Experimental Study on Dairy waste water treatment by Photosynthetic bacteria

Shuai Wang1, Changhao Yao1, Lianying Jia1, Yang Yang1,*
1University of East University of Heilongjiang, Heilongjiang, China

*Corresponding author e-mail: okyangyang@yeah.net

Abstract. Compared with the results of experiments, the effect of PSB on dairy waste water treatment and influencing factors were studied. The experimental results show that the removal efficiency of COD and BOD5 in dairy wastewater by PSB is much higher than the traditional methods. Under the anaerobic acidification-semi micro oxygen and semi-darkness conditions, the removal efficiency of COD is better than that under anaerobic light-illumination and aerobic darkness conditions. The optimal conditions are that the temperature is controlled between 15℃ and 30℃, and the value of pH is 6.5-8.5, and the volume ration of wastewater and bacterial liquid is at 3:1, and DO in system is about 0.1-0.8mg/L. The stable water quality and higher removal efficiency of COD and BOD5 provide the basis for the further treatment of high concentration organic wastewater.

1. Introduction

With the improvement of people's living conditions, China's dairy processing industry has developed rapidly, meanwhile, which caused a large amount of dairy wastewater discharge. Dairy wastewater contains a lot of organic pollutants, such as protein, fat, lactose, oil and so on. COD concentration is in the range of 1 000 mg/L to 4000 mg/L. Biological methods are mostly used in the treatment of dairy wastewater in China, particularly, aerobic process has achieved some research and application results. However, when dealing with dairy wastewater containing a large number of hardly degradable substances, aerobic process has the problems of energy consumption by aeration and high operating costs [1]. Therefore, it is an urgent task to find a better treatment process and treatment method in sewage treatment engineering. Photosynthetic bacteria (PSB) are a group of bacteria that photosynthesize under anaerobic conditions without releasing oxygen. They can utilize low molecular weight organic matter under anaerobic light, aerobic dark, semi-dark and slightly aerobic conditions. Using PSB to treat high concentration organic wastewater not only has simple process equipment, low treatment cost and high organic load, but also produces bacteria which can be used comprehensively without secondary pollution, which has strong practicability and applicability.

2. Materials and methods

2.1. Materials

2.1.1. Wastewater quality

The test wastewater is taken from the production wastewater discharged from a dairy enterprise. The specific water quality index is shown in Table 1.
Table 1. Qualities of the wastewater from dairy processing industry.

| Item      | Concentration (mg/L) |
|-----------|-----------------------|
| COD       | 1480-1960             |
| BOD$_5$   | 590-720               |
| SS        | 180-220               |
| NH$_4^+$-N| 18-28                 |
| TP        | 5-15                  |

2.2. Experimental strain
The mixed strains of PSB were used in the experiment, and most of them were Palustris R P and Sphaeroides R P. The composition of culture medium was CH$_3$COONa 3.0 g, CH$_3$CH$_2$COONa 0.3 g, NaCl 1.0 g, (NH$_4$)$_2$SO$_4$ 0.3 g, MgSO$_4$.7H$_2$O 0.2 g, KH$_2$PO$_4$ 0.5 g, K$_2$HPO$_4$.0.3 g, CaCl$_2$ 50 mg, MnSO$_4$ 5 mg, FeSO$_4$ 5 mg, yeast extract 0.1 g, peptone 10 mg, distilled water 1000 mL.

2.3. Process flow and test model
2.3.1 Process flow
The experimental process of treating dairy wastewater by PSB process is shown in Fig.1.

![Process Flow Diagram](image)

1. Wastewater tank; 2. Water pump; 3. Flowmeter; 4. Hydrolyzer; 5. First PSB reactor; 6. Secondary PSB reactor; 7. Settling tank; 8. Fostering tank of PSB

Figure 1 Work process

2.3.2 Test model
The effective volume of water storage tank is 1 m$^3$, which can store wastewater to ensure the normal operation of the system. The effective volume of hydrolysis column is 0.35 m$^3$, which is used for the soluble pretreatment of wastewater. Two series operation PSB reactors are operated in the effective volume of 0.7 m$^3$ and 0.3 m$^3$ respectively, and a gas supply device is installed at the bottom of the reactor. The effective volume of sedimentation tank is 0.1 m$^3$. The sediment sludge is pumped back into the culture tank of photosynthetic bacteria, and then cultured as the bacterial liquid supply of PSB reaction column.

