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Practical research on treatment and recycling of automotive industrial wastewater

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ABSTRACT

The wastewater discharged from the automobile industry is characterized by complicated components, a high concentration of mineral oil and toxicity. This study processes and recycles wastewater from a coking plant in the automotive industry through the upgrade of the original wastewater treatment system, as well as the combination of bio-augmentation and ordinary treatment technology. The results show the wastewater treatment capacity of the new system reaches 40 m^3/h, and the treated water meets the national first-class discharge standard (GB8978-1996). Its depth treatment capacity is 10 m^3/h, and the quality of the recycled water conforms to the standard for reclaimed water quality (CJ25.1-89). After the introduction of bio-augmentation, one ton of wastewater treatment costs as low as RMB 5.90 Yuan, which is worth the promotion and application in automotive industries (such as coking enterprises).

Keywords: Wastewater treatment; Bio-augmentation; Wastewater recycling; Environment; Automotive industry

1. Introduction

With the development of society and the economy, the problem of environmental pollution is becoming more and more serious [1,2]. In the situation of the shortage of water resources in developing countries, the influences of water pollution on people's production and life are particularly prominent [3–6]. At present, it has only 1/4 of the world's per capita amount of freshwater in China, that half of the country is lack of water [7], with more than 200 million of the population of water being seriously inadequate. At this historical stage, water pollution is such a serious problem that, large water systems, urban waters, and groundwater are generally contaminated, forming a sharp contradiction between daily needs and production demand.

Industrial wastewater is an important source of water pollution, which is very different from agricultural wastewater and domestic wastewater [8,9]. Industrial productions are of various categories, so industrial wastewater containing a variety of heavy metals, inorganic and organic compounds, which is of strong toxicity and long remaining time, being a serious threat to human health and ecosystem stability. In the case of serious water shortage and serious water pollution, it is of great significance to strengthen the research and practice of industrial wastewater treatment and reuse technology. At present, there are four kinds of industrial wastewater treatment technologies, as the physical method, chemical method, physical-chemical method and biological method [10,11].

The physical method is the use of physical or mechanical to separate the recovery of the solid particles or suspended pollutants in wastewater. The technology involves filtration, precipitation, centrifugal separation, and magnetic separation. The treatment process does not change the species and chemical properties of pollutants. The chemical method is the addition of chemical substances that the pollutants of the dissolved and colloidal state in wastewater are converted

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into harmless substances through a chemical reaction. There are coagulation, neutralization, oxidation-reduction and chemical precipitation. The physicochemical method is the use of mass transfer principles to separate the soluble substances and ions in the wastewater. There is commonly adsorption, ion exchange, membrane separation, extraction and so on. The biological method is to absorb or degrade the organic matter in wastewater through the metabolism of microorganisms, to make them into the stable, non-toxic state from the dissolved, colloidal or suspended toxic state. The method is subdivided into aerobic biological treatment and anaerobic biological treatment according to treatment conditions and microbial species. The method is directed to wastewater of different sources and characteristics [12].

The pollutants in industrial wastewater are diverse and complex, and any single method cannot achieve the goal of effective removal of all pollutants. So, in practice, a variety of methods should be used in combination to make the treated wastewater meet the requirements of emissions [13]. The order of the treatment methods is physical, chemical and biological methods. The pollutants were treated as massive refuse, floating matter, suspended matter, and colloid and dissolved substances. According to the different sources of wastewater and water quality characteristics, the choice of treatment methods will have some differences. Wastewater subjected to the above treatment is generally capable of meeting the discharge requirements. However, if wastewater is to be reused, advanced treatment is required to remove the soluble material. The main methods used in the depth treatment are physicochemical and chemical methods. Some new technologies such as ultrasonic and high-energy ray methods are currently in the experimental stage that its practicality in the advanced treatment of wastewater remains to be further verified [14–16].

