http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 10 (17): 2905-2909, 2007
ISSN 1028-8880

The Treatment of Wastewater Containing Crude Oil with Aerated Submerged Fixed-Film Reactor

H. Izanloo, A. Mesdaghinia, R. Nabizadeh, K. Naddafi, S. Nasseri, A.H. Mahvi and S. Nazmara
Center of Environmental Research and Department of Environmental Health Engineering,
School of Public Health, Medical Sciences/University of Tehran, Tehran, Iran

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 70.87-93.12% removal efficiencies of Chemical Oxygen Demand (COD) in the organic loading rate range of 1.310 to 15.797 g COD m^{-2} day^{-1}. Data gained exhibited that the effluent COD concentration ranged between 68.68 and 292.60 mg L^{-1} 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, COD 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. A large portion of it leaves this industry as wastewater that contains oil, phenols, many 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 *et al*., 2000; Chen *et al*., 2002; Vegueria *et al*., 2002).

Biological treatment processes are economical and efficient methods that can be used for treating wastewater from oil industry (Jou and Huang, 2003). In many refineries, suspended growth systems, such as Conventional Activated Sludge (CAS) process, are applied to treat refinery wastewater (Tellez *et al*., 2002; Stepnowski *et al*., 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 is limiting factor in oil industries because these are located in populous areas without enough space for expansion (Park *et al*., 1996; Loukidou and Zouboulis, 2001; Xianling *et al*., 2005). Therefore, it is important that biological treatment systems can be easy to operate and can treat a large amount of wastewater in a space which is as small as possible (Park *et al*., 1996; Xianling *et al*., 2005). As a consequent, 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 have some advantages, such as presence of higher concentrations of biomass in bioreactor, short hydraulic resistance time, resistance to toxic loading and adverse environmental conditions, easy operation, handling shock loads with high efficiency, lower consumption of energy and producing less waste sludge, (Park *et al*., 1996; Jianlong *et al*., 2000; Loukidou and Zouboulis, 2001; Jou and Huang, 2003; Guimarães *et al*., 2005):

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 and Abd-El-Bary, 1987; Park *et al*., 1996; Hamoda and Al-Ghusain, 1998, 1999; Al-Sharekh and Hamoda, 2001). Also, diffusers provide bubbles of diffused air for both aeration and turbulence. The turbulence created by this way prevents the excessive biofilm growth (Hamoda and

---

Corresponding Author: A. Medsdaghinia, Center for Environmental Research and
Department of Environmental Health Engineering, School of Public Health,
Medical Sciences/University of Tehran, Tehran, Iran

Al-Sharekh, 1999). ASFF process has been successfully applied for treatment of both urban and industrial wastewaters by several researchers (Park *et al.*, 1996; Hamoda and Al-Sharekh, 1999; Gálvez *et al.*, 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 wastewater containing crude oil under normal operating conditions.

MATERIALS AND METHODS

Experimental set-up: Figure 1 shows a schematic diagram of the pilot plant that was set up during 11 months in 2006 at Health Environmental Engineering Department of Tehran University of Medical Sciences, in Tehran, Iran, for this study. The pilot plant included: one experimental ASFFR, one peristaltic pump in order to pump wastewater into ASFFR, 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 round 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 containing crude oil was continuously pumped into the bioreactor at the base, with a flow rate ranged from 8.5 to 102 L day^{-1}. The air was supplied at the bottom of the bioreactor. The air flow rate was increased with increasing organic loading in the range 5-30 L min^{-1} in order to maintain dissolved oxygen level of more than 2 mg L^{-1} throughout the bioreactor. Table 1 gives a summery of the experimental mean hydraulic and organic loading rates.

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.

The artificial wastewater containing crude oil: The artificial wastewater containing crude oil was prepared by adding 75 mg L^{-1} 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 containing crude oil are shown in Table 1. Because this wastewater was very strong, it was diluted. Table 2 shows 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 3).

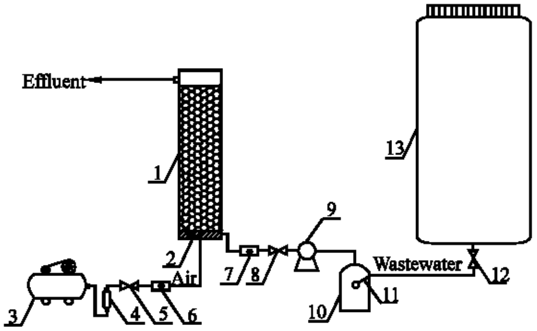

Fig. 1: Schematic diagram of the pilot plant: (1) aerated submerged fixed-film bioreactor, (2) round diffuser, (3) air compressor, (4) activated carbon column, (5, 8 and 12) cutoff valve, (6) air rotameter, (7) liquid rotameter, (9) wastewater pump, (10) equalization tank, (11) floater, (13) reservoir

