Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2012.749037

51 (2013) 3248–3256
April

Taylor & Francis
Taylor & Francis Group

Study and application of biological-aerated filter (BAF) in soybean protein advanced wastewater treatment

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Received 26 October 2011; Accepted 9 September 2012

ABSTRACT

Laboratory study and practical application of biological-aerated filter were investigated for soybean protein advanced wastewater treatment. The influences of media height, hydraulic retention time (HRT), and air–liquid ratio (A/L) on chemical oxygen demand (COD_{Cr}), biochemical oxygen demand (BOD_5), ammonium (NH_4^+–N), suspended solid (SS), and chromaticity of effluent were investigated in laboratory study and practical application. The results indicated that media height of 80 cm, HRT of 4 h, and A/L of 15:1 were the optimum conditions in laboratory study, and the mean effluent concentration of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity was 39, 5.8, 2.5, 13.6 mg L^{-1}, and 16, respectively. When the optimum conditions of laboratory study were applied in practical project, the mean effluent concentration of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity was 50, 7.9, 3.2, 18.8 mg L^{-1}, and 24, respectively. All the indicators was lower than the limits of the discharge standards of Shandong Province ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}, NH_4^+–N ≤ 5 mg L^{-1}, SS ≤ 20 mg L^{-1}, chromaticity ≤ 30).

Keywords: Laboratory study; Practical application; BAF; Soybean protein wastewater; Advanced treatment

1. Introduction

As a novel, flexible, and effective reactor, biological-aerated filter (BAF) was first developed in Europe and then widely applied all over the world as a wastewater treatment system [1,2]. BAF is a type of immobilization reactor which can maintain high organic and hydraulic loadings, retain much higher biomass concentration than conventional suspended growth activated sludge systems and tricking filters [3] and is characterized by less sludge formation, stronger environmental shock resistance, and a smaller size of reactor [4,5]. The land required for a BAF system is only approximately one-fifth of that needed for plastic media trickling filters and one-tenth of that needed for activated sludge plants [6,7]. Therefore, it is crucial to investigate and apply BAF in wastewater treatment.

In some developing countries, a great number of BAFs were designed for chemical oxygen demand (COD), ammonia nitrogen (NH_4^+–N), total nitrogen (TN), total phosphorus (TP), and suspended solid (SS) removal in secondary and tertiary wastewater treat-

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ment [8–11]. In recent years, BAF have been utilized to treat wastewater from slaughterhouses, pulp, mill industries [12,13], and refractory wastewater such as electroplating, picric acid, pharmaceutical, and textile wastewater [14–17]. Because of its smaller space requirement and lower practical project investment, more and more attention will be paid to the investigation and application of BAF.

As a kind of main foodstuff additive, soybean protein is produced from soybean; during the whole process, a large quantity of industrial water is consumed and a great deal of wastewater is generated. Abundant and functional organic substances contain in the wastewater from soybean protein processing [18], which was characterized by high COD, biological oxygen demand (BOD) [19,20], and SS values due to the high protein content [21], and it certainly causes serious pollution to the environment. Currently, the treatment studies on soybean protein processing wastewater have mostly focused on SBR and membrane technology [22,23]. However, if just relying on primary and secondary treatment, soybean protein processing wastewater could not reach the requirement of the discharge standards. Therefore, tertiary or advanced treatment on soybean protein processing wastewater is essential.

In this research, BAF was designed for COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity removal in advanced treatment of soybean protein processing wastewater. There were three objectives in this work. Firstly, BAF was designed for advanced treatment of soybean protein processing wastewater in laboratory and the optimum conditions (including media height, hydraulic retention time (HRT), and air–liquid ratio (A/L)) for the wastewater treatment were determined according to the limits of the discharge standards of Shandong Province ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}, NH_4^+–N ≤ 5 mg L^{-1}, SS ≤ 20 mg L^{-1}, chromaticity ≤ 30). Secondly, the optimum conditions for the wastewater treatment in laboratory study were applied in practical project for advanced treatment of soybean protein processing wastewater in BAF. Thirdly, the removal efficiency of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity in laboratory study was compared to that in practical application under the same conditions.