2.4. Testing method
The test method is shown in Table 2.

Table 2. The determination method of the test

| Item      | Means name                    | Means standard size |
|-----------|--------------------------------|---------------------|
| pH        | Glass electrode method         | GB6302-86           |
| COD       | Dichromate method              | GB/T 11914-1989     |
| BOD$_5$   | Dilution and inoculation       | HJ 505-2009         |
3. Results and discussions

3.1 Static inoculation domestication and growth conditions of PSB

In this device, photosynthetic bacteria strains and culture medium were added to the PSB reactor in a certain amount. During the domestication process, the proportion of dairy wastewater was gradually reduced, and the number of culture medium was reduced until all the dairy wastewater was added. The dissolved oxygen in the PSB reactor was controlled at 0.1-0.8 mg/L by proper aeration. The transmittance of the liquid in the reactor was measured, by which the growth of photosynthetic bacteria was described[2].

During the experiment, the concentration of photosynthetic bacteria increased with the increasing proportion of wastewater. The reciprocal of $1/T$ transmittance is used as ordinate to describe the growth of photosynthetic bacteria. The smaller the transmittance (T), the larger the transmittance ($1/T$), which indicates that the higher the concentration of photosynthetic bacteria at early, the slower the growth rate of photosynthetic bacteria is. With the increase of culture and domestication time, photosynthetic bacteria gradually adapt, the density of bacteria increases, the transmittance decreases, and the $1/T$ increases. The growth of photosynthetic bacteria is shown in Figure 2.

![Figure 2](image)

**Figure 2** The PSB growth situation during the static inoculation acclimation

The variation of COD in the inlet and outlet water of PSB reactor system with time during static culture and acclimation stage is shown in Table 3.

| Time (d) | Influent COD (mg/L) | Effluent COD (mg/L) | Removal rate of COD (%) |
|----------|----------------------|---------------------|-------------------------|
| 5        | 1150                 | 750                 | 34.8                    |
| 10       | 920                  | 550                 | 40.2                    |
| 15       | 1050                 | 496                 | 52.8                    |
| 20       | 980                  | 380                 | 61.3                    |
| 25       | 1250                 | 430                 | 65.6                    |
| 30       | 850                  | 230                 | 72.9                    |

After 15 days of cultivation and domestication, the removal rate of COD increased significantly due to the rapid increase of bacterial density. After 30 days, the removal rate of COD reached more than 70%. The experimental results show that the PSB reactor is easy to start up and the cultivation and domestication cycle is short.

3.2 Static PSB Growth Conditions Test

3.2.1 Effect of Bacterial Density on COD Degradation by PSB

The volume ratio of dairy wastewater to PSB bacterial solution (bacterial density 107-108 cell mL-1) is shown in Fig. 3. The operation results are adjusted to 1:1, 2:1 and 3:1 respectively.
At the beginning of the reaction, COD decreases gradually with the reaction time. When the reaction reaches 24 hours, the decreasing trend of COD slows down obviously, and almost stagnates after 36 hours[3]. When the volume ratio of wastewater to bacterial liquid is 3:1, the degradation rate of COD is the highest, followed by 1:1 and 2:1, and the removal efficiency of COD is the best when the volume ratio of wastewater to bacterial liquid is 3:1. Experiments to continue to increase the proportion of wastewater and the reasons for this effect remain to be further explored.

3.2.2 Effect of pH Value on COD Degradation by PSB
Photosynthetic bacteria can use organic acids, amino acids or other nitrogen-containing compounds produced by hydrolysis pretreatment to produce deamination and decarboxylation in the metabolic process. The experimental results of different pH values are shown in Fig. 4. When pH < 7.0, decarboxylation is greater than deamination, which makes the wastewater treatment system alkaline reaction; when pH > 7.0, deamination is greater than decarboxylation, which makes the wastewater treatment system acidic reaction, and makes PSB have a wide range of pH adaptability. Therefore, in the range of pH 6.5-8.5, the treatment effect is less affected by the pH value.