Table 1: The experimental mean hydraulic and organic loading rates

Run	HRT † (h)	Influent SCOD (mg L^{-1})	Flow rate (l h^{-1})	Organic loading rate (g SCOD m^{-2} day^{-1})
1	24.0	641.73	0.3542	0.8423
2	12.0	570.54	0.7083	1.5014
3	8.0	640.54	1.0625	2.5249
4	6.0	571.36	1.4167	2.9954
5	4.0	562.80	2.1250	4.4430
6	3.0	562.75	2.8333	5.9005
7	2.4	600.07	3.5417	7.8954
8	2.0	598.53	4.2500	9.4135

† Hydraulic retention time

Table 2: Characteristics of the artificial oil-based wastewater

Constituent	Average concentration	Range
pH	6.3	5-8
TCOD (mg L^{-1})	30795.0	30143-31462
SCOD (mg L^{-1})	17867.0	17039-18791
TN (mg L^{-1})	48.0	32-102
TP (mg L^{-1})	0.9	0.2-2.3
Cl-(mg L^{-1})	13.0	9-45
Alkalinity (mg $CaCO_3$ L^{-1})	185.0	95-370

Table 3: Composition of diluted oil-based wastewater

Constituent	Average concentration	Range
pH	7.5	6.8-7.9
TCOD (mg L^{-1})	999.5	975-1023
SCOD (mg L^{-1})	593.0	544-653
TN (mg L^{-1})	1.7	1.1-3.4
TP (mg L^{-1})	< 0.01	0-0.08
Cl-(mg L^{-1})	0.5	0.1-1.5
Alkalinity (mg $CaCO_3$ L^{-1})	50.0	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 media surface, a given number of media were randomly selected and taken from several depths of the bioreactor once a week. The media with biomass attached to them were put in a very dilute sulfuric acid solution for several days so as to detach biomass from surface of medium. Detached biomass was used for determining VS according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

RESULTS AND DISCUSSION

There was a linear relationship between the COD percentage removal efficiency and surface area COD loading rate (Fig. 2). It is indicated that removal efficiency decrease with increasing the COD loading rate. While the surface area loading rate ranged between 1.310-15.797 g COD m^{-2} day^{-1}, the COD removal efficiency was more than 70%. It can be seen that the COD removal

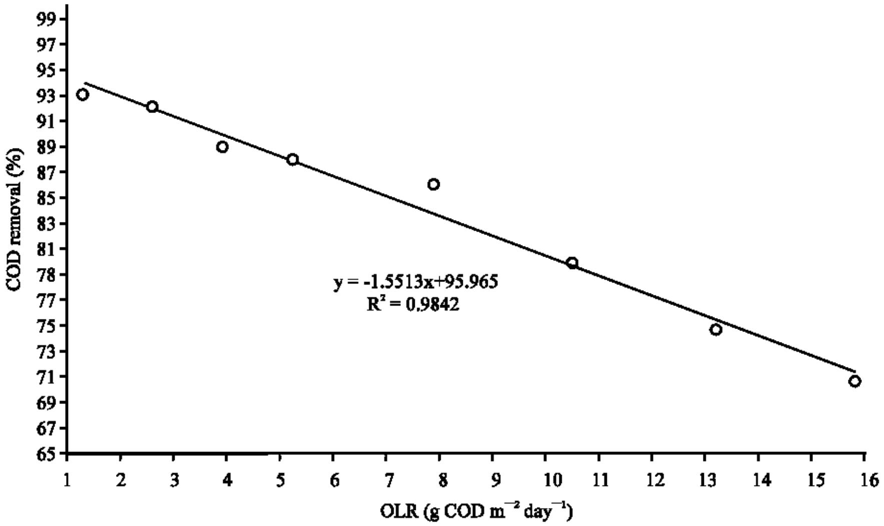

Fig. 2: Effect of OLR on COD removal efficiency

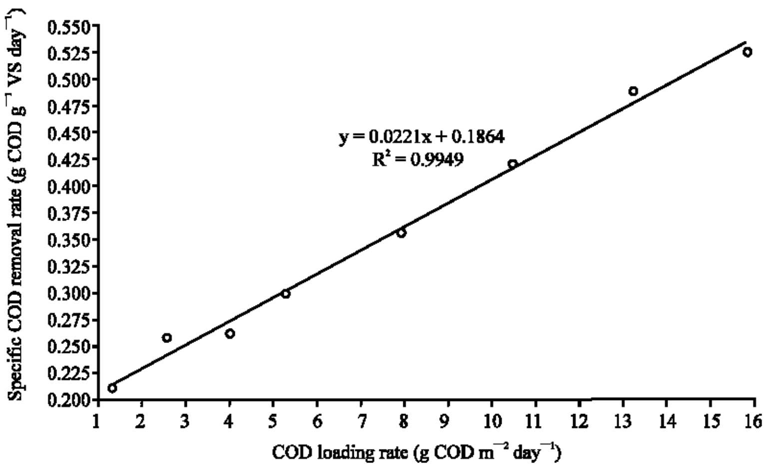

Fig. 3: Relationship between the COD loading rate and the specific substrate utilization rate

