EFFECT OF ORGANIC LOADING ON THE PERFORMANCE OF AERATED SUBMERGED FIXED-FILM REACTOR (ASFFR) FOR CRUDE OIL-CONTAINING WASTEWATER TREATMENT

H. Izanloo, *A Mesdaghinia, R. Nabizadeh, S. Nasseri, K. Naddafi, A. H. Mahvi, Sh. Nazmara

Department of Environmental Health Engineering, School of Public Health and Center for Environmental Research, Medical Sciences/University of Tehran, Tehran, Iran

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ABSTRACT

An aerated submerged fixed-film (ASFF) bioreactor was developed to treat an artificial wastewater based on crude oil. Bee-Cell 2000 was used as support media having porosity of 87% and a specific surface area of 650 m^2/m^3. The system was able to achieve 83.14–97.05 percentage removal efficiencies of soluble chemical oxygen demand (SCOD) in the organic loading rate range of 0.84 to 9.41 g $SCOD/m^2$.day. Results showed that the effluent SCOD concentration ranged between 18.93 and 100.93 mg/L at organic loadings experienced. Therefore, an ASFF process showed that it was feasible to treat high oily wastewater in order to meet the discharge standards.

Key words: Aerated submerged fixed-film (ASFFR) bioreactor, SCOD removal, attached growth, organic loading rate, oily wastewater, discharge standards

INTRODUCTION

A large amount of water is used in oil industry for a wide variety of purposes and basic portion of it leaves this industry as wastewater containing oil, phenols, different solvents, and toxic substances (Zhao, *et al*., 2006; Toril, 2001). Such wastewater can pollute water bodies, soil, and even the air if it is not treated (Yang, 2000; Chen, 2002; Vegueria, 2002). Biological treatment processes are economical and efficient methods that can be used for treating wastewater from oil industry (Jou, 2003). In many refineries, suspended growth systems, such as conventional activated sludge (CAS) process, are applied to treat refinery wastewater (Tellez, 2002; Stepnowski, 2002). However, CAS process has some operational problems, such as the inability to settle the sludge, formation of excessive scum and foam, and sludge bulking, and requires operators' skill and large space which are considered as the limiting factors in oil industries because these are located in populous areas without enough space for expansion (Park, 1996; Loukidou, 2001; Xianling, 2005). Therefore, it is important that biological treatment systems can be easy to operate and treat large amounts of wastewater in a space which is as small as possible (Park, 1996; Xianling, 2005). As a consequence, some novel biological treatment methods have been developed during recent years. Attached growth bioreactors such as trickling filters and rotating biological contactors have been used for treatment of wastewaters for over a century. However, during the past two decades new versions of attached growth bioreactors that apply totally submerged media with high specific surface areas have been developed. These systems are known as submerged attached growth bioreactors (SAGB). Currently, submerged attached growth systems have attracted attention due to the high biomass concentrations that can be gained, leading to short hydraulic residence times (HRTs). Short HRTs cause these systems to be compactly constructed (Leslie Grady *et al*., 1999). In comparison to suspended growth biological treatment systems, such as CAS process, this system can provide advantages as follows (Park, 1996; Hamoda, 1999; Jianlong *et al*., 2000; Loukidou, 2001; Jou, 2003; Guimarães *et al*., 2005):

*Corresponding author E-mail: *a_mesdaghinia@hotmail.com*
Tel: +98 21 8895 4914, Fax: +98 21 6646 2627

- Higher concentrations of biomass in bioreactor, leading to short hydraulic resistance time
- No need to return the sludge to the process
- Resistance to toxic loading and adverse environmental conditions
- Handling full-scale flow rates
- Easier to operate
- Handling shock loads with high efficiency
- Lower rates of energy consumption
- Producing less waste sludge
- being applicable to where the land area available is limited