Coking wastewater is produced from coal coke, coal gas purification, and coking product recovery process. It contains a high concentration of pollutants, great toxicity, and poor biodegradability, which is one of the most difficult industrial wastewater to deal with. Based on the research of microbiology, the new method of wastewater treatment is developed as a biological enhancement technology. It adds to the wastewater biological treatment system with a specific function of microorganisms, as one special kind of microorganisms for degradation of one type of pollutants. At present, many kinds of bacteria have been isolated and domesticated, as the target pollutants are phenol, cyanide, chlorobenzene, naphthylamine, etc. Therefore, it is especially suitable for treating coking wastewater [17–20].

This research is based on the renovation project of a steel enterprise in China, whose annual production capacity is 1 million tons of coking per year. To protect the environment and to save water resources, the plant has upgraded the original wastewater treatment system, and introduced the combination technology of biological strengthening and general treatment and added advanced treatment functions. The original wastewater discharge of the coking plant was 900 m^3/d. After the upgrade through this study, the system's wastewater treatment capacity can reach 40 m^3/h, meeting the production needs. After treatment, the water quality can reach the national effluent standard (GB 8978-1996). Also, some of the water met the effluent standard requirements for depth treatment by the reuse of urban recycling water - water quality standard for urban miscellaneous water consumption (GB/T 18920-2002), with a processing capacity of 10 m^3/d, which are reused in equipment cooling, plant road cleaning and flushing. The design and debugging results are as follows.

2. Wastewater source and effluent quality

Wastewater from ammonia wastewater, crude benzene separation of water and benzene purification wastewater in coal coke production process of the tar plant, mixed with a small amount of dust and washing water and indirect cooling water. In the wastewater with a pH value of 6–9, the phenolic substances are the most content, and there are benzene and pyridine organic compounds, while inorganic compounds are based on cyanate and thiosulfate. There are 57 organic compounds detected by Agilent SureTarget GC/MSD analysis. The main types and contents of organic compounds are shown in Table 1.

Wastewater treatment capacity by system design is 40 m^3/h, and after treatment, water quality can meet the emission requirements. By this, it can also deal with some part of the effluent in-depth, and its processing capacity can be 10 m^3/h. The effluent can be reused as equipment cooling, plant road cleaning, and flushing. Indices of the raw, the treated and the recycled water quality are shown in Table 2.

3. Technological process and engineering design

3.1. Technological process

Treatment and recycling of coking wastewater processes are shown in Fig. 1. Coking wastewater caused by operation from each workshop of coal coke flows through the pipe into the regulation pool. Regulating reservoir regulates the quality and the flow rate of different coking wastewater generated in each process, to be more suitable for the next step of grease treatment. The wastewater is adjusted and then forced into the grease trap through the pump. After the removal of large-diameter oil particles and a large density of pollutants, the treated wastewater re-enters the flotation tank. Demulsifiers, coagulants and floc coagulants are used to remove the emulsified tar in the air floatation tank further, while reducing the concentration of chemical oxygen demand (COD) and biochemical oxygen demand (BOD), excluding scum.

And then the wastewater flows through the anaerobic pond followed by the aerobic pond, circulating between the two. Where the ammonium nitrogen is converted to nitrate nitrogen by the various nitrification and de-nitrification bacteria to the nitric form of the elemental form, the wastewater is completing the nitrification process and excluding some of the sludge. Due to the high concentration of pollutants in the coking wastewater, strains of various degrading bacteria from the domesticated factory sludge separation are added to the bio-fortification treatment [21–23]. Wastewater gets the initial purification by microbial treatment and then goes into the secondary clarifier, in which the remaining sludge is further precipitated and concentrated, and then be disposed of after being separated from the wastewater. The secondary clarifier provides