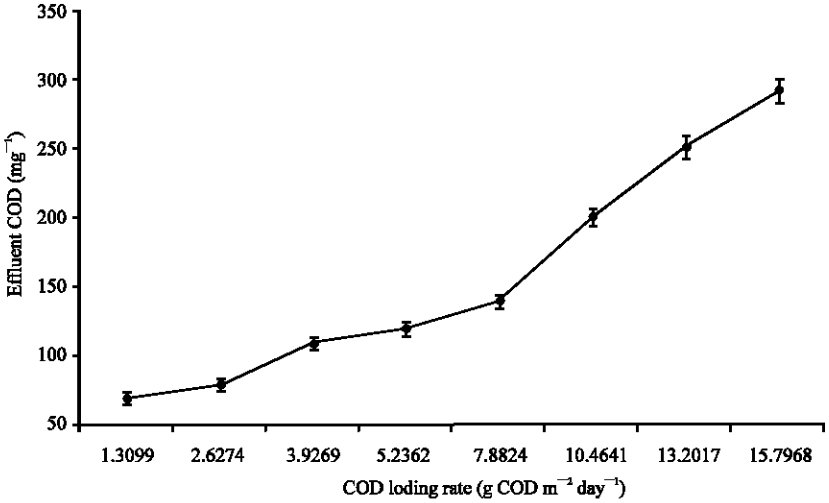

Fig. 4: The effluent COD variation with OLR

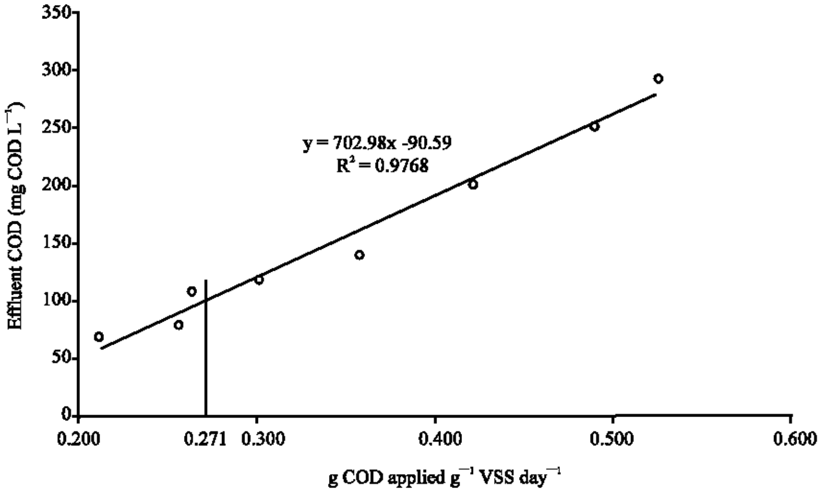

Fig. 5: Effect of specific organic loading rate on the effluent COD

efficiencies at the high COD loading rates of up to 10 g COD m^{-2} day^{-1} are reasonably satisfactory, which indicates that the process had been perfectly efficient.

The relationship was a straight line with a high correlation coefficient ($R^2 = 0.9949$). This implies that the specific substrate utilization rate increases when the COD loading rate is increased although increases in the COD loading rate lead to the decreased percentages of COD removed (Fig. 3). Therefore, this shows that the process can utilize more organics at higher surface area loading rates.

It is indicated that the effluent COD concentration increased with increases in the surface organic loading rate. The effluent COD varied between 68.67 and 292.6 mg L^{-1} at the surface organic loading rates experienced in this study (Fig. 4).

For an effluent COD of 100 mg L^{-1}, an applied food to biomass ratio of up to 0.271 is quite reasonable for satisfactory operation (Fig. 5).

CONCLUSIONS

The COD removal efficiencies ranging from 70.87 to 93.12% were achieved by aerated submerged fixed-film reactor.

The biofilm growth considerably increases with the increases in the organic loading rate, because the system can retain significant amounts of attached biomass.

For a wide range of organic loading rates, the process is cable of attaining high organic removal rates.

