Treatment of slaughter wastewater by coagulation sedimentation- anaerobic biological filter and biological contact oxidation process

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Abstract. The optimal process parameters and conditions for the treatment of slaughterhouse wastewater by coagulation sedimentation-AF - biological contact oxidation process were studied to solve the problem of high concentration organic wastewater treatment in the production of small and medium sized slaughter plants. The suitable water temperature and the optimum reaction time are determined by the experiment of precipitation to study the effect of filtration rate and reflux ratio on COD and SS in anaerobic biological filter and the effect of biofilm thickness and gas water ratio on NH3-N and COD in biological contact oxidation tank, and results show that the optimum temperature is 16-24 ℃, reaction time is 20 min in coagulating sedimentation, the optimum filtration rate is 0.6 m/h, and the optimum reflux ratio is 300% in anaerobic biological filter reactor. The most suitable biological film thickness range of 1.8-2.2 mm and the most suitable gas water ratio is 12:1-14:1 in biological contact oxidation pool. In the coupling process of continuous operation for 80 days, the average effluent’s mass concentrations of COD, TP and TN were 15.57 mg/L, 40 mg/L and 0.63 mg/L, the average removal rates were 98.93%, 86.10%, 88.95%, respectively. The coupling process has stable operation effect and good effluent quality, and is suitable for the industrial application.

1. Introduction
Industrial wastewater and domestic sewage directly or substandard’s emissions are the main causes of pollution. Among them, slaughter industry is one of the largest organic pollution sources in China [1]. The national slaughter wastewater’s discharge accounts for about 6% of the total industrial wastewater discharge and its proportion is still increasing [2]. Slaughter wastewater is a typical high concentration organic wastewater which has characteristics of large displacement and strong volatility [3]. The
The concentration of COD is generally 1000 ~ 2000 mg/L, BOD/COD is greater than 0.5, and the biodegradability of wastewater is better. The main pollution indicators were COD, suspended solids, organic nitrogen, TN, NH₃-N, NO₃-N, TP, SO₄²⁻, sulfide, total alkalinity and Escherichia coli [4].

At present, the treatment of this kind of waste water is mainly based on biological process, including aerobic, anaerobic and facultative treatment systems [5-7]. The front end of the biological treatment process is provided with bailing machine, a rack, an oil separating tank, a regulating pool or a sedimentation tank, to reduce the suspended substance and the oil content in the biological treatment structure, and to ensure the normal operation of the structure.

In order to solve the high concentration of organic wastewater from the slaughter house, the treatment effect and influencing factors of slaughter wastewater by coagulation sedimentation -- AF -- biological contact oxidation process were studied and they provide support for the engineering application.

2. Materials and methods

2.1. Experimental device

The AF reactor is made of Polymethyl methacrylate (PMMA), H=2.88 mm, d=100 mm, two filter columns, the total effective volume is 14.1 L, the water flow is from the upper part of the reactor to the bottom, and the reactor water temperature is between 20 and 25 degrees Celsius. The biological contact oxidation device is made of organic glass, the size of the reactor is 0.5 m*0.5 m*0.5 m, and volume is 100 L, moreover, the reaction chamber is filled with composite filler composed of plastic rings and high fiber bundle. The experimental flow chart is shown in figure 1.
Figure 1. AF-biological contact oxidation combined process.

2.2. Inoculated sludge
The excess sludge of urban sewage treatment plant was inoculated into the sludge of anaerobic biological filter reactor. In the initial stage, adding the flocculant of polyacrylamide to reactor to increase the stability of sludge and the depths of biological film, the concentration of polyacrylamide flocculant is 2-3 mg/L. The bio contact oxidation reactor’s sludge was taken from the northern Shenyang wastewater treatment plant, and the mixed liquid suspended solid was 2.539 g/L.

2.3. Experimental water
The experimental water is from a slaughterhouse, and the quality of the water is shown in table 1.