2. Materials and methods

2.1. Soybean protein processing wastewater

During the whole experimental period, the wastewater was obtained from a soybean protein processing

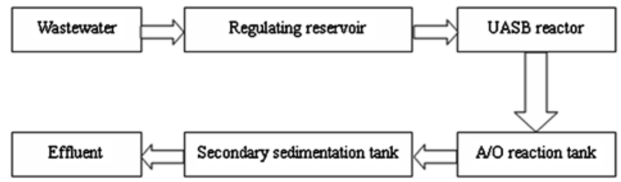

Fig. 1. The preliminary treatment of soybean protein processing wastewater.

enterprise (in Dezhou, Shandong Province, China). The preliminary wastewater treatment is shown in Fig. 1. It can be seen that the wastewater was firstly led to Upflow Anaerobic Sludge Bed (UASB) reactor, then effluent of UASB was fed into Anoxic/Oxic (A/O) reaction tank, and the treated water was collected into secondary sedimentation tank. The quality of effluent is shown in Table 1. It revealed that all the indicants of effluent exceeded the limits of the discharge standards of Shandong Province of China ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}, NH_4^+–N ≤ 5 mg L^{-1}, SS ≤ 20 mg L^{-1}, chromaticity ≤ 30). Therefore, the BAF system was designed for advanced treatment on effluent of secondary sedimentation tank.

2.2. Reactor in laboratory

As shown in Fig. 2, a labscale upflow BAF was designed for this experiment. The cylindrical reactor was made from polymethyl methacrylate, the diameter, effective volume, and height of this reactor were 100 mm, 18.8 L, and 2.0 m, respectively. The column was filled with ceramic fillers (37.7 L) and the height of fillers was 120 cm. The characteristics of the ceramic fillers media were as follows: diameter of 3–5 mm, grain density of 1,137 kg m^{-3}, bulk density of 885 kg m^{-3}, specific surface of 5.365 m^2 g^{-1}, and water absorption of 5.78%. Under the fillers, there was a graded gravel layer with the height of 20 cm, which made the wastewater and air distribute throughout. In order to aerate sufficiently and supply backwashing gas during the backwashing operation, three air diffusers were located at the bottom of the graded gravel layer. The reactor was supported by the bracket made from steel, and there was a buffer zone with a height of 35 cm at the top of the column, which could prevent the fillers from being washed away by backwashing gas and water. A feed pump was utilized to feed the raw wastewater into the column and an effluent tank was used to collect the treated effluent, which was utilized as backwashing water. From the bottom of the fillers, there were six sampling ports which were placed at 20, 40, 60, 80, 100, and 120 cm, respectively.

Table 1
The quality of effluent after the preliminary treatment

Indicant	COD_{Cr} ($mg\,L^{-1}$)	BOD_5 ($mg\,L^{-1}$)	NH_4^+–N ($mg\,L^{-1}$)	SS ($mg\,L^{-1}$)	pH	Chromaticity (°)
Numeral value	120–150	20–30	12–15	60–70	6–9	48–64

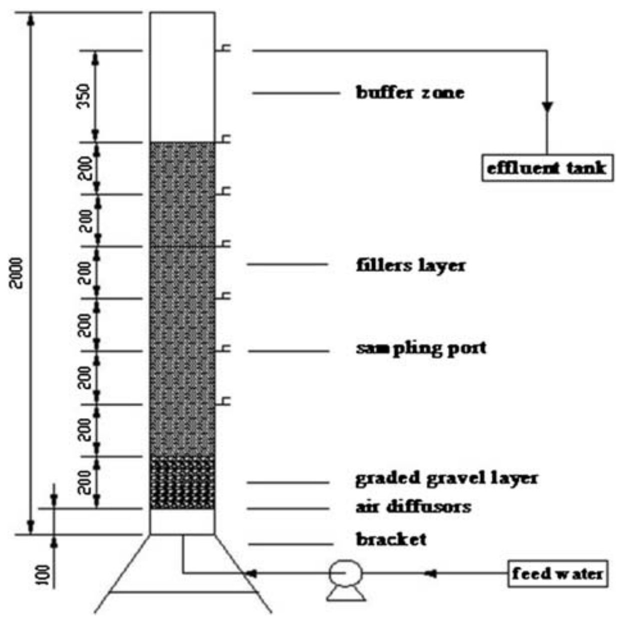

Fig. 2. Schematic diagram of experimental (dimensioning unit: mm).

