy consumption               | 81093   | 65225   | 65225   |
| Major equipments                 | 3702    | 3800    | 3800    |
| Replacement of equipments        | 0       | 1212    | 1212    |
| Wastewater quantity loss         | 0       | 260     | 260     |
| Environmental load cost          | 0       | 0       | 2005    |
| Total                            | 84795   | 70497   | 72502   |
| Area cover(m²)                   | 10349.0 | 7822.9  | 7822.9  |

Shown as table 5, the LCC mainly depends on the cost of energy consumption whatever blasting aeration system or surface aeration. The WWTP adopting blasting aeration system could save 60,000 RMB per year and floor space of 2500m², comparing with the surface aeration system within a 20-year life cycle comparing with surface aeration system, which was also the reason why some WWTPs carried out remodeling project or select blasting aeration equipment. Therefore, the blast aeration system should be the priority selection in wastewater plant upgrading and reconstruction to reduce its life cycle cost.
6. Conclusion and suggestion
On the premise of the standard discharge, the LCC comparison research result of surface aeration system and blasting aeration system shows that:

1) The energy consumption of the blast aeration system was lower than that of the surface aeration system.

2) The life cycle costs of blasting aeration system were also better than that of surface aeration system, which could save about 600,000RMB per year and effectively reduce the occupied area. Besides, the annual costs saving were related to the service life and equipment cost of air blasting aerator.

3) Considering the cost of environmental load, and there was no other WWTP or available backup system within the life cycle, which exercised a great influence on the total costs of blasting aeration system. During the operation maintenance period, the unavoidable discharge into the water environment was proposed to be arranged in the rainy season, in order to minimize the adverse effects of wastewater on the environment through the rain attenuation.

4) On the premise of the standard discharge, the NH$_4^+$-N and TN concentration of A$^2$/O wastewater plant adopting surface aeration system was superior to that adopting blasting aeration system.

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