Aerated submerged fixed-film (ASFF) process is a novel attached growth biological treatment system that uses totally submerged fixed media to support biomass growing as a thin biofilm on their surfaces (Hamoda, 1987; Park, 1996; Hamoda, 1998; Hamoda, 1999; Al-Sharekh, 2001). Also, diffusers provide air bubbles for both aeration and turbulence. The turbulence created by this way prevents the excessive biofilm growth (Hamoda, 1999). ASFF process has been successfully applied for treatment of both urban and industrial wastewaters by several researchers (Park, 1996; Hamoda, 1999; Gálvez, 2003; Nabizadeh and Mesdaghinia, 2006). This pilot-scale study was conducted to examine the performance of Aerated submerged fixed-film bioreactor in treatment of artificial oil-based wastewater under normal operating conditions.

MATERIALS AND METHODS

Experimental set-up

Fig. 1 shows a schematic diagram of the pilot plant that was set up at department of environmental health engineering of Tehran University of Medical Sciences, in Tehran, Iran. The pilot plant included one experimental reactor, one peristaltic pump for pumping wastewater into the reactor, one 400 L holding tank, and one air compressor. Bioreactor consisted of a Plexiglas cylindrical column with 14.1 cm internal diameter, 64 cm effective height, and a total volume of 10 L, a suitable circular diffuser located at the bottom of the bioreactor which produced air bubbles of medium size, and Bee-Cell 2000 as support media having porosity of 87% and a specific surface area of 650 m^2/m^3. Artificial wastewater based on crude oil was continuously pumped into the bioreactor at the base, with a flow rate ranged between 8.5 and 102 L/day. The air was supplied at the bottom of the bioreactor. The air flow rate was increased with increasing organic loading in the range of 5-30 L/min in order to maintain dissolved oxygen level at more than 2 mg/L throughout the bioreactor. Table 1 gives the experimental mean hydraulic and organic loading rates.

Table 1: The experimental mean hydraulic and organic loading rates

Run	HRT† (h)	Influent SCOD (mg/L)	Flow rate (L/h)	Organic loading rate (g SCOD/m^2.day)
1	24	641.73	0.3542	0.8423
2	12	570.54	0.7083	1.5014
3	8	640.54	1.0625	2.5249
4	6	571.36	1.4167	2.9954
5	4	562.80	2.1250	4.4430
6	3	562.75	2.8333	5.9005
7	2.4	600.07	3.5417	7.8954
8	2	598.53	4.2500	9.4135

* Hydraulic retention time

Seed sludge

A return activated sludge from wastewater treatment plant of Behran oil refinery located in Tehran was selected as seed sludge in the experiment, because microorganisms within this sludge was acclimated with oily wastewater. The bioreactor was first inoculated by seed sludge and it was allowed to operate on batch mode for a few days before changing to a continuous mode.

Artificial wastewater based on crude oil

The artificial wastewater based on crude oil was prepared by adding 75 mg/L sodium dodecyl sulphate (SDS) as an emulsifier, to a mixture of 40 L water and 10 L crude oil. Crude oil used was abstracted from crude oil storage tanks of Tehran petroleum refinery. Characteristics of the artificial wastewater based on crude oil are shown in Table 1. Because this wastewater was very strong, it was diluted. Table 2 shows the composition of diluted oil-based wastewater. The wastewater was enriched with the inorganic nutrients by adding NH_4Cl as nitrogen source and $(NH_4)_3PO_4$ as phosphorus source based on a COD:N:P ratio of

100:5:1. Sodium bicarbonate ($Na_2 CO_3$) was used to maintain the pH at 7.56 ± 0.25.