2.3. Start-up and run

Concentrated activated sludge of an aeration basin in the A/O process from the soybean protein processing plant enterprise was fed into this BAF reactor. At the beginning, the reactor ran in batch mode for about one week and then turned to continuous operation. During the acclimatization period, the basic operation conditions were as follows: media height of 120 cm, HRT of 12 h, A/L of 20:1, and total flow rate of 1.6 L h^{-1}. The hydraulic and organic loads were varied in terms of the removal of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity, respectively. After three weeks, the column reached steady state according to the removal efficiency of indicants. During the period of culture organism, the column was backwashed every three days. A backwashing sequence included three phases—air scour, air–water scour and water scour, every phase continued for 10 min, air flow and water flow rate were 6 L min^{-1} and 4 L min^{-1}. During the backwashing process, the automatic system was used.

After reaching steady state, media height, HRT and A/L were varied, respectively. Firstly, six media heights (20, 40, 60, 80, 100, and 120 cm) were selected, and other operation parameters were as follows: HRT of 12 h, A/L of 20:1, and total flow rate of 1.6 L h^{-1}. Secondly, eight HRTs (12, 10, 8, 6, 4, 2, 1, and 0.5 h) were determined in terms of the effective volume of the column. Thirdly, five A/Ls (5:1, 10:1, 15:1, 20:1, and 25:1) were selected according to effluent quality. During the running state, the reactor was backwashed every three days according to the growth of biofilm and effluent quality. In order to reuse the wastewater, the effluent which was collected in effluent tank was used in the backwashing operation.

Under every condition, two days were used as acclimatization period and all samples were collected and measured on the third day. Measurement for the indicants (COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity) in the influent and effluent was continued in the next three days after reaching steady state. Finally, the optimum operation parameters were determined by effluent quality in terms of the discharge standards of Shandong Province ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}, NH_4^+–N ≤ 5 mg L^{-1}, SS ≤ 20 mg L^{-1}, chromaticity ≤ 30).

After the laboratory investigation, the optimum conditions were applied in practical project for advanced treatment of soybean protein processing wastewater in BAF. The BAF system in practical project was run under the optimum conditions for about one month, and backwashed according to the growth of biofilm and effluent quality, the operational mode of the backwashing phase was the same as the labscale BAF. The dimension of the BAF system was 10 times larger than it in labscale BAF, and the same surface and volume ratios have been applied. Moreover, the media was the same as it in labscale BAF and the BAF system was operated continuously. Then the removal efficiency of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity in laboratory study and practical project were compared.

2.4. Analytical methods

COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity (degree of coloration of wastewater, the unit was degree or times) in influent and effluent were measured according to the standard methods (State Environmental Protection Administration of China, 2002) [24]. Other conditions including pH, temperature, and dissolved oxygen, were monitored by pH meter (PHS-3CW, made in Shanghai, China), mercury thermometer (WLB-21, made in Beijing, China) and dissolved oxygen meter (YSI Model 85, made in USA), respectively. The measurements of each sample were verified in three replicates. The BAF system in laboratory was operated at room temperature ranging from 26.5 to 31.5˚C.

3. Results and discussion

3.1. The influence of media height on effluent

Media height is a key running parameter in wastewater treatment of BAF. Six media heights (20–120 cm) were selected, and other conditions were as follows: HRT of 12 h, A/L of 20:1 and total flow rate of 1.6 L h^{-1}.

3.1.1. The influence of media height on COD_{Cr} and BOD_5 removals

The effect of media height on COD_{Cr} and BOD_5 of effluent is shown in Fig. 3. It can be seen that COD_{Cr} and BOD_5 of effluent decreased gradually as media height increased, and the variation tendency of COD_{Cr} was almost the same as that of BOD_5. COD_{Cr} and BOD_5 of effluent decreased rapidly as media height increased from 20 to 60 cm. It can be deduced that the nutrient substance was abundant at the inlet of the BAF reactor, and the growth and reproduction of heterotrophic bacteria was rapid which was beneficial to COD_{Cr} and BOD_5 removals [25]. When media height increased from 60 to 80 cm, COD_{Cr} and BOD_5 of effluent was almost constant. The reason may be that the nutrient substance was deficient at the media far from the inlet, and growth and reproduction of heterotrophic bacteria were slow. It can be seen that COD_{Cr} and BOD_5 of effluent did not exceed the limits of the discharge standards of Shandong Province of China ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}) when the media height was not lower than 40 cm (Table 2).