Table 1
Types and contents of main organic compounds in coking wastewater

No.	Organic species	Mass percent (%)	TOC concentrations (mg/L)
1	Phenols and derivatives	62.3	183.8
2	Benzene and derivatives	12.5	36.9
3	Quinoline compounds	10.7	31.6
4	Carbazoles	2.9	8.6
5	Indoles	2.4	7.1
6	Pyridines	1.9	5.6
7	Imidazoles	1.8	5.3
8	Furans	1.5	4.4
9	Pyrrole	1.4	4.1
10	Biphenyl	2.3	6.8
11	Thiophenes	0.9	2.7
12	Tricyclic compounds	1.6	4.7

Table 2
Indices of the raw, the treated and the recycled water quality

Water sample	pH value	COD (mg/L)	BOD (mg/L)	ρSS (mg/L)
Raw	6–9	1,800–2,200	800–900	220–250
Treated	6.5–8.5	<100	<20	<70
Reused	6.5–8	<50	<10	<5

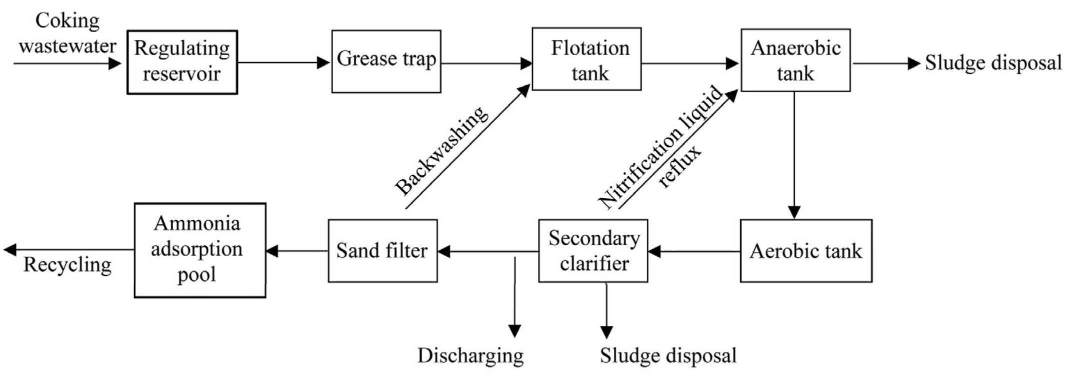

Fig. 1. Technological process of coking wastewater treatment and recycling.

a certain amount of active microorganisms, which are returned to the anaerobic tank with the nitrification solution. After secondary clarification, the water quality can achieve the discharge standards, as some are for the depth treatment and the remaining discharges.

There is a certain gap between the wastewater from the secondary clarifier and the recycled water, which depends mainly on the concentration of suspended solids (SS). It flows first through the sand filter for the advanced treatment of wastewater. The sand filter material of quartz retains most of the solid particles, to clear the water. The backwashing of the flotation tank is carried out by extracting part of the wastewater. The wastewater finally flows through the ammonia adsorption pool. The ammonia nitrogen in wastewater is rapidly and efficiently absorbed by zeolite, and the water has finally reached the standard of reuse.

3.2. Unit design

3.2.1. Regulation reservoir

First of all, it sets up a regulation pool with an aeration tube for the regulation of wastewater. It degrades some organic matter and also plays a role in mixing water quality. Its size is 15 m × 10 m × 4 m, and the effective volume is 500 m^3, with steel concrete structure, and installed of submersible pumps. The designed wastewater treatment capacity is 50 m^3/h and the hydraulic retention time of 9 h.

3.2.2. Grease trap

The grease trap is mainly used to remove large-diameter oily particles and large density contaminants, to meet the requirements of the subsequent processing operations. The effective volume of a grease trap is designed as 450 m^3, with the structure of rectangular advection. It sets up a scraping machine on the pool surface, and the mud pipe at the bottom. The wastewater is drained out of the pool through an overflow pipe. The processing capacity of a grease trap is 50 m^3/h, and the hydraulic retention time is 8 h.