Table 2: Characteristics of the artificial crude oil-containing wastewater

Parameter	Average concentration	Range
pH	6.3	5 – 8
TCOD (mg/L)	30795	30143 – 31462
SCOD (mg/L)	17867	17039 – 18791
TN (mg/L)	48	32 – 102
TP (mg/L)	0.9	0.2 – 2.3
$Cl^?$ (mg/L)	13	9 – 45
Alkalinity (mg $CaCO_3$ /L)	185	95 – 370

Table 3: Composition of diluted artificial crude oil-containing wastewater

Parameter	Average concentration	Range
pH	7.5	6.8 – 7.9
TCOD (mg/L)	1000	975 – 1023
SCOD (mg/L)	593	544 – 653
TN (mg/L)	1.7	1.1 – 3.4
TP (mg/L)	< 0.01	0 – 0.08
$Cl^?$ (mg/L)	0.5	0.1 – 1.5
Alkalinity (mg $CaCO_3$ /L)	50	35 – 110

Analytical methods

Samples were analyzed for total and dissolved chemical oxygen demand (TCOD and SCOD), volatile suspended solids (VSS), alkalinity, total kajeldal nitrogen (TKN), total phosphorus (TP), and dissolved oxygen (DO) according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Temperature was measured by a thermometer and pH was measured by a pH-meter (E520 Metrohm Herisau). In order to determine soluble COD, all influent and effluent samples were filtered through Whatman membrane filters of 0.45 µm pore size.

Attached biomass analyses

In order to determine the amounts of biomass attached to the surface of Bee-Cell 2000, a given number of media was randomly selected and taken from several depths of the bioreactor once a week. The media with attached biomass were put in a very dilute sulfuric acid solution (2%) for several days so as to detach biomass from surface of the medium. Detached biomass was used for determining VS according to the Standard Methods for the Examination of Water and Wastewater.

RESULTS

The SCOD removal efficiency versus the surface area COD loading rate based on soluble COD is depicted in Fig. 2. Fig. 3 shows the relationship between the specific substrate utilization rate and the SCOD loading rate. The effluent SCOD concentrations determined during the bioreactor operation period are illustrated in Fig. 4. The effect of specific SCOD loading rate, which is expressed as food to biomass ratio, on the quality of the effluent SCOD is shown in Fig. 5.

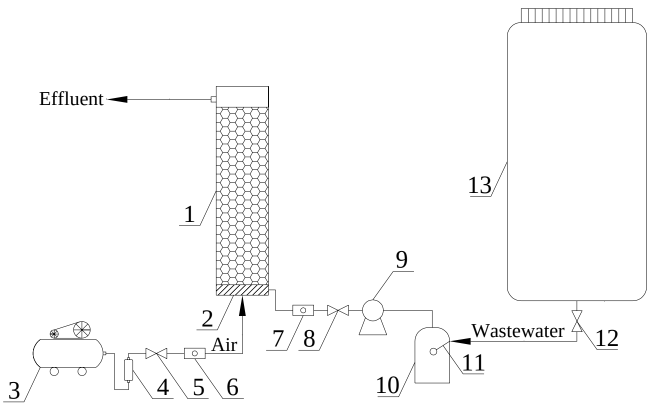

Fig. 1: Schematic diagram of the pilot plant:
(1) aerated submerged fixed-film bioreactor, (2) circular diffuser, (3) air compressor, (4) activated carbon column, (5, 8 and 12) cutoff valve, (6) air rotameter, (7) liquid rotameter, (9) wastewater pump, (10) equalization tank, (11) floater, (13) reservoir.