3.1.2. The influence of media height on SS and chromaticity removals

Fig. 3 shows the influence of media height on SS and chromaticity of effluent. It revealed that SS and chromaticity of effluent decreased gradually as the media height increased, and the variation tendency of SS was almost the same as that of chromaticity. When

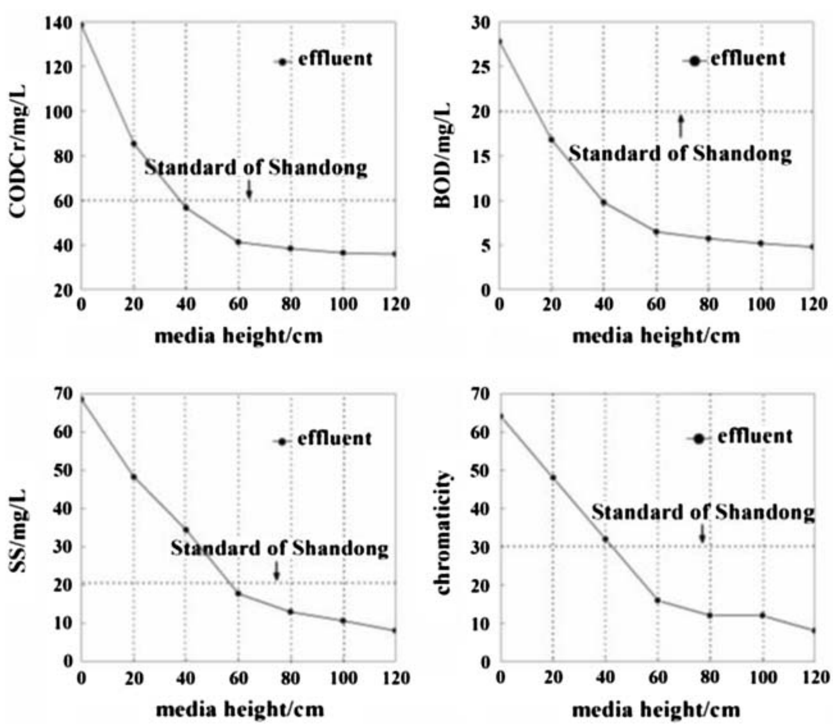

Fig. 3. The influence of media height on effluent (COD_{Cr}, BOD_5, SS, and chromaticity).

Table 2
The standard deviation (SD) of Fig. 3

Media height (cm)	0	20	40	60	80	100	120
COD_{Cr} ($mg\,L^{-1}$)	3.5590	2.9439	2.1602	1.4142	1.3568	0.7071	0.8015
BOD_5 ($mg\,L^{-1}$)	2.1213	1.1662	0.7257	0.3559	0.3603	0.3473	0.3395
SS ($mg\,L^{-1}$)	2.3549	2.0356	1.5234	1.1125	0.8936	0.7693	0.8324
Chromaticity (°)	2.4368	2.1325	1.4397	1.1096	1.0036	0.8813	0.7854

the media height increased from 20 to 60 cm, SS and chromaticity of effluent decreased rapidly. The reason may be that the concentrations of SS and chromaticity were high at the inlet of the BAF system, and the concentrations became smaller and smaller because of filtration of BAF. SS and chromaticity of effluent decreased slowly as the media height increased from 60 to 120 cm. It can be deduced that the concentrations of SS and chromaticity were low at the media far from the inlet, and the influence of filtration on SS and chromaticity was small. The results also revealed that chromaticity of the wastewater may be caused by SS of the wastewater. It can be seen that SS and chromaticity of effluent did not exceed the limits of the discharge standards of Shandong Province of China ($SS \leq 20$ mg L^{-1}, chromaticity ≤ 30) when the media height was not lower than 60 cm.

