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UASB-A/O-BAF treatment of high strength wastewater: a case study for soybean protein wastewater

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ABSTRACT

During the soybean protein production process, a large amount of wastewater is being produced. Currently in China, the soybean protein wastewater produced everyday has reached over 60,000 m^3. A technology to bring about a better wastewater treatment effect with reasonable cost of the wastewater treatment is expected to be employed. In the present study, with a view to enhancing the discharge water quality, a combined processing method incorporating a pretreatment unit, an upflow anaerobic sludge blanket (UASB) reactor, an anoxic–oxic treatment system, and a biological aerated filter (BAF), was employed. After a steady performance of all the wastewater treatment units, the facilities will have the capacity to can handle 1,000 m^3 wastewater with the chemical oxygen demand (COD) of 18,000 mg/L each day. The total COD removal efficiency can reach 99.84%, and the final discharge water will contain a COD of 40 mg/L. The wastewater treatment cost amounts to only about 2 Yuan RMB/m^3 wastewater. Additionally, the CH_4 gas produced mainly from the UASB reactor is use to serve as the energy for the soybean protein production plant and thereby bring about a saving in the energy cost to the tune of about 3,500 Yuan RMB each day.

Keywords: UASB; BAF; COD; Soybean protein wastewater

1. Introduction

The soybean protein is widely used as a food additive on account of its comprehensive nutritional components. The global demand for soybean protein is far above its actual production [1]. The soybean protein production is assured of good demand in the future. The isolation process of a soybean protein usually employs the alkaline extraction method [2]. Sodium hydroxide is first added to make the soybean protein soluble, and hydrochloric acid is added for pH adjustment to separate the protein from the solution. During the production process, a large amount of wastewater, which contains organic substances such as protein, sugar, etc., as well as inorganic substances such as salt, Cl^-, and SO_4^{2-}, is produced; therefore, it is difficult to treat the wastewater [3]. The production of soybean protein has far exceeded 0.04 billion t per year and its wastewater load has been over 60,000 t per day in China. Meanwhile, the production scale tends to increase every year. It is necessary to improve the wastewater treatment technique and enhance the discharge water quality, and all these measures are expected to be carried out with reasonable cost of wastewater treatment.

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The current biological wastewater treatment technology for in use covers the membrane reactor, anoxic treatment, oxic treatment, etc. [4,5]. The membrane reactor displays the features of high treatment efficiency, low sewage production, and simple operation process, but with high cost; oxic treatment can remove the large quantity of organics, but for the high strength of organics in soybean protein wastewater, a high aeration rate is required and it is followed by energy consumption and high cost; the use of only anoxic process in the soybean wastewater treatment such as upflow anaerobic sludge blanket (UASB) [6–8], anaerobic baffled reactor (ABR) [9], and anaerobic filter (AF) [10] system, while the application of these methods by us in full-scale plants cannot attain a satisfactory discharge water quality. Considering both the technological and economical factors, the anoxic methods combined with oxic means are an appropriate way for soybean wastewater treatment. From the literature related to treatment effect by the anoxic and oxic combined method, most of the studies can meet the "*Integrated Wastewater Discharge Standard in China*" (GB 8978-1996), which requires the chemical oxygen demand (COD) of wastewater to be reduced to below 1,000 mg/L. But with expansion of the soybean protein production and the enhancement of the COD discharge amount control by the Chinese government, a more strict discharge water quality is bound to be required in the near future.

The present study set up a combined processing method, including a pretreatment unit, an UASB reactor, an anoxic–oxic treatment (A/O) system, and a biological aerated filter (BAF). After being treated by the combined process, the discharge water from a soybean protein production plant can attain the COD of 40 mg/L, biochemical oxygen demand (BOD) of 8 mg/L, ammonia of 4 mg/L, which has been better than the current value of first class A in "*Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant*" (GB 18918-2002, COD below 50 mg/L is required).

2. Materials and methods

2.1. Experimental setup

A schematic diagram of the experimental system is shown in Fig. 1.

The process includes the following four periods:

(1) *Pretreatment period*: First, the grid was used to remove the rough particles and suspended particles, followed by the pH adjustment. Then the wastewater entered the primary settling tank, where a part of the COD and the suspended solid (SS) removal by sedimentation and a large part removal and a large part by flocculation and air flotation were achieved.
(2) *Anoxic treatment period*: By the application of UASB, the anaerobe and denitrifying bacteria in the reactor can hydrolyze, ferment, and degrade organic pollutants.
(3) *Anoxic–oxic treatment period*: The organic pollutants in wastewater were eliminated through biological conversion by the aerobes and anaerobes in this period.
(4) *Deep treatment period*: The aerobes, anaerobes, and facultative aerobes in BAF act to decompose the organic pollutants.