Although the organic removal efficiency decreases with increased organic loading rate, the organic removal rate increases as the organic loading rate increases.

ACKNOWLEDGMENTS

The authors wish to thank all the staff of the laboratories of the Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Iran, who collaborated with them in this study. The authors would also like to acknowledge gratefully the fact that the completion of this research would not have been possible without the support of Tehran University of Medical Sciences, Iran.

REFERENCES

Al-Sharekh, H.A. and M.F. Hamoda, 2001. Removal of organics from wastewater using a novel biological hybrid system. Water Sci. Technol., 43: 321-326.

American Public Health Association (APHA), 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edn., Washington, DC: APHA.

Chen, Z., G.H. Huang and J.B. Li, 2002. A GIS-based modeling system for petroleum waste management. Water Sci. Technol., 47: 309-317.

Gálvez, J.M., M.A. Gómez, E. Hontoria and J. González-López, 2003. Influence of hydraulic loading and air flow rate on urban wastewater nitrogen removal with a submerged fixed-film reactor. J. Hazard Mater., B101: 219-229.

Guimarães, C., P. Porto, R. Oliveira and M. Mota, 2005. Continuous decolourization of a sugar refinery wastewater in a modified rotating biological contactor with *Phanerochaete chrysosporium* immobilized on polyurethane foam disks. Process. Biochem., 40: 535-540.

Hamoda, M.F. and M.F. Abd-El-Bary, 1987. Operating characteristics of aerated submerged fixed-film (ASFF) bioreactor. Water Res., 21: 939-947.

Hamoda, M.F. and I.A. Al-Ghusain, 1998. Analysis of organic removal rates in the aerated submerged fixed film process. Water Sci. Technol., 38: 213-221.

Hamoda, M.F. and H.A. Al-Sharekh, 1999. Sugar wastewater treatment with aerated fixed-film biological systems. Water Sci. Technol., 40: 313-321.

Jianlong, W., S. Hanchang and Q. Yi, 2000. Wastewater treatment in a Hybrid Biological Reactor (HBR): Effect of organic loading rates. Process Biochem., 36: 297-303.

Jou, C.J.G. and G.C. Huang, 2003. A pilot study for oil refinery wastewater treatment using a fixe-dfilm bioreactor. Adv. Environ. Res., 7: 463-469.

Leslie Grady, C.P., G.T. Daigger and H.C. Lim, 1999. Biological Wastewater Treatment. 2nd Edn., Marcel Dekker, Inc, pp: 949-970.

Loukidou, M.X. and A.I. Zouboulis, 2001. Comparison of two biological treatment processes using attached-growth biomass for sanitary landfill leachate treatment. Environ. Pollut., 111: 273-281.

Nabizadeh, R. and A. Mesdaghinia, 2006. Behavior of an aerated submerged Fixed-film Reactor (ASFFR) under simultaneous organic and ammonium loading. J. Environ. Qual., 35: 742-748.

Park, T.J., K.H. Lee, D.S. Kim and C.W. Kim, 1996. Petrochemical wastewater treatment with Aerated Submerged Fixed-film Reactor (ASFFR) under high organic loading rate. Water Sci. Technol., 34: 9-16.

Stepnowski, P., E.M. Siedlecka, P. Behrend and B. Jastorff, 2002. Enhaced photo-degradation of contaminates in petroleum refinery wastewater. Water Res., 36: 2167-2172.

Tellez, G.T., N. Nirmalakhandan and J.L. Gardea-Torresdey, 2002. Performance evaluation of an activated sludge system for removing petroleum hydrocarbons from oilfield produced water. Adv. Environ. Res., 6: 455-470.

Toril, I.R.U., 2001. Chemical characterization of produced water from four off-shore oil production platforms in the North Sea. Chemosphere, 39: 2593-2606.

Vegueria, S.F.J., J.M. Godoy and N. Miekeley, 2002. Environmental impact studies of barium and radium discharges by produced waters from the Bacia de Campos oil-field offshore platforms. Brazil. J. Environ. Radioact., 62: 29-38.

Xianling, L., W. Jianping, Y. Qing and Z. Xueming, 2005. The pilot study for oil refinery wastewater treatment using a gas-liquide-solid three-phase flow airlift bioreactor. Biochem. Eng. J., 27: 40-44.

Yang, L., C.T. Lai and W.K. Shieh, 2000. Biodegradation of dispersed diesel fuel under high salinity conditions. Water Res., 34: 3303-3314.

Zhao, R., Y. Wang, Z. Ye, A.G.L. Borthwick and J. Ni, 2006. Oil field wastewater treatment in biological aerated filter by immobilized microorganisms. Process Biochem., 41: 1475-1483.