3.2.3 Effects of Light Mode and DO on COD Degradation by PSB
Fig. 5 is the experimental results under anaerobic light (DO < 0.2 mg/L-1, indoor natural light, night light source (2 *100 W tungsten iodide lamp), aerobic darkness (DO > 1 mg/L-1, container wrapped in black cloth) and semi-dark micro-aerobic (DO= 0.1-0.8 mg/L-1, indoor natural light).
It can be seen that under semi-dark and micro-aerobic conditions, COD degradation rate is fast and the treatment effect is the best, followed by aerobic darkness, and anaerobic light is poor. Under semi-dark and slightly aerobic conditions, bacteria can obtain energy through aerobic respiration, which can inhibit the anaerobic bacteria in wastewater. Proper control of oxygen supply can promote the growth of facultative aerobic bacteria in water, so that photosynthetic bacteria can continuously obtain the small molecular organic substances needed for proliferation, thereby improving the purity of PSB to wastewater. In the wastewater treatment system of PSB, photosynthetic bacteria and facultative aerobic bacteria have an intergrowth relationship. Facultative aerobic bacteria provide suitable carbon source for the growth and proliferation of photosynthetic bacteria and create an appropriate anaerobic environment. The growth of photosynthetic bacteria eliminates the negative feedback inhibition of toxic metabolites on facultative aerobic bacteria, so half of them. The effect of dark micro-aerobic treatment is much better than other methods.

4. Dynamic Continuous Operation Test

4.1. Operation effect and analysis

The dynamic experiment started in March 2018. Under semi-dark and slightly aerobic conditions, reciprocating plunger pump was used to continuously water the PSB system. Flow meter was used to control the volume ratio of photosynthetic bacteria in the culture tank to the wastewater.

In the initial stage of dynamic continuous operation, the suspended matter in the effluent of the system is higher and photosynthetic bacteria are lost. By gradually adjusting the inflow flow, the suspended matter in the effluent decreases. When the PSB reactor hydraulic residence time is 36 h, the effluent is clear and the water quality is stable. The operation effect is shown in Figure 6.

![Figure 5 Influence of way of illumination the PSB degrading COD](image)

![Figure 6 Dynamic operation effects under the condition of slight aerobic and semi-darkness](image)
During the dynamic operation period, the COD concentration of PSB system water is 1400-1800 mg/L, the COD of effluent water is 127-185 mg/L, the average removal rate is 90.7%, the BOD₅ of system water is 620-820 mg/L, and the BOD₅ of effluent water is 32-62 mg/L, the average removal rate is 94.8%.

The experimental results show that photosynthetic bacteria have strong adaptability to dairy wastewater and strong degradation ability. This is mainly due to the photosynthetic bacteria not only absorb nutrients in water to maintain the energy needed for self-growth and reproduction, but also absorb trace oxygen to maintain the oxygen required for degradation of organic matter in wastewater. Through photophosphorylation and tricarboxylic acid cycle, the metabolism of organic matter can be closely linked with the photo-oxidation-reduction reaction. Therefore, the metabolic efficiency of organic matter in wastewater is high and the utilization speed is fast, which makes COD and BOD₅ have higher removal rate. Because the concentration of effluent from PSB system is still high, COD is 1257-1689 mg/L, BOD₅ is 330-614 mg/L. After aerobic treatment, the discharge requirement can be met (COD < 100 mg/L, BOD₅ < 60 mg/L).

5. Conclusion

A. Using PSB process to treat dairy wastewater, PSB system has a high removal efficiency of COD in high concentration organic wastewater. Under semi-dark and slightly aerobic conditions, the treatment effect of wastewater is better than that under anaerobic illumination and aerobic darkness. The effluent quality is stable, and the average removal rate of COD reaches 90.75%.

B. Experiments show that PSB has the advantages of easy start-up, short incubation and domestication period, stable operation under high organic loading, high concentration organic wastewater treatment without dilution.

C. PSB not only has strong adaptability to temperature, but also has a wide range of adaptability to pH value. The treatment of dairy wastewater under semi-dark and slightly aerobic conditions is recommended under the following conditions: temperature 15-30°C; pH 6.5-8.5; volume ratio of wastewater to bacterial liquid 3:1; dissolved oxygen in PSB system 0.1-0.8 mg/L; hydraulic retention time 32-38 h.

D. Dairy wastewater treated by PSB system can meet the discharge requirements after aerobic treatment.

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