3.1.3. The influence of media height on NH_4^+–N removal

The influence of media height on NH_4^+–N of effluent is shown in Fig. 4. It can be seen that the concentration of NH_4^+–N in effluent decreased gradually as the media height increased. When the media height increased from 20 to 40 cm, NH_4^+–N of effluent decreased slowly, and decreased rapidly as the media height increased from 40 to 80 cm. It can be deduced that a large quantity of heterotrophic bacteria existed at the inlet of the BAF reactor, and growth and reproduction of nitrobacteria and nitrosobacteria may be restricted due to the competition effect [26,27]. Therefore, NH_4^+–N of effluent at the media height of 20–40 cm decreased faster than that at the media height of 40–80 cm. The results also revealed that NH_4^+–N of effluent did not exceed the limits of the discharge standards of Shandong Province of China (NH_4^+–N $\leq$ 5 mg L^{-1}) when the media height was not lower than 80 cm.

Overall, the media height of 80 cm was a better choice than other media heights according to the effluent quality and investment in the wastewater treatment (Table 3).

3.2. The influence of HRT on effluent

HRT is a crucial influence factor in the BAF system. According to the effective volume of the column, eight HRTs (0.5–12 h) were selected and determined. Other conditions were as follows: media height of 80 cm, A/L of 20:1. Under every HRT, there was a two-day acclimatization period and all samples were collected and measured on the third day.

3.2.1. The influence of HRT on COD_{Cr} and BOD_5 removals

The influence of HRT on COD_{Cr} and BOD_5 removals is shown in Fig. 5. The results indicated that COD_{Cr} and BOD_5 of effluent increased gradually as HRT decreased. When HRT decreased from 12 to 4 h, the variation tendency of COD_{Cr} and BOD_5 in effluent was small. It can be deduced that organic substance of the wastewater could be degraded effectively because of the sufficient time. The concentration of COD_{Cr} and BOD_5 in effluent increased rapidly as HRT decreased from 4 to 0.5 h. Generally, with shorter HRT, corresponding to faster flow rate of air and water and stronger shearing force, micro-organisms in the reactor were highly affected, and organic substance of the wastewater could not be degraded effectively. Therefore, COD_{Cr} and BOD_5 of effluent could not exceed the limits of the discharge standards of Shandong Province of China ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1}) when HRT was not shorter than 4 and 1 h, respectively.

3.2.2. The influence of HRT on SS and chromaticity removals

The influence of HRT on SS and chromaticity in effluent is shown in Fig. 5. It can be seen that SS and chromaticity in effluent increased gradually as HRT decreased. When HRT decreased from 12 to 4 h, SS and chromaticity in effluent increased slowly, and increased rapidly as HRT decreased from 4 to 0.5 h. It