3.2.3. Flotation tank

The flotation tank is used to inject demulsifiers, coagulants, and coagulants to remove the dispersed state of the oil and the small SS, to complete the pre-treatment process. The size of the flotation tank is 12 m × 10 m × 5 m, with an effective volume of 450 m^3. It is of steel structure, installed a dissolved air pump, a set of the dissolved gas tank, a type of Z-0.05/6 compressor. The designed wastewater treatment capacity is 50 m^3/h, and the hydraulic retention time is 8 h.

3.2.4. Anaerobic tank

In the anaerobic tank, the biochemical treatment of wastewater is started to achieve the effect of removing COD and improving the biodegradability of wastewater. The size of the anaerobic pool is 10 m × 6 m × 8 m, with an effective volume of 400 m^3. There is a special water distributor at the bottom, whose single working area is 3 m^3. And the pipeline is also arranged to remove the sludge. The solid elastic method is used, with the parking height of 3 m, and the filling amount of 200 m^3. The designed wastewater treatment capacity of 40 m^3/h, with the COD volume load of 2 kg/(m^3 d); and the hydraulic retention time is 8 h. The anaerobic type of degradation bacteria (*Desulfomonile tiedjei*) and degrading bacteria (*Burkholderia pickettii*) are put into the tank, and the temperature is controlled at 25°C–30°C to ensure the active state of bacteria.

3.2.5. Aerobic tank

The aerobic tank comprises three parts of a pool body, a water distribution system, and a gas-distributing system. It belongs to the activated sludge aeration tank of push flow type. Its size is 10 m × 10 m × 10 m, with an effective volume of 800 m^3. It is equipped with three sets of HSR250 type blower, 200 sets of BZQ-W-192 aeration, and two units of reflux pump. The designed wastewater treatment capacity is 500 m^3/h, and the hydraulic retention time is 8 h. The aerobic type of phenol-degrading bacteria (*Pseudomonas putida*) is put into the tank, and the temperature is controlled at 25°C–30°C to ensure the active state of bacteria.

3.2.6. Secondary clarifier

The secondary clarifier is an important part of wastewater treatment by using activated sludge. Its size is designed for the stream of 10 m × 10 m × 4 m, with an effective volume of 50 m^3. Its hydraulic retention time is 5 h with a surface load of 0.35 m^3g/(m^3 d). Sludge return well is set at the poolside. Mud suction-scraper is installed at the bottom to discharge activated sludge into the sludge return well. Also, there is a reflux pump, to disposal of the nitrification liquid back to the anaerobic tank. The remaining wastewater can be achieving the standard discharge or into the depth of treatment procedures.

3.2.7. Sand filter

The sand filter is a component of the wastewater advanced treatment system. The corrosion-resistant steel structure was used, and the expansion rate of the backflushing was 20%. Double layer filter materials are filled with quartz sand and anthracite, with the diameter being 0.5–1.2 mm and the pore range of quartz sand being 10–15 μm. It can hold back the majority of small particles suspended in the wastewater, resulting in clear water, and partly drainages through the submerged pump, backwashing for flotation tank. The filling height of the filter material is 1 m, installed of the pressure filter, whose speed is up to 5 m/h. The treatment capacity of the sand filter is designed as 30 m^3/h.

3.2.8. Ammonia adsorption pool

The establishment of an ammonia adsorption pool is mainly used to deal with the excessive discharge of ammonia nitrogen in the water led by the full load production of coking plants or the poor treatment effect in winter. Each process dimension of these two pools is 6 m × 6 m × 4 m, as the reinforced concrete structure of semi-underground. The zeolite was filled in the ammonia adsorption pool. Its maximum adsorption capacity is 4.5 mg (ammonia nitrogen)/g (zeolite). The ammonia nitrogen in the water which flows through the pool can be quickly absorbed, and the effluent can reach the standard of recycling. The pool sets the zeolite adsorption layer and supporting layer of gravel, with the flow rate of 2 m/h and the total processing capacity of 40 m^3/h.