Table 1. Slaughter waste water table.

| Item     | COD g/L | BOD₅ g/L | NH₃-N mg/L | TN mg/L | PO₄³⁻-P mg/L | SS mg/L | Grease mg/L | pH       | chroma degree | turbidity NTU | coliform MPN/L |
|----------|---------|----------|------------|---------|--------------|---------|-------------|----------|---------------|---------------|---------------|
| 1.5-2.4  | 1-1.5   | 70-95    | 97-135     | 8.5-25  | 500-800      | 50-150  | 6.5-7.7     | 150-250  | 750-900       | 2.5x10⁴       |

2.4. Analysis method
Experimental analysis methods are shown in table 2.

Table 2. Analytical methods.

| Items     | Methods               | Instruments                                |
|-----------|-----------------------|-------------------------------------------|
| COD       | Fast hermetic digestion method (photometric) | WFJ2100 type visible spectrophotometer     |
| NH₄⁺-N    | Nessler regent spectrophotometric       |                                           |
| TN        | Persulfate oxidation-UV spectrophotometry | UV-Vis spectrophotometer                   |
| TP        | Mo-Sb Anti-spectrophotometry            |                                           |
| chroma    | Platinum cobalt standard colorimetric method | WFJ2100 type visible spectrophotometer |

3. Results and discussion

3.1. Influencing factors of coagulation sedimentation

3.1.1. Reaction temperature. The removal of COD and turbidity in coagulation sedimentation experiment are shown in figure 2.

From figure 2, the COD and turbidity’s removal rate increased with the increase of response temperature [8]. This is because when the water temperature is low, the viscosity of water is larger and the flocculation rate is slow, so it cannot get a better effect in a short time. As the temperature increased rapidly from 8°C to 16°C, the COD’s removal rate increased from 43.2% to 65.8%, and
turbidity’s removal rate increased from 67.8% to 85.3%, and when the temperature reached 16 ℃, the removal rate increased slowly. At this time, the influence of water temperature gradually began to weaken. In summary, the suitable water temperature of coagulation sedimentation was 16-24 ℃, the COD and turbidity’s removal rate were stable at 70% and 90%, respectively.

![Figure 2. Effect of feed temperature on COD.](image)

3.1.2. Reaction time. The COD and turbidity’s removal in coagulation sedimentation experiment are shown in figure 3.

![Figure 3. Effect of flocculation time of COD.](image)

From figure 3, the COD and turbidity’s removal rate increased with the increase of response time. When the reaction time was 20 min, the COD and turbidity’s removal rate were basically stable. So
the optimal reaction time was 20 min, and the removal rates were stable at 65.2% and 92.2%, respectively.

3.2. Influencing factors of AF reaction

3.2.1. Effect of filtration rate on the removal of COD and SS. The concentration of influent COD was 850 mg/L, and the influent concentration of SS was controlled by 82 mg/L.

The effect of filtration speed on COD and SS’s removals is shown in figure 4.

![Figure 4](image-url)  
**Figure 4.** Effect of the filtration rates on COD and SS.

From figure 4, the COD and SS’s removal rate decreased with the increase of filtration rate. When the filtration rate ratio was 0.2, best removal effect, but the length of the hydraulic retention time will affect the economic efficiency of sewage treatment. When the filtration rate was 1.4 m/h, the COD’s average removal rate was 40.76%, and the removal rate of SS was only 71.84%. The removal rate was mainly due to the interception and adsorption of filter material and microorganism. In summary, the reaction should keep the reaction filter rate of 0.6 m/h, and at this time, the mean value of COD and SS removal rate was 64.42% and 82.55%.