2.2. Sewage quality

The sewage parameters of the soybean protein processing are listed in Table 1.

2.3. Setup and operational details of the combined system

2.3.1. Pretreatment

At first, 3 kg/m^3 $Ca(OH)_2$ was added into the sewage to adjust the pH and remove parts of COD and phosphate. By this step, the COD removal efficiency can reach beyond 20%. The polyacrylamide (PAC) and poly aluminum chloride (PAM) flocculent were then added and the removal efficiencies of the COD and the suspended solids were about 25 and 60%. The conditions favorable for the microbial growth were then obtained and the effluent entered the following biological treatment units.

2.3.2. Start-up and operation of UASB

The seed sludge was collected from the anaerobic digestion tank at the Jinan Sewage Treatment Plant. The seed sludge occupied about 20% of the effective capacity of the UASB reactor. In the beginning, the COD concentration was about 4,000–5,000 mg/L and the effective capacity was maintained at about 3 kg COD/m^3 d, with a reflux ratio of 100%. After 30 days of operation, the COD concentration was about 8,000–10,000 mg/L, and the volumetric loading was 6 kg COD/m^3 d, and then a continuous water inflow was kept for another 30 days. The influent COD and volumetric loading were elevated gradually until they reached 12,000–15,000 mg/L and 10 kg COD/m^3 d, at this time, the COD removal efficiency was about 90%

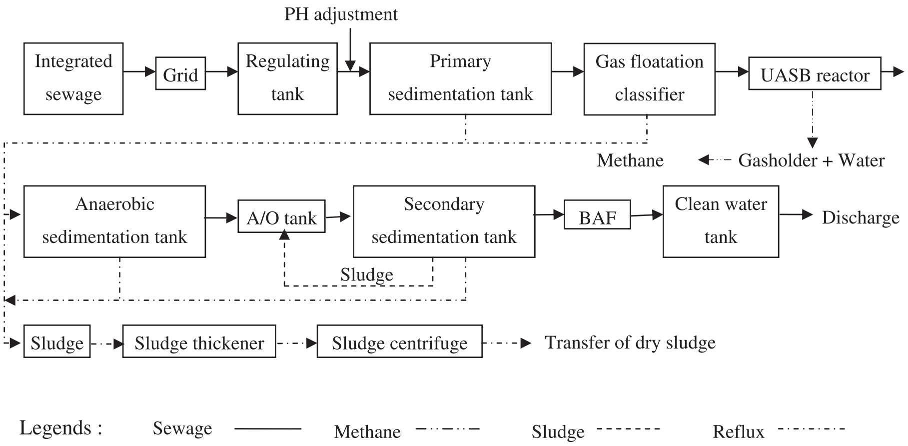

Fig. 1. Schematic diagram of the UASB-A/O-BAF treatment process.

Table 1
Characteristics of the influent sewage

Parameters	Average value
PH	4.5
Sewage temperature (℃)	46
Load (m^3/d)	1,000
COD (mg/L)	18,000
BOD (mg/L)	8,000
Ammonia (mg/L)	60
Kjeldahl nitrogen (mg/L)	800
Sulfate (mg/L)	450
SS (mg/L)	3,000

and the sludge granulation was carried out to the finish. The UASB stage was started up successfully in total 90 days and entered a steady operation period.

2.3.3. Start-up and operation of an A/O process

The seed sludge collected from the aerobic sedimentation tank at the Jinan Sewage Treatment Plant was incubated in an aerobic tank and introduced into the anaerobic tank at a reflux ratio of 200% to guarantee sufficient sludge concentration and to supply enough carbon source to the anaerobic tank. After incubation with batch water feeding for 20–30 days, the mixed liquor suspended solids (MLSS) increased to 4,000 mg/L, and the settling velocity (SV) increased to about 30%; the dissolved oxygen (DO) of the aerobic tank was maintained at around 2–4 mg/L and the influent COD was about 1,000 ~1,200 mg/L; the effluent
COD decreased gradually to 100–150 mg/L and the COD removal efficiency was about 90%; ammonium concentration reached 10 mg/L with a removal efficiency of 92%, and SS also decreased to about 100 mg/L; the floc structure of sludge was good. Then, the incubation process of sludge was completed and the A/O tank could perform normally to full capacity.

2.3.4. Start-up and operation of BAF

In the early stage of the start-up period, the clay ceramisite was added into the aerobic tank, and the secondary sedimentation tank effluent was introduced into the aerobic and kept without water flow for 3 days. The batch water feeding was followed till the influent reached the designed capacity. The whole process took about 20 days. The removal efficiency of the COD and ammonia finally reached 75 and 70%.