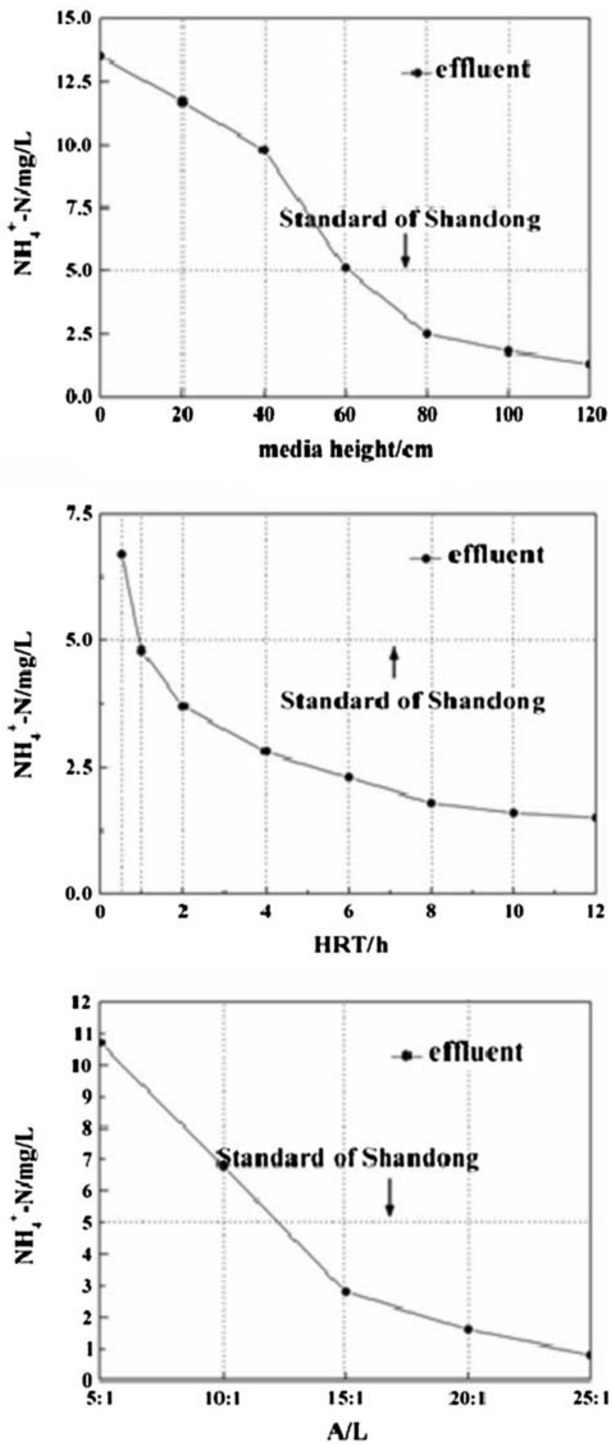

Fig. 4. The influence of media height, HRT, and A/L on NH_4^+–N of effluent.

can be deduced that the filtration of BAF was sufficient with long time. Then with shorter HRT, corresponding to faster flow rate of air and water, the filtering velocity of BAF system was faster, and the filtration of BAF may not be sufficient. Therefore, SS and chromaticity in effluent could not exceed the limits of the discharge standards of Shandong Province of China (SS $\leq$ 20 mg L^{-1}, chromaticity $\leq$ 30) when HRT was not shorter than 2 and 4 h, respectively (Table 4).

3.2.3. The influence of HRT on NH_4^+–N removal

Fig. 4 shows the effect of HRT on NH_4^+–N of effluent. It revealed that NH_4^+–N of effluent increased gradually as HRT decreased from 12 to 0.5 h. With longer HRT, there was enough time for transformation of NH_4^+–N by nitrobacteria and nitrosobacteria, and NH_4^+–N of effluent was lower. It can be seen that the influence of HRT on NH_4^+–N of effluent was smaller than that on other indicants of effluent. It can be deduced that NH_4^+–N of the influent was low and the effect of HRT on NH_4^+–N of effluent was small. The results also revealed that NH_4^+–N of effluent did not exceed the limits of the discharge standards of Shandong Province of China (NH_4^+–N $\leq$ 5 mg L^{-1}) when HRT was not shorter than 1 h.

Overall, HRT of 4 h should be selected as the optimum HRT in terms of the effluent quality and running cost in the wastewater treatment.

3.3. The influence of A/L on effluent

The influence of A/L on treatment efficiency for soybean protein wastewater was investigated at media height of 80 cm and HRT of 4 h as determined above. Five A/Ls (5:1–25:1) were selected and determined. Under every A/L, there was a two-day acclimatization period, and all samples were collected and measured on the third day.

3.3.1. The influence of A/L on COD_{Cr}, BOD_5, SS, and chromaticity removals

The results of the effect of A/L on COD_{Cr} and BOD_5 in effluent are shown in Fig. 6. It can be seen that COD_{Cr} and BOD_5 in effluent decreased gradually as A/L increased, and the variation tendency of COD_{Cr} was almost the same as that of BOD_5. With higher A/L, corresponding to higher dissolved oxygen in wastewater, it was beneficial for degradation of organic substance by aerated heterotrophic bacteria. Then when A/L was higher than 15:1, the influence of A/L on COD_{Cr} and BOD_5 in effluent was small, which may be because that dissolved oxygen was enough for the degradation of organic substance by

Table 3
The SD of Fig. 4

Media height (cm)	0	20	40	60	80	100	120	–
NH_4^+–N ($mg\,L^{-1}$)	0.5888	0.4967	0.4365	0.4164	0.1414	0.1035	0.0962	–
HRT (h)	12	10	8	6	4	2	1	0.5
NH_4^+–N ($mg\,L^{-1}$)	0.0878	0.1106	0.1057	0.1518	0.1493	0.4721	0.5004	0.4525
A/L	5:1	10:1	15:1	20:1	25:1	–	–	–
NH_4^+–N ($mg\,L^{-1}$)	0.4216	0.4354	0.1592	0.1125	0.0729	–	–	–