4. Debugging and operation

Before the air flotation, it adjusts the pressure of the container, the return flow and the degree of opening of the valve. Run 8 d in a variety of conditions, when the tank pressure is 0.5 Mpa, and the backflow is 25%, by adjusting the valve opening degree, it can realize the oil removal rate to be stabilized at 85%, and removal rate of SS at 69%, and get good effluent quality.

The microbes in anaerobic and aerobic ponds are the key factors for the transformation and degradation of pollutants. Therefore, according to the characteristics of low concentration of organic pollutants while a high concentration of phenol and ammonia nitrogen in coking wastewater, the cultivation and acclimation conditions of the bacteria are debugged, to make the activity of the bacteria being highest. The bacterial strain comes from biochemical sludge discharged from a sewage treatment plant. Take 90 t of sludge to formulate nutrients according to BOD5:N:P=95:5:1. At the same time, the dissolved oxygen in the anaerobic tank is regulated as DO ≤ 0.08 mg/L in the aeration and intermittent water inlet. The reflux of the digestive juice is between 15%–25%, and the sludge backflow rate is 70%–95%. Water inflow increases from a small number of continuous gradually to full load. It is debugging for each phase. When the biofilm thickness is about 1.5 mm, and the effluent quality from the secondary clarifier stably reaches the standard, it can end the debugging and then enter the stable operation.

After many experiments in the secondary clarifier, the optimal dosage of polymeric aluminum chloride (PAC) is determined as 200 mg/L, and polyacrylamide (PAM) is 15 mg/L. After 10 d of continuous adjusting of the mixing air volume and debugging of the dosage, it has discovered that alum is dense and easy to precipitate, and water is relatively clear when PAC and PAM are 150 and 15 mg/L. It is determined as the operating condition.

The debugging of the filter system is used mainly to determine the inflow amount, the back-flushing amount and the backwash cycle. After running 10 d under various working conditions, there is a positive correlation between the inflow amount and the incoming flow amount [24,25]. Therefore, the filter pump needs to be adjusted according to the status of the sewage pump. When the filter pump is adjusted to 35 t/h, it can run continuously 15 h. Then the water quality will gradually deteriorate. In this setting, the counter flushing period is 12 h. The expansion rate is the highest, without sand losing phenomenon when the water amount is 135 t/h, the intensity is 12 L/(m^2 s), and the expansion rate of the back-flushing time is 10 min. After the normal operation of 13 d, water in the ammonia adsorption tank begins to muddy. Thus, the back-flushing time is determined to be once per 10 d. The best parameter for the back-flushing amount is 200 t/h and is 20 min for the back-flushing time.

After 90 d operations of the system, samples of the wastewater are collected to analyze the water quality. The results are shown in Table 3. The treated water meets the integrated wastewater discharge standard (GB8978-1996), and the recycled water meets the reuse of urban recycling water - water quality standard for urban miscellaneous water consumption (GB/T 18920-2002).

In the process of operation, the dissolved gas in the floatation tank gradually becomes smaller. The possible reason is that the sucking sludge in the air-dissolving pump is not discharged, and is eventually entering the saturator leading to insufficient air solubility, influencing water quality. The solution plan is timely inspections and discharging sludge, regularly cleaning solution pump and dissolving tank, that can avoid sludge deposition. After taking the above measures, the test results show that the dissolved gas in a flotation tank can maintain at a stable state.

There are too many bubbles in operation. One of the reasons is that the water quality of raw water varies greatly, and the oil content in the wastewater is too high, which forms a stable foam on the surface of the aerobic tank. Another reason is that the temperature changes make some filamentous bacteria in the aerobic tank to become an advantage that the growth rate is so fast to form a biological foam. The measures adopted in the grease trap and the flotation tank is increasing the treatment of oil pollution, as well as increasing the reflux of sludge and nitrification liquid to weaken the growth advantage of filamentous bacteria so that the bubble problem has been solved.