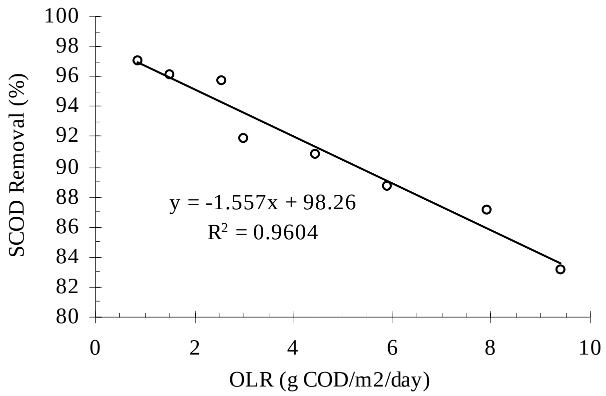

Fig. 2: Effect of OLR on COD removal efficiency

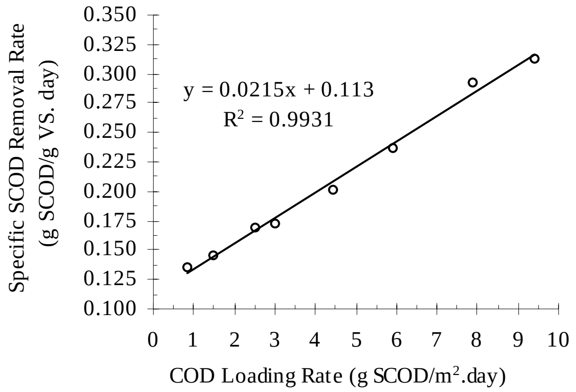

Fig. 3: Relationship between the SCOD loading rate and the specific substrate utilization rate

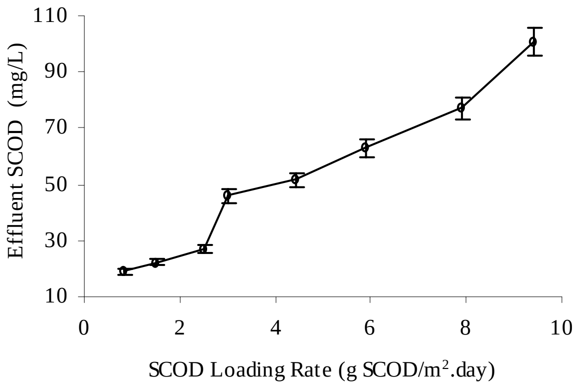

Fig. 4: The effluent SCOD variation with OLR

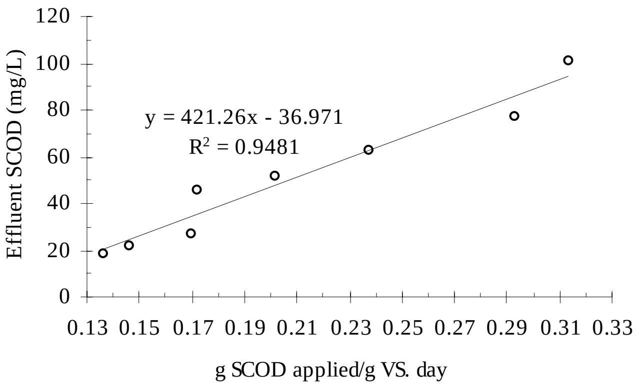

Fig. 5: Effect of specific organic loading rate on the effluent SCOD

DISCUSSION

Fig. 2 shows a linear relationship between the SCOD percentage removal efficiency and surface area SCOD loading rate. It indicats that removal efficiency decreases with increasing SCOD loading rate. While the surface area loading rate ranged between 0.842-9.413 g COD/m^2.day, the SCOD removal efficiency was more than 83.14%. It can be seen that the SCOD removal efficiencies at the high SCOD loading rates are still satisfactory, which indicates that the process had been perfectly efficient. Fig. 3. evidences that the relationship between the specific substrate utilization rate and the SCOD loading rate was a straight line with a high correlation coefficient (R^2 = 0.9931). This implies that the specific substrate utilization rate increases when the SCOD loading rate is increased; although increase in SCOD loading rate leads to decreased percentages of SCOD removed. Therefore, this shows that the process can utilize more organics at higher surface area loading rates. Fig. 4 indicates that the effluent SCOD concentration increased with raising the surface organic loading rate. The effluent SCOD varied between 18.93 and 100.93 mg/L at the surface organic loading rates experienced in this study. Fig. 5 implies that for an effluent SCOD of 100 mg/L, an applied food to biomass ratio of up to 0.325 is quite reasonable for satisfactory operation.

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