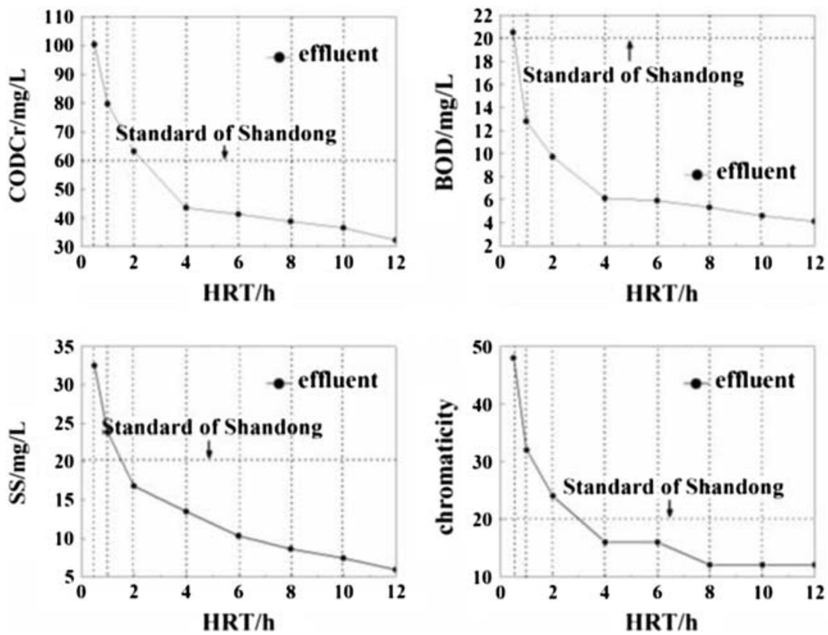

Fig. 5. The influence of HRT on effluent (COD_{Cr}, BOD_5, SS, and chromaticity).

Table 4
The SD of Fig. 5

HRT (h)	12	10	8	6	4	2	1	0.5
COD_{Cr} ($mg\,L^{-1}$)	0.8876	0.8065	0.9532	1.3826	1.4068	2.1011	2.8635	3.1247
BOD_5 ($mg\,L^{-1}$)	0.3244	0.3423	0.4001	0.3629	0.3876	0.8065	1.0531	1.5678
SS ($mg\,L^{-1}$)	0.7193	0.8439	0.8525	0.9302	0.8267	1.1038	1.3618	1.5096
Chromaticity (°)	0.8735	0.8657	0.9013	1.1126	1.1237	1.2811	1.4085	2.2014

aerated heterotrophic bacteria. Therefore, A/L of 15:1was a better choice than other A/Ls (Table 5).

The influence of A/L on SS and chromaticity of effluent is also shown in Fig. 6. The results revealed that SS and chromaticity of effluent increased gradually as A/L increased. With higher A/L, corresponding to faster flow rate of air and stronger shearing force, some of suspended substance was dashed out from the reactor, and SS and chromaticity of effluent increased. Therefore, A/L in the wastewater treatment should be low in order to decrease SS and chromaticity of effluent.

3.3.2. *The influence of A/L on NH_4^+–N removal*

Fig. 4 shows the effect of A/L on NH_4^+–N in effluent, and it revealed that the concentration of NH_4^+–N in effluent decreased gradually as A/L increased. When A/L increased from 5:1 to 15:1, the concentration of NH_4^+–N in effluent decreased rapidly. The rea-