5. Discussion

Coking wastewater is a kind of high concentration organic wastewater that is difficult to be treated. It should be treated by the wastewater treatment station before discharged into the environment to purify the pollutants in the wastewater and avoid polluting the environment. In the treatment of coking wastewater, a single physical, biological or chemical method has been used, such as the use of biological fluidized bed [19], iron-carbon micro-electrolysis, ion technology, reactor and other technologies [26–28]. The depth of the wastewater treatment capacity is weak through these single physical, chemical, biological methods, although it can effectively remove some of the organic wastewater. Based on previous studies, this research provided the innovative combination of physical and chemical treatment technology and bio-enhanced technology, designed the system, did operation and analysis, to treat the coking wastewater, and to establish the best working conditions. It was found that the COD value of the coking wastewater treated by the system was <50 mg/L, BOD < 10 mg/L, and ρSS < 5 mg/L, which met the national first-class emission standard (GB8978-1996). Also, it has the function of in-depth treatment according to the reuse of urban recycling water - water quality standard for urban miscellaneous water consumption (GB/T 18920-2002), which can be used for equipment cooling, road cleaning, and flushing.

Due to the cost-effectiveness of the study, the various test condition is chosen (Tables 4 and 5). The results show that before air flotation, the container pressure of the system should be adjusted to 0.5Mpa, with a 25% returned flow, to obtain the best oil removal rate and water rate.

For anaerobic tank and aerobic tank, the nutrient should be prepared as BOD5:N:P=95:5:1 for every 90 t biochemical sludge, the dissolved oxygen being DO ≤ 0.08 mg/L, digested liquid returned in 15%–25%, and sludge returned flow in

Table 3
Water quality monitoring in different processes

Water sample	pH value	COD (mg/L)	BOD (mg/L)	ρSS (mg/L)
Influent of regulating reservoir	6–9	1,800–2,200	800–900	220–250
Influent of anaerobic tank	6–9	1,000–1,200	400–500	150–170
Influent of the secondary clarifier	6.5–9	200–300	80–100	100–120
Influent of sand filter	6.5–8.5	<100	<20	<70
Influent of ammonia adsorption pool	6.5–8	<50	<10	<5

Table 4
Oil tank operation tests

No.	Pressure (Mpa)	Return flow	Oil removal rate	SS removal rate
1	0.2	25%	79%	51%
2	0.5	25%	85%	69%
3	0.8	25%	84%	47%
4	0.5	15%	52%	44%
5	0.5	25%	85%	69%
6	0.5	35%	86%	68%

Table 5
Anaerobic tank, aerobic tank run tests

No.	BOD_5:N:P	DO (mg/L)	Digestive juice reflux	Sludge return flow	Biofilm thickness (mm)
1	95:7:1	0.08	15%–25%	70%–95%	1.5
2	95:3:1	0.08	15%–25%	70%–95%	1.2
3	95:5:1	0.08	15%–25%	70%–95%	1.5
4	95:5:1	0.10	15%–25%	70%–95%	0.9
5	95:5:1	0.04	15%–25%	70%–95%	1.1
6	95:5:1	0.08	30%–45%	70%–95%	1.4
7	95:5:1	0.08	15%–25%	80%–95%	1.3

70%–95%, to get the best biofilm thickness of about 1.5 mm. When PAC and PAM dosage in the secondary sedimentation tank are of 150 and 15 mg/L, Alum precipitated easily, and the effluent is clear.

In summary, the system can achieve the best operating conditions. At the same time, running backflush every 10 d, with water amount of 200 t/h, in 20 min or so, it can make the system to obtain the best running state. Based on the above analysis, several days after the operation, the water quality is as follows:

Through Table 6, we can find that the system has been able to run normally and have better water quality, and it is established as the best running state.