3.2.2. Effect of reflux ratio on the removal of COD and SS. The COD and SS’s removals are displayed in figure 5.

From figure 5, COD’s removal rate increased with the increase of reflux ratio, and the SS’s removal rate decreased with the increase of reflux ratio, and the reason is that the flow of water to make the suspended solid suspended matter has been absorbed into the water body so that the water quality becomes worse. When reflux ratio increased from 300% to 500%, the COD’s removal rate increased from 78.4% to 82.5%, and the change of COD removal rate was not obvious. Therefore, select 300% as the test reflux ratio, and the COD and SS’s removal rates were 78.40% and 71.22%, respectively.
Figure 5. Influence of reflux ratio on SS and COD removal efficiency.

3.3. Influencing factors of biological contact oxidation pool reaction

3.3.1. Effect of biofilm thickness on the removal of COD and NH3-N. The removal efficiency of NH3-N and COD is shown in figure 6.

Figure 6. Biofilm characteristics influence on simultaneous nitrification and denitrification.

From figure 6, the COD and NH3-N’s removal rate increased with the increase of biofilm thickness. This is because of the biological membrane with adsorption and carbon storage function. In the early
stage of the reaction, some of the organic matter is adsorbed and transferred to the biological membrane, and it is used as a carbon source for denitrification. When the thickness of the biofilm is relatively small, the anoxic environment in the biofilm is not fully formed, and the carbon source is less, which leads to the lack of denitrification ability, and the effect of nitrogen removal is not good. When the biofilm thickness increased from 0.2-0.6 mm to 1.8-2.2 mm, the COD’s removal rate increased from 40.67% to 86.45%, and the NH$_3$-N’s removal rate increased from 43.65% to 88.96%. Considering synthetically, the optimum biofilm thickness should be 1.8 mm-2.2 mm, and the removal rates of NH$_3$-N and COD were 88.96% and 86.45%, respectively.

3.3.2. Effect of gas water ratio on the removal of COD and ammonia nitrogen. Effect of gas water ratio on removal of ammonia nitrogen and COD is shown in figure 7.

![Figure 7. Effect of gas water ratio on ammonia nitrogen and COD.](image)

From figure 7, the average COD’s removal rate increased from 44.91% to 93.94% as the gas water ratio increased from 4:1 to 14:1. But after continuing to increase the gas water ratio, the COD’s removal rate decreased. The reason is that the gas water ratio is increased, the DO’s concentration is gradually increasing in the water, and the removal of organic matter is also gradually strengthened. The nitrification bacteria in the biofilm belong to aerobic bacteria, and the nitrification intensity increases with the increase of the concentration of DO. The biological contact oxidation pool is mainly transmitted through the interface transfer pathway. According to the double film theory [9], the obstruction of the air and hydraulic two-phase membrane decided the oxygen transfer rate, and the concentration of oxygen in aerobic zone will be increased by the increase of the ratio of air to water, and promote the degradation of organic matter by aerobic microorganisms. When the gas water ratio is too large, DO concentration will no longer increase. On the one hand, the amount of aeration is too large, the corresponding power consumption will increase. On the other hand, dissolved oxygen in the water will occur under the strong turbulence, biological membrane on the filler will also occur off, and the water quality of the effluent will be poor [4]. With the increase of gas-water ratio from 4:1 to 14:1,
the ammonia nitrogen’s removal rate first increased and then decreased. When the gas to water ratio was 12:1--14:1, the concentration of dissolved oxygen was 3.4-4.6 mg/L. At the time, the ammonia nitrogen’s removal rate was the highest. This is because the low concentration of dissolved oxygen resulted in the nitrification reaction is inhibited, the erosion of biological membranes are small enough, the aging biofilm was not updated, resulting in the decrease of overall activity of biofilm, which is bound to reduce the degradation of biological contact oxidation pool. Therefore, the comprehensive economic and treatment effects, the gas water ratio should not be too high, the most suitable gas water ratio is 12:1-14:1, the COD and ammonia nitrogen’s removal rate are 90% and 92.55%.

3.4. Treatment effect of AF- biological contact oxidation process

According to the above experimental conditions, stable operation has lasted for 80 days to investigate the removal efficiency of COD, TN and TP by AF- biological contact oxidation process.