2.4. Chemical analysis method

Ammonia (NH_3-N), COD, BOD, pH, and SS were analyzed according to the Standard Methods for the Examination of Water and Wastewater.

3. Results and discussion

3.1. Pretreatment

The raw influent sewage contains salts, acids, and other substances that will inhibit the microbial growth, and suitable ambient conditions are required for implementing the following UASB process. As regards a USAB reactor's performance, the granulation process is one of the most important sections that determine the wastewater treatment effect. Many factors can influence this section, such as pH, operating temperature, compo-

Table 2
Characteristics of effluent in the pretreatment process

Parameters	Average value
PH	6.5
COD (mg/L)	12,000
BOD (mg/L)	4,500
Ammonia (mg/L)	50
SS (mg/L)	1,000
Biogas production (m^3/kg COD)	–

sition, and concentration of organic matter in wastewater, hydrodynamic conditions, and so on [11].

In this pretreatment process, pH adjustment, grid block, flocculent and flotation, the COD and BOD decreased to a level that fitted the UASB treatment (Table 2). Apparent results have been gained, especially for the flocculants added, as previous laboratory experiments have shown (Fig. 2). In a UASB reactor treating dairy manure, the addition of polymer flocculants also helped improve the performance [12].

3.2. UASB process

For the high COD concentration of soybean protein wastewater, the UASB was selected to act as one of the most important treatment processes. In the UASB reactors, the microorganism is mainly adsorbed in the granular sludge, resulting in a large microbial biomass in the unit volume of the reactor [13]. The UASB reactor can treat heavy-loaded sewage with high organics removal efficiency [14,15]. With a gas–solid–liquid triphase separator set up below the reactor, an additional sediment separator, return sludge equipments, and assistant degassing facilities were not needed, thereby effectively bringing down the requirement on energy and costs required for the process. In the present study, as Table 3 shows, when the COD concentration was reduced by about 90%, the largest part of COD was removed from this unit. And about 0.3 m^3 CH_4 for per kg COD was obtained in the steady operation period, which means an additional profit was gained. The conversion rate of the removed COD to methane is similar to that of the sewage discharged from a sunflower oil factory, whose study gained a ratio of 0.16–0.354 m^3 CH_4/kg COD [16].

Fig. 2. Control of soybean protein wastewater with and without addition of PAC.

3.3. A/O process

The soybean protein wastewater contained a high concentration of ammonia and Kjeldahl nitrogen. The A/O system supplies sufficient carbon source for biological denitrification, and both the sludge and bacteria present in the system reduce the nitrogen concentration [17]. With low-cost and flexible operation modes, the A/O system also occupies a smaller space than the traditional denitrification facilities, and it can perform well at a large range of hydraulic shock loads [18]. So in the present study the A/O system was set up for removing nitrogen. From Table 4, it can be calculated that ammonia has reduced 95.3%,

Table 3
Characteristics of the effluent in the UASB process

Parameters	Average value
PH	7.2
COD (mg/L)	1,200
BOD (mg/L)	350
Ammonia (mg/L)	300
SS (mg/L)	800
Biogas production (m^3/kg COD)	0.3

Table 4
Characteristics of the effluent in the A/O process

Parameters	Average value
PH	7
COD (mg/L)	120
BOD (mg/L)	40
Ammonia (mg/L)	14
SS (mg/L)	150
Biogas production (m^3/kg COD)	–

Table 5
Characteristics of the effluent in the BAF process

Parameters	Average value
PH	7
COD (mg/L)	40
BOD (mg/L)	8
Ammonia (mg/L)	4
SS (mg/L)	30
Biogas production (m^3/kg COD)	–

while the COD and BOD concentration has reduced 90 and 88.6% respectively.

3.4. BAF process

The BAF has a high removal efficiency of SS, COD, nitrogen, and adsorbable organic halides (AOX), featuring biological oxidation and withholding of suspended solids [19], high volumetric loading and hydraulic loads, short retention times, low investment, good effluent quality and low energy and cost needed [20]. To use BAF in the present study is to further elevate the sewage effluent quality. As Table 5 shows, COD reduced 66.7%, BOD reduced 80%, and ammonia reduced 71.4%.

