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UPGRADING AN EXISTING WASTEWATER TREATMENT PLANT BASED ON AN UPFLOW ANAEROBIC PACKED-BED REACTOR

[*1]A. H. Mahvi, [1]A. R. Mesdaghinia, [2]R. Saeedi

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

[2]Department of Environmental Health Engineering, School of Public Health, Medical Sciences/University of Tehran, Tehran, Iran

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ABSTRACT

The performance of an upflow anaerobic packed-bed reactor in the upgrading of Parkandabad (Mashhad, north east of Iran) wastewater treatment plant was studied in a pilot plant. The experiments were performed at hydraulic retention times of 6, 12, 18 and 24h based on empty reactor volume and the performance of the reactor was evaluated based on the removal of organic matter (BOD_5 and COD) and SS. The average BOD_5 and COD removal efficiencies were in the ranges of 79.0-89.3% and 75.7-87.2%, respectively, depending on HRT. The relationship between the organic loading rate and organic removal rate was linear in the loading range of 0.52-2.10kg BOD_5/m^3.d. The average SS removal efficiencies at hydraulic retention times of 6, 12, 18 and 24h were obtained to be 82.9, 83.6, 81.2 and 87.4%, respectively. The results indicated that the reactor in combination with existing biological treatment process (completely mixed aerated lagoon) can produce a high quality effluent.

Key words: Wastewater treatment, Upgrading, Upflow anaerobic packed-bed reactor

INTRODUCTION

Upgrading a wastewater treatment plant (WWTP) may be necessary to meet the existing effluent quality and/or to meet the stricter future effluent quality requirements and/or to increase its capacity because of population growth or sewerage expansion to serve more areas. Inability to meet the existing effluent quality may result from lack of proper plant operation and maintenance, inadequate plant design capacity and increased hydraulic or organic loading rate caused by a change in wastewater flow or characteristics (Bub *et al*., 1994; Qasim, 1999; WEF, 2005; Mahvi *et al*., 2006). As the space available at a WWTP is limited, processes are required which can accommodate the need for increased treatment capacity and/or improvement of effluent quality without requiring much more space (Brinch *et al*., 1994).

Parkandabad WWTP is located in the city of Mashhad, Iran. The WWTP has been operating since 2000. The biological process used in the WWTP is a completely mixed aerated lagoon. The municipal WWTP was designed for a population of 100,000 person and an average influent flow of 15,200m^3/d, but presently the WWTP serves a population of 152,000 person and the average flow of influent municipal wastewater is about 30,400m^3/d. In addition, neighboring industries including food processing, power plant etc. discharge a combined wastewater flow of 4,600m^3/d to the WWTP. At present, the effluent quality of the WWTP is undesirable and does not satisfy the Iranian effluent discharge standards, because of hydraulic and organic over-loadings, high concentration of organic matter in the influent wastewater, presence of toxic compounds in the influent and acidic or basic pH of input wastewater. The WWTP effluent concentrations of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and suspended solids (SS) are 95, 260 and 125mg/L, respectively; whereas the Iranian effluent discharge standards for these parameters are 30, 60 and 40mg/L, respectively

*Corresponding author-Email: *ahmahvi@yahoo.com*
Tel: +98 21 8895 4914, Fax: +98 21 8895 0180

for discharge to surface waters (Iranian Environmental Protection Agency, 1992). Therefore, upgrading of Parkandabad WWTP presented a challenge due to inadequate efficiency in the removal of BOD_5, COD, SS, nitrogen and phosphorus.

Anaerobic fermentation and oxidation processes are used primarily for the treatment of waste sludge and high-strength organic wastewaters. However, applications for dilute wastewater streams have also been demonstrated and are becoming more common (Reyes *et al.*, 1999). Furthermore, the organic content of the municipal wastewater is considered to be on the suitable range for the development and good operation of the methanogenic bacteria (Grady *et al.*, 1999; Lew *et al.*, 2004). Major advantages of anaerobic wastewater treatment are less energy required, methane production, lower biomass yield, fewer nutrients required and higher volumetric loadings as compared to aerobic wastewater treatment processes (Patel and Madamwar, 2002; Metcalf and Eddy, 2003). However these processes have some disadvantages including slowness, production of obnoxious odors and corrosive gases, alkalinity addition required, more susceptibility to lower temperatures and toxic substances and no efficiency in the removal of nitrogen and phosphorus. It has been proven from several full-scale upgrading projects that the anaerobic systems are best suitable to implement in the structure of aerobic plants that have to be extended in capacity (Gerards *et al.*, 2005).

A newer modification of the anaerobic systems is known as the upflow anaerobic packed-bed reactor. In the system, the packing is fixed and the wastewater flows up through the spaces between the packing and biogrowth. A large portion of the biomass responsible for treatment in the upflow anaerobic packed-bed reactor is loosely held in the packing void spaces and not just attached to the packing material (Young and Dehab, 1983; Metcalf and Eddy, 2003). The reactor offers some advantages over other types of anaerobic processes such as high organic loadings, relatively small reactor volumes, operational simplicity and ability to effectively treat dilute wastewater. Furthermore, no clarification is used with the reactor and excess solids from biomass growth and influent suspended solids are trapped in the system and must be periodically removed by a backwashing system. The system is an appropriate alternative for upgrading of municipal WWTPs with high-strength influent wastewater (Reyes *et al.*, 1999; Nandy and Kaul, 2001; Metcalf and Eddy, 2003).

The objective of this paper was to study the performance of the upflow anaerbic packed-bed reactor in the upgrading of Parkandabad WWTP. The influence of hydraulic retention time (HRT) on the efficiency of the system in the removal of BOD_5, COD and SS was investigated.

MATERIALS AND METHODS

The present investigation employed a pilot-scale upflow anaerobic packed-bed reactor for field evaluation of the performance of the system in the upgrading of Parkandabad WWTP. The pilot plant was installed and operated at Parkandabad WWTP in the city of Mashhad using raw wastewater (mixture of municipal and industrial wastewaters). The experimental setup of the reactor is shown in Fig. 1. The reactor used in this study was cylindrical in shape with inner diameter of 1.0m, bed depth of 1.3m and a volume of 1.0m^3. The reactor was made from synthetic plastic and was filled with trunk-shape tubular packing media. Diameter and height of the packing were 1.5 and 1.4cm, respectively. The kind of the the packing media was synthetic plastic. A perforated plate was installed at the top of the packing materials to keep them submerged in the reactor.

Raw wastewater was injected at the bottom of the reactor to maintain an upflow current of liquid. The reactor was operated as a continuous flow system by pumping the feed wastewater at a pre-set flowrate by a peristaltic pump.

The experiments were performed in a period of seven months. The reactor was shaded from sunlight to prevent algal growth from intervening with microbial attachment. Startup of the experiments included seeding the anaerobic reactor with activated sludge which was kept under anaerobic condition and the reactor was operated on the batch mode for one month followed by a period of two months of continuous flow operation at a gradually increasing flowrate to promote biofilm growth. Each experimental run lasted for at least one month to approximate steady state operation. To investigate the performance of the system, field experiments were performed at hydraulic retention times (HRTs) of 6, 12, 18 and 24h based on empty reactor volume. In each experimental run on the reactor, samples were collected from influent and effluent of the reactor. Each sample was analyzed to determine the concentrations of BOD_5, COD and SS. The quality characteristics of the influent wastewater varied only slightly, because the feed tank equalized the influent flow to the reactor. The characteristics of the raw wastewater used in this study are presented in Table 1. All of the examinations were performed according to the instructions of Standard Methods (APAH/AWWA/WEF, 1998).