3.4.1. Removal effect of AF-biological contact oxidation process on COD. The COD’s removal by AF- biological contact oxidation process under optimized conditions is shown in figure 8.

![Figure 8. AF - biological contact oxidation coupling process during the stable operation of COD removal efficiency.](image)

From figure 8, we can know that the COD’s concentration was about 2400 mg/L in the influent, after physical and chemical treatment and the average value was 836.5 mg/L. After a brief stay in anaerobic biofilter about 3 h-5 h, the treatment of the concentration of COD was about 680 mg/L-800 mg/L. To a certain extent, anaerobic biological filter can improve the biodegradability of the slaughter wastewater, which makes the subsequent biological contact oxidation process be reduced by the impact of the effect of slaughterhouse wastewater treatment [10]. Finally, the removal rate of COD
was about 98.93%, and the COD was basically stable at about 40 mg/L, the effluent quality was better, and it could meet the discharge standards.

3.4.2. Removal effect of AF-biological contact oxidation process on TN. The TN’s removal efficiency by AF-biological contact oxidation process under optimized conditions is shown in figure 9.

![Figure 9](image)

**Figure 9.** AF-biological contact oxidation coupling process during the stable operation of TN removal efficiency.

From figure 9, we can know that the concentration of TN in the influent was about 110 mg/L, during the anaerobic biological filter, TN’s removal rate was low, and the average TN removal rate was about 88.82% and after the process of biological contact oxidation tank, the average TN’s concentration in the effluent was about 11.44 mg/L. This is because the anaerobic biological filter process makes the slaughter wastewater biodegradability be further improved, at the same time, it is conducive to the conversion of organic nitrogen in wastewater to NH$_3$-N, which is conducive to the subsequent nitrification and denitrification.

3.4.3. Removal effect of AF-biological contact oxidation process on TP. The removal efficiency of TP by AF-biological contact oxidation process under optimized conditions is shown in figure 10.

From figure 10, we can see that the average concentration of TP in the waste water is 5.5 mg/L after physical and chemical treatment. Due to the death of their own microorganisms increasing the concentration of TP, anaerobic biological filter’s effluent TP removal rate is only about 5%. Therefore, the influent concentration of TP in the biological contact oxidation tank process was essentially flat with the concentration of TP in the slaughter wastewater, and the average TP’s concentration was about 5.0 mg/L, but because the anaerobic biological filter can improve the biodegradability of wastewater, and directly affect the operation effect of the process of biological contact oxidation pool, the final average TP’s removal rate was about 88.95% and the average effluent TP’s concentration was about 0.63 mg/L, so it needs further depth processing to reach the wastewater discharge standards.
4. Conclusion
Coagulation sedimentation experiments determine that the best reaction temperature is 16-24 degrees Celsius and the best reaction time is 20 min. When the reaction pH was about 7, after coagulation and sedimentation treatment, the COD’s removal rate and turbidity were 70% and 90%, which reached the ideal physical and chemical treatment effect.

Treatment of slaughterhouse wastewater by AF process, the best reaction filtration rate is 0.6 m/h, after the treatment process by AF, the COD and SS’s removal rates were 64.42% and 83.06%. The optimum reflux ratio is 300%; the COD and SS’s removal rates were 78.40% and 71.22% under the reaction conditions to achieve the best treatment effect.

When the biological contact oxidation process is treated with separate treatment of slaughter wastewater, the optimum biofilm thickness is 1.8-2.2 mm, the optimum reaction gas-water ratio is 12:1--14:1, and the best treatment effect is achieved under the above conditions.

According to slaughter wastewater treatment under the optimal parameters of AF - biological contact oxidation process, the effluent concentration of COD, TP, TN were 40 mg/L, 0.63 mg/L and 11.44 mg/L. The average removal rates were 98.93%, 88.95%, 88.82% and wastewater treatment effect is very good.

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