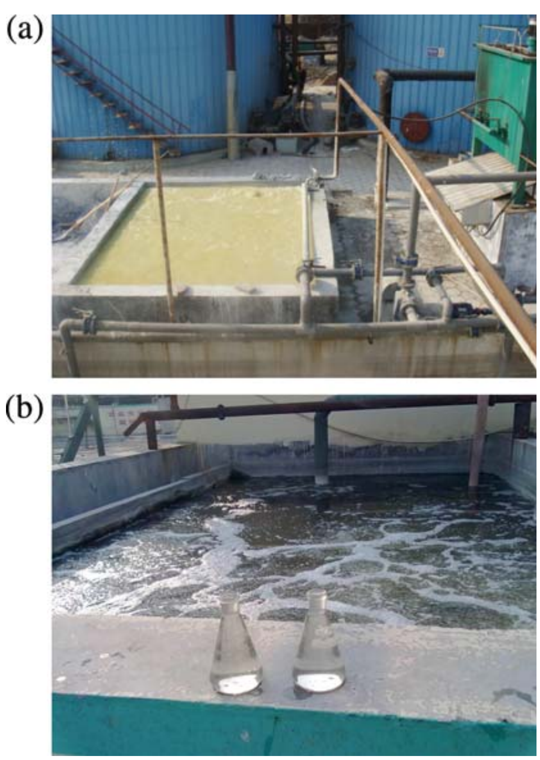

Fig. 3. Comparison of the influent (a) and effluent (b).

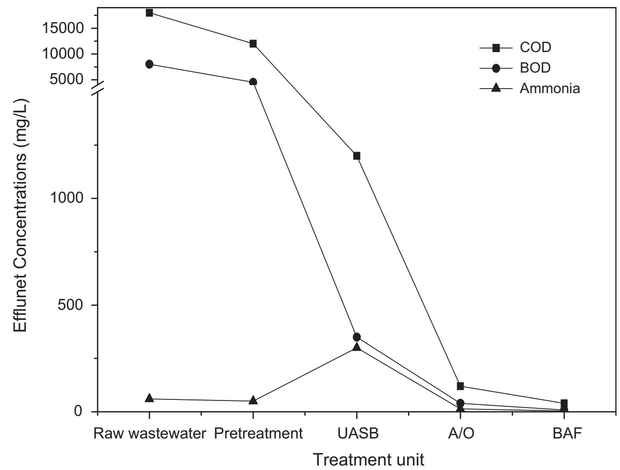

Fig. 4. COD, BOD and ammonia concentrations in the effluent of different treatment units.

3.5. Review of the combined process

A good performance of the combined process is possible to be attained, as it can be observed from Figs. 3 and 4. The total removal efficiency of COD, BOD, and NH_3-N has reached 99.84, 99.90, and 93.33%, respectively (Table 6). The UASB reactor shows the highest removal efficiency of COD and BOD, while A/O shows the highest removal efficiency of NH_3-N among the four treatment units.

The combined process shows a better treatment efficiency than those reports that used one-stage process or any other combined methods. For example, Wang et al. obtained a COD removal efficiency of 98.7% on the treatment of potato starch wastewater with an anaerobic–aerobic bioreactor [18]. Zhu et al. used an anaerobic baffled reactor for soybean protein wastewater treatment and the COD removal efficiency ranged from 92 to 97% [9].

Table 6
Review of the results of the combined process treatment (Indicated by removal efficiency (%))

Units	COD	BOD	NH_3-N
Pretreatment	59.26	43.75	16.67
UASB	92.22	92.22	–
A/O	81.36	88.57	95.33
BAF	80.43	80	71.43
Total	99.84	99.9	93.33

Table 7
Cost for the combined process treatment

	Unit	Daily consumption	Unit price	Cost
	Unit		Data	
Electricity cost				
Electric rate	Yuan/KW h		0.6	
Daily operation time	h		24	
Daily power	KW		1,156.08	
Daily electricity cost	Yuan/d		694	
	Unit	Daily consumption	Unit price	Cost
Chemical cost (according to the maximum amount)				
Base consumption	T/d	1	150	150
PAC consumption	T/d	0.15	1,800	270
PAM consumption	T/d	0.01	10,000	100
Daily chemical cost	Yuan/d		520	
Labor cost				
Operators	Person		6	
Unit labor cost	Yuan/person d		30	
Daily labor cost	Yuan/d		180	
Total				
Daily cost	Yuan/d		1,394	
Daily sewage production	m^3/d		720	
Unit sewage treatment cost	Yuan/m^3		1.92	

Note: Depreciation expense and maintenance expense were not covered.

3.6. Total cost

From Table 7, it can be found that the treatment cost is only about 2 Yuan RMB/m^3 wastewater. Additionally, the CH_4 gas produced from the UASB reactor can save the energy cost to the tune of about 3,500 Yuan RMB each day.

4. Conclusions

The combined processing method was successfully applied to treat soybean protein wastewater, composed of a pretreatment unit, an UASB reactor, an A/O system, and a BAF. By the treatment, the COD decreased from 18,000 to 40 mg/L, the BOD reduced from 8,000 to 8 mg/L, and NH_3-N decreased from 60 to 4 mg/L. The economic investment needed for this combined processing method is very low, only about 2 Yuan RMB/m^3 wastewater was the cost.

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