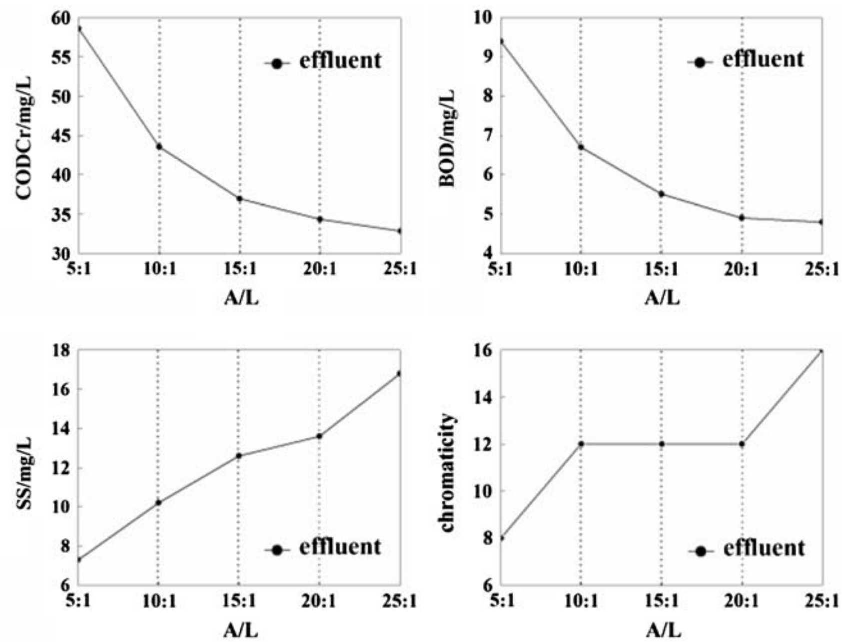

Fig. 6. The influence of A/L on effluent (COD_{Cr}, BOD_5, SS, and chromaticity).

Table 5
The SD of Fig. 6

A/L	5:1	10:1	15:1	20:1	25:1
COD_{Cr} (mg L^{-1})	2.2538	1.4326	1.1257	0.8641	0.7935
BOD_5 (mg L^{-1})	0.7068	0.3482	0.3527	0.3316	0.3283
SS (mg L^{-1})	0.8068	0.9219	0.9107	0.8725	1.0641
Chromaticity (°)	0.6895	0.8774	0.8623	0.9006	1.1527

son may be that dissolved oxygen increased as A/L increased, which was beneficial for transformation of NH_4^+–N by aerated nitrobacteria and nitrosobacteria [15]. The concentration of NH_4^+–N in effluent decreased slowly as A/L increased from 15:1 to 25:1, which may be because that dissolved oxygen in wastewater was enough for transformation of NH_4^+–N by aerated nitrobacteria and nitrosobacteria. The results also revealed that A/L should not be lower than 15:1, so that NH_4^+–N of effluent could not exceed the limits of the discharge standards of Shandong Province of China (NH_4^+–N ≤ 5 mg L^{-1}).

Overall, A/L of 15:1 should be a better choice than other A/Ls according to the effluent quality and running cost in the wastewater treatment.

3.4. Practical project application

Media height of 80 cm, HRT of 4 h, and A/L of 15:1 were selected and determined as the optimum conditions for soybean protein wastewater treatment in BAF in laboratory investigation, and the mean effluent concentration of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity was 39, 5.8, 2.5, 13.6 mg L^{-1}, and 12, respectively. When the optimum conditions were applied in BAF for soybean protein wastewater treatment in practical project, the BAF was run for about one month, and the mean effluent concentration of COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity was 50, 7.9, 3.2, 18.8 mg L^{-1}, and 24, respectively.

It can be seen that under the same running conditions, COD_{Cr}, BOD_5, NH_4^+–N, SS, and chromaticity of the effluent in practical project were a little higher than that in laboratory investigation. The reason may be that operation conditions, running environment, and scale of BAF system were different between laboratory investigation and practical application. Then both the indicants of the effluent did not exceed the limits of the discharge standards of Shandong Province of China ($COD_{Cr} \leq 60$ mg L^{-1}, $BOD_5 \leq 20$ mg L^{-1},

NH_4^+–N $\leq$ 5 mg L^{-1}, SS $\leq$ 20 mg L^{-1}, chromaticity $\leq$ 30). Therefore, the investigation on BAF for soybean protein wastewater treatment in laboratory was significant for the design of BAF in practical project.

Moreover, when BAF was utilized in the soybean protein wastewater treatment in practical project, the per ton cost of the wastewater treatment was 0.40 Chinese Yuan, however, the cost reached 1.70 Chinese Yuan as Fenton reagent was utilized in this wastewater treatment. Therefore, BAF was economical methods in the soybean protein wastewater treatment.

4. Conclusions

BAF in laboratory and practical project was investigated for soybean protein advanced wastewater treatment. The results were as follows:

(1) The feasibility of utilization of BAF in soybean protein advanced wastewater treatment was very well verified according to the effluent quality.
(2) The optimum conditions in laboratory investigation were media height of 80 cm, HRT of 4 h, and A/L of 15:1 based on running cost and the discharge standards of Shandong Province.
(3) When the optimum conditions were applied in practical project, the indicants of the effluent could not exceed the limits of the discharge standards of Shandong Province, which indicated that laboratory investigation on BAF for soybean protein advanced wastewater treatment was helpful for design in practical project.

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