Based on the actual operation, it has discovered two problems, such as the decrease of dissolved air in the flotation tank and the excessive bubble in the aerobic tank. Sludge deposition has been analyzed as the main reason for the reduction of dissolved air in the air flotation tank. The low treatment of oil pollution, the low return of sludge and nitrification solution, and the rising temperature in grease traps and flotation tanks, which bring about some filamentous hyphae bio-advantage, result in excessive foam. Based on the above findings, it is possible to stabilize the dissolved air volume of the air floatation tank in time by inspecting the flotation tank, cleaning the dissolved gas pump and the dissolved gas tank in time. And, it can effectively weaken the biological advantages and stabilize aerobic pool foam, by improving the oil disposal intensity of the grease traps and flotation tanks, stabilizing the temperature, increasing the return of sludge and nitrification solution. In this paper, the analysis and processing of the above situations make the system in practical applications to obtain a more stable operating state and get better results through Tables 7 and 8.

And, compared with the existing universal application technologies (Table 9), our COD treatment capacity of the technology system is excellent that it is much lower than that of other technologies, and has higher industrial application values and environmental protection values. (1) For biological fluidized bed technology, its purified water COD value is 200 mg/L. And for the membrane bioreactor, the COD value is 150 mg/L after purification. Both can only meet the national secondary discharge standards (GB8978-1996) that their water purification capacity is low. (2) For iron-carbon micro-electrolysis technology, it needs to adjust the PH value

Table 6
Tests on effluent quality of ammonia adsorption pond in different operation groups

No.	COD (mg/L)	BOD (mg/L)	ρSS (mg/L)
1	47	7	3
2	49	9	4
3	31	9	3
4	44	6	4
5	42	6	4
6	36	8	4

Table 7
Dissolved air volume rate of the floating pool before and after clearing

Detection period	3 h	6 h	12 h	24 h
Before (g/L)	3.259	2.768	1.952	1.043
After (g/L)	3.144	3.085	2.861	2.606

Table 8
Nitrification liquid and sludge reflux ratio under different oil contents

Oil content (mg/L)	150–250	250–350	350–450	450–550
Return of nitrification solution	30%	50%	70%	90%
Return of sludge	100%	200%	300%	300%

Table 9
Comparison of current different application techniques

Techniques	COD value of water after treatment (mg/L)	Standard grade	Is there any other pollution?
Biological enhancement technology	50	Class *A*	
Biological fluidized bed	200	Class *B*	
Membrane bioreactor	150	Class *B*	
Iron carbon micro electrolysis	100	Class *B*	Fe^{3+} pollution
Pulsed discharge technology	1,000	Class *C*	Ammonia nitrogen, COD

to around 4 to have a relatively better COD reduction rate, but still up to 100 mg/L or so, and the state of pH = 4 easily leads to iron electrode corrosion-causing water chroma increase and easily leads to Fe^{3+} pollution. (3) While in the application of pulse discharge technology, it has found that pulsed discharge technology cannot effectively reduce the COD, nor purify the water body.

This project covers an area of 1,200 m^3, with fixed investment of about three million 650 thousand Yuan, of which the construction cost of one million 100 thousand Yuan, and equipment and installation of two million 550 thousand Yuan. Compared with the wider application of biological fluidized bed technology, which costs 6.6 Yuan, and its treatment of water quality only reached the national secondary discharge standards (GB8978-1996); our wastewater treatment costs only 5.90 Yuan per ton, and the water quality is better than the national level emission standards (GB8978-1996) [29–34]. Taking into account the capital investment of secondary purification for biological fluidized bed technology, we consider the project operation of our system is cost-effective.

6. Conclusion

By the introduction of biological technology and the combination of general treatment technology, the treatment of refractory pollutants is more effective and thorough, and running costs are lower with only 5.90 Yuan per ton. Also, the processing system has a reasonable layout, compact structure, and at the same time, in ensuring the processing power, it covers a small area with less investment and is simple for operation and maintenance. Compared with the currently widely used technologies, there are some advantages that it is worth to promote application at coking enterprises.

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