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Cosmetic wastewater treatment by a combined anaerobic/aerobic (ABR+UBAF) biological system

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ABSTRACT

The cosmetics industry has been growing steadily for the past several tens of years in China, yet very few researches exist on cosmetic wastewater treatment system. This study gave new insight to develop a combined anaerobic baffled reactor (ABR) and upflow biological aerated filter (UBAF) system for the treatment of cosmetic wastewater. The chemical oxygen demand (COD) removal efficiency in the cosmetic wastewater was mainly investigated in the front two compartments of ABR reactor, while it was treated by the same reactor with six compartments. When the influent COD load was set at 1.5 g COD/L.d, the COD removal efficiency reached a maximum in the No. 1 compartment. The highest COD removal efficiency achieved 2.0 g COD/L.d for the complete ABR reactor. The optimal hydraulic retention time (HRT) of the ABR was 48 h. A UBAF reactor was applied to advanced treatment for ABR effluent. The coke powder with the diameter of 0.5–1.0 mm and the gas-water ratio of 7:1 were chosen the optimal experimental conditions. Under the above-optimal experimental conditions, the COD removal efficiency of UBAF was 69.5–82.6%. After the combined treatment by ABR and UBAF, the cosmetic wastewater effluent can effectively supply the discharge standard in China.

Keywords: Cosmetic wastewater; Biological treatment; Anaerobic baffled reactor (ABR); Upflow biological aerated filter (UBAF)

1. Introduction

In China, the cosmetics industry has basically grown more than 10% annually over the past decade and is currently the largest emerging market in the world. The cosmetics products include several segments: skin care, hair care, make-up, fragrances, and others. The wastewaters generated by cosmetics industry have high values of chemical oxygen demand (COD), suspended solids, fats, oils, and detergents, arising from the presence of compounds, such as surfactants, natural oils, dyes, and fragrances, some of which are difficult to biodegrade due to high toxicity [1,2]. For the above circumstances, the cosmetic wastewater should be treated before its discharge or reuse.

Preciously, some techniques have been applied to the treatment of cosmetic wastewater. The cosmetic wastewater is often treated by means of conventional

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physical, chemical, and biological treatment methods [3,4]. However, advanced treatment technologies, such as Fenton oxidation, activated carbon adsorption, and ultrafiltration have been applied to meet more strait regulations concerning industrial wastewaters, which include the cosmetic wastewater [5,6]. Especially, an upflow anaerobic sludge blanket reactor has been developed for the treatment of cosmetic wastewater [2].

The anaerobic baffled reactor (ABR) was described as a series of upflow anaerobic sludge blankets. Many results demonstrate that the ABR has many advantages, such as: a high degree of sludge retention, a higher tolerance to shock loads and stable reactor performance, easy construction, maintenance, and operations [7,8]. Upflow biological aerated filter (UBAF) is a kind of biofilm aerobic method, which can combine amonia, carbonaceous matter, and solids removal in a simple-unit process [9]. In the other hand, ABR and UBAF have been widely used in many kinds of wastewaters, respectively [10,11]. In this research, the combined ABR and UBAF system is applied to the cosmetic wastewater treatment. Particularly, a kind of waste product, such as coke powder, generated by the coal chemical industry was used as the UBAF's carrier materials.

2. Materials and methods

2.1. Wastewater samples

The wastewater samples were collected from a cosmetic factory located in Miyun County of Beijing. The main characteristics of these wastewater samples are summarized in Table 1.

2.2. Experimental setup

The ABR reactor was made up of plexiglass with rectangular shape containing a volume of 21.0 L and an effective volume of 18.0 L. The ABR reactor was separated into six compartments equally by vertical baffles. Each compartment (10 × 10 × 30 cm) was further separated into two parts where down-flow and up-flow regions were formed. The wastewater flowed upward and downward alternatively between each compartment. The volume ratio of upward and downward zone was set at 4:1. The lower part of baffle plate in ABR reactor had a 45° chamfer deflector. The baffle plate length was 25 cm. The influent was fed by a peristaltic pump. The produced gas was collected via a porthole at the top of reactor.

The UBAF reactor was made up of plexiglass, which was a cylindrical vessel with 60 cm in height and 40 cm in diameter. The UBAF reactor was filled with coke powder as carrier materials with 45 cm in height. The coke powder used in UBAF reactor was purchased from Shanxi Jiaomei Co., Ltd. Shanxi, China. Before being put into use, the coke powder should be rinsed and soaked with water for more than 24 h until the absorbed ability of coke powder was saturated. Peristaltic pumps were used to transport feed and remove effluent from the reactor. The gas-water combined method was used as backwash way for UBAF. Micro-bubbles were connected to an air compressor through micro-porous aerators. The laboratory-scale experimental setup is illustrated in Fig. 1.

2.3. Experimental methods

The digested sludge collected from Beijing Miyun wastewater treatment plant was taken as the seed sludge for ABR and UBAF units. Large particles and debris from the sludge were removed by passing it through American Society of Testing Materials sieve No. 16 (1.18 mm), which was introduced uniformly into six compartments of ABR and UBAF units. Then the remaining part of ABR and UBAF was initially filled with raw cosmetic wastewater. After seeding, the ABR reactor was sealed and the head space above each compartment was flushed with oxygen-free nitrogen gas in order to displace residual air from the system. The ABR reactor was allowed to stabilize for 72 h before starting the continuous feeding. The start-up of ABR was carried out under a low load of 0.2 g COD/L.d, the hydraulic retention time (HRT) of 24 h. Before the wastewater was fed, the reactor was seeded with digested sludge and kept airtight for 10 days. Nutrients including KH_2PO_4, urea, and other trace elements were dosed to meet the demands for the anaerobic microbial growth. The ambient temperature ranged from 19 to 26°C during the start-up period.

Table 1
Characteristics of the cosmetic wastewater

Parameter	pH	BOD_5 (mg/L)	COD_{Cr} (mg/L)	NH_4^+-N (mg/L)	SS (mg/L)	TP (mg/L)
Concentration	7.9–8.4	1,550–1,740	2,180–2,810	356–418	108–141	1.77–9.23
Effluent standard	6–9	30	100	15	70	1.0

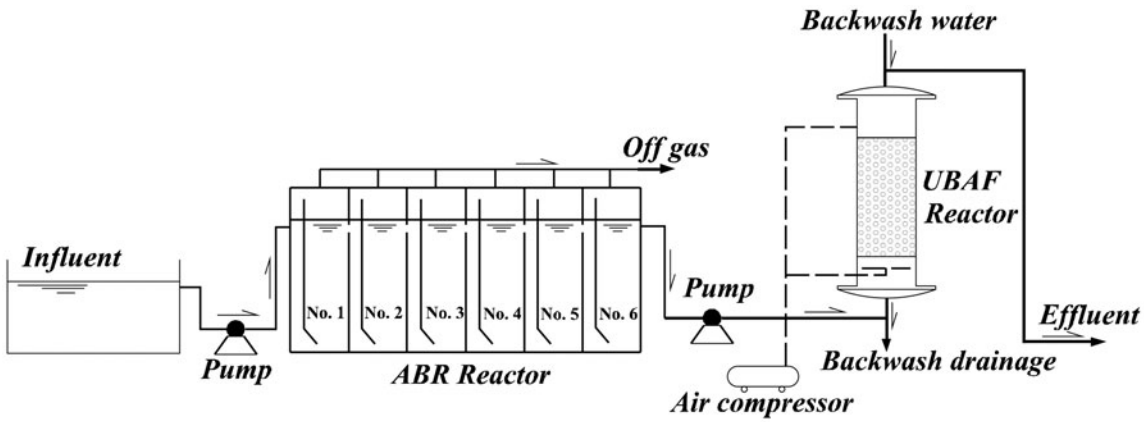

Fig. 1. Diagram of the laboratory-scale combined ABR + UBAF system.

The following HRTs were set in the UBAF experiments: 0.05. 0.1, 0.15, 0.2, 0.25, and 0.3 $m^3/(m^2 h)$. The UBAF reactor worked nearly two weeks with a set loading rate for reaching steady state conditions before the beginning of measurements. Measurements were continued for the next two weeks after the COD removal efficiency was gradually increased up to 70%. Three kinds of coke powders, as waste products in the coal chemical industry with 0.1–0.4, 0.5–1.0, and 1.0–2.0 mm in diameter, were used as the UBAF's carrier materials.

2.4. Analysis

COD, BOD, pH, NH_4^+-N, SS, and TP were analyzed in accordance with Standard Methods [12]. The volatile fatty acids (VFA) measurements were made twice-daily by using five-point titration method [13], and the results came from relative calculation program. The biogas production (CH_4, CO_2) was monitored daily by using a gas chromatography model with a flame ionization detector under the following operational conditions: carrier gas, N_2; packing material, TDX-01; column temperature, 75˚C; and detector temperature, 70˚C. Quality control was ensured by using standards and duplicates.

3. Results and discussion

3.1. Start-up of ABR and UBAF

In the beginning, the sludge in ABR reactor was dark in color. After a short time, the sludge turned into grey and sticky in the first compartment and was spread to the downstream. The physical appearance of anaerobic sludge gradually turned into small granules. The size of the granules significantly increased according to the time mode. After a period of three months, the ABR reactor was able to remove about 80% of influent COD. All of these indicated that inoculated digested sludge was fully acclimatized and the ABR unit could be operated at steady state. At the same time, the UBAF reactor was tested for reaching steady state.

3.2. Performance of ABR at steady-state

The acclimatization of sludge in ABR and UBAF units was completed and then began to steady-state operation. The effect of different parameters on the performance of ABR and UBAF was evaluated.

3.3. COD removal of ABR reactor

The COD concentrations in raw cosmetic wastewaters were 2,199–2,695 mg/L. After the ABR treatment, the removal efficiencies of COD were between 82.5 and 89.7%, while the HRT of ABR was controlled at 48 h. Fig. 2 demonstrates that the COD degradation and the removal efficiency of each compartment effluent in ABR reactor under different influent load from 0.5 g COD/L.d to 2.5 g COD/L.d.

As shown in Fig. 2, the COD removal capability of ABR unit was mainly concentrated in the Nos. 1 and 2 compartment, which were located in the front of ABR. With the COD influent load growth, the COD removal efficiency increased first and then decreased in the No. 1 compartment. To be specific, when the COD influent load gradually increased from 0.5 g COD/L.d to 1.5 g COD/L.d, the COD removal efficiency increased from 49 to 72% in No. 1 compartment of ABR. After that, when COD influent load increased from 1.5 g COD/L.d to 2.5 g COD/L.d, the COD removal efficiency decreased to 38%. When the

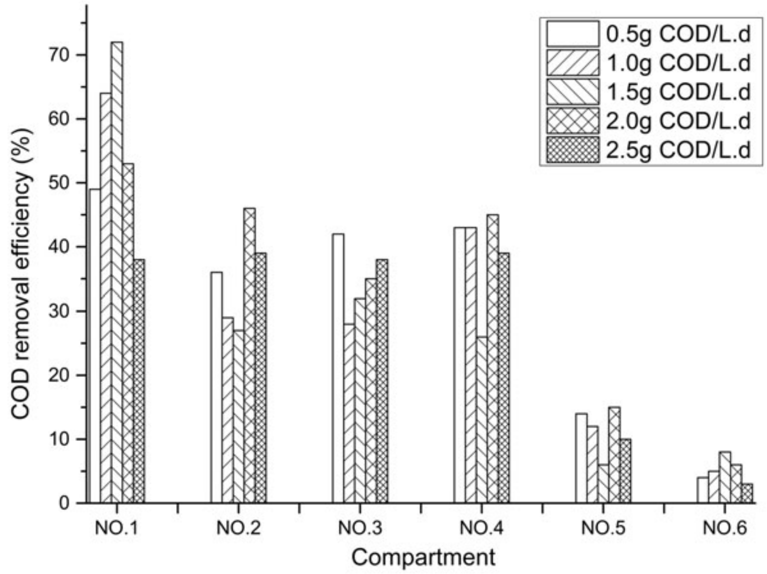

Fig. 2. COD removal efficiency of each compartment effluent in ABR reactor under different influent load.

influent COD load was set at 1.5 g COD/L.d, the COD removal efficiency reached a maximum in the No. 1 compartment, while the highest COD removal efficiency was achieved with the COD influent load of 2.0 g COD/L.d for the whole ABR system.

This was mainly because with the COD influent load growth, increased sludge concentration, the removal of COD was mainly through the retention of influent suspended solids and the utilization of influent substrate by acidogenic bacteria. High COD influent load led to acidogenic bacteria yet not to take full advantage of substrate and flowed into the next compartment.

With the COD influent load of 2.0 g COD/L.d, the HRT was controlled to vary from 6 to 72 h. The performance of ABR reactor was shown in Table 2.

As shown in Table 2, accordingly, the COD removal efficiency increased with the increasing of HRT. During the initial 48 h operation, the COD removal efficiency increased rapidly and reached 92.5% at HRT 48 h, and then increased slightly. Considering the effect and cost of the treatment, the optimal HRT was defined as 48 h.

3.4. Gas production of ABR reactor

The Biogas and methane conversion rates of ABR reactor tested once every 10 days at 48 h HRT and 2.0 g COD/L.d COD load were shown in Table 3.

As shown in Table 3, the total gas production keeps 0.73–0.76 m^3/m^3 day. Results from the GC-analysis show that the produced gas composition

Table 2
Performance of ABR reactor at different HRTs

	COD			SS			pH		
HRT (h)	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent	Effluent	VFA (mg/L)
6	2512.9	902.1	64.1	109	44	59.6	8.0	6.8	95.6
12	2635.5	564.0	78.6	121	42	65.3	7.9	7.0	88.7
24	2488.2	328.4	86.8	118	35	70.3	8.2	6.9	80.1
48	2536.0	190.2	92.5	130	31	76.2	8.0	6.8	62.5
60	2497.6	179.8	92.8	126	29	77.0	8.4	7.2	59.3
72	2733.8	175.0	93.6	139	30	78.4	8.3	7.0	57.4

Table 3
Biogas and methane conversion rates

No.	Total gas production (m^3/m^3 day)	Gas composition (%)		COD removal rate kg/m^3 day	CH_4 conversion rate m^3/kg COD removed
		CH_4 (%)	CO_2 (%)		
1	0.73	50	32	1.82	0.20
2	0.76	46	42	1.84	0.19
3	0.74	52	35	1.83	0.21
4	0.73	58	31	1.85	0.23
5	0.75	49	40	1.84	0.20

is 46–58% of CH_4 and 31–45% of CO_2. The total CH_4 production is 0.19–0.23 m^3/kg COD removed. It can be seen that the reactor has maintained a relatively stable methane conversion rate which is similar with other researchers [14,15].

3.5. pH, COD, and VFA profiles of ABR

The pH, COD, and VFA profiles for the ABR at 48 h HRT and 2.0 g COD/L.d COD load are shown in Fig. 3.

Moreover, the COD decreases longitudinally in the ABR, and a sudden drop of the pH value in the first compartment is quite noticeable (Fig. 3). It gradually increases as wastewater moves towards the later compartments. The pH in the effluent of ABR was close to 7.0. The pH in compartment 1 was lowest and increased along with ABR compartments due to the degradation of VFA [16]. The VFA concentration also decreased longitudinally in the ABR, which was similar with the results of Wang et al. [17]. The highest VFA concentration was found in the first compartment with average value of 486.3 mg/L.

3.6. The advanced treatment of UBAF

After the treatment of ABR, the cosmetic wastewater effluent still can not supply the effluent standard. Hence, the UBAF reactor was chosen as the advanced method for the cosmetic wastewater treatment. Setting the gas-water ratio of 7:1, the UBAF reactor was tested with coke powders with 0.1–0.4, 0.5–1.0, and 1.0–2.0 mm in diameter. The experimental results show that the coke powders with 0.1–0.4 and 0.5–1.0 mm diameters can obtain better COD and NH_4^+–N removal efficiency than those with 1.0–2.0 mm diameters. It appeared to be a little difference between the performance of coke powders with diameters of 0.1–0.4 and 0.5–1.0 mm. For small particle size being increased head loss and decreased filtration flux, we

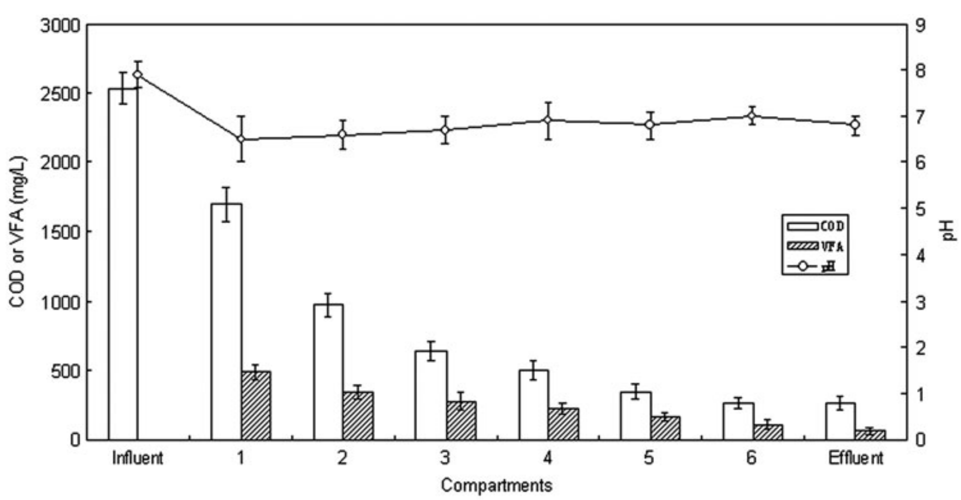

Fig. 3. Compartment-wise variation of parameters in ABR along with influent and effluent concentrations.

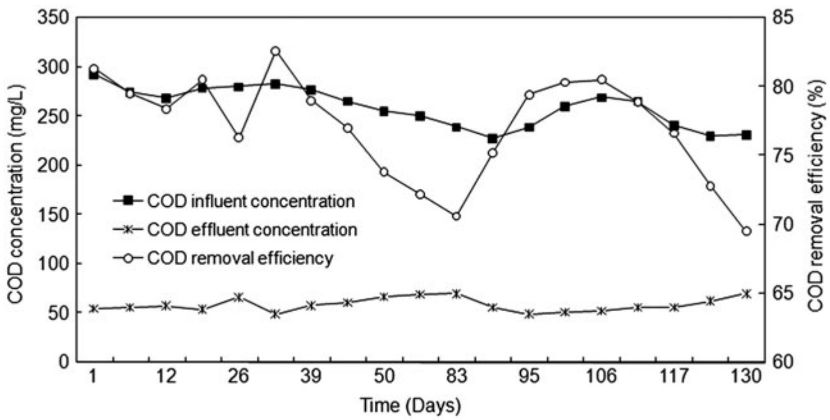

Fig. 4. COD removal efficiency of UBAF reactor.

Table 4
Performance of combined ABR and UBAF

Parameter	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)
BOD_5	1,550–1,740	19.3–27.8	97.3–98.9
COD_{Cr}	2,180–2,810	49.2–87.4	94.6–97.9
NH_4^+-N	356–418	6.4–12.7	95.9–99.4
SS	108–141	11.4–21.5	83.2–91.3
TP	1.77–9.23	0.57–0.94	89.6–94.5

selected the coke powder with diameter of 0.5–1.0 mm as the optimal carrier medium of UBAF. The COD removal efficiency of UBAF is shown in Fig. 4.

It can be seen in Fig. 4 that the COD removal efficiency of UBAF is 69.5–82.6%. After the advanced treatment of UBAF, the COD concentration in wastewater effluent can meet the discharge standard in China.

3.7. Performance of combined ABR and UBAF

With ABR reactor's HRT of 48 h and the optimal experimental conditions of UBAF, the performance of combined ABR and UBAF is depicted in Table 4.

In Table 4, it can be expected that the cosmetic wastewater effluent can supply the discharge standard in China, after the combined treatment by ABR and UBAF system. The ABR system assures for the industrial wastewater treatment since it can withstand severe hydraulic and organic shock loads, intermittent feeding, and temperature changes. Despite comparable performance with other well-established technologies, its use in future will depend on exploiting its structure in order to treat wastewaters which cannot be readily treated. UBAF is a good choice for wastewater advance treatment. Based on the results obtained in this study and recent literature [18], the most effectively removal mechanism of UBAF includes the mechanical interception, contact cohesion, and biological flocculation. In the case of different scale cosmetics companies in developing countries, especially in China, selection of treatment processes must be considered financial constraints that often prevent adsorption of highly sophisticated processes that require technical economic resources beyond their means. The combined ABR and UBAF system provides a cost-effective way to solve the cosmetic wastewater problems.

4. Conclusions

The cosmetic wastewater is a kind of refractory wastewater with high values of COD. A combined ABR and UBAF system for the better treatment of cosmetic wastewater was introduced. The key factor affecting ABR unit for COD and other organics in cosmetic wastewater has been investigated. Accordingly, the COD removal efficiency increases with the increasing of HRT. The total gas production keeps 0.73–0.76 m^3/m^3 day, and the total CH_4 production is 0.19–0.23 m^3/kg COD removed. The COD and VFA decreases longitudinally in the ABR, while the pH in the effluent of ABR is not decreased significantly. The COD removal efficiency of UBAF unit is 69.5–82.6% individually. After the combined treatment by ABR and UBAF system, the cosmetic wastewater effluent can supply the discharge standard in China, which indicates the feasible and promising technology for refractory wastewater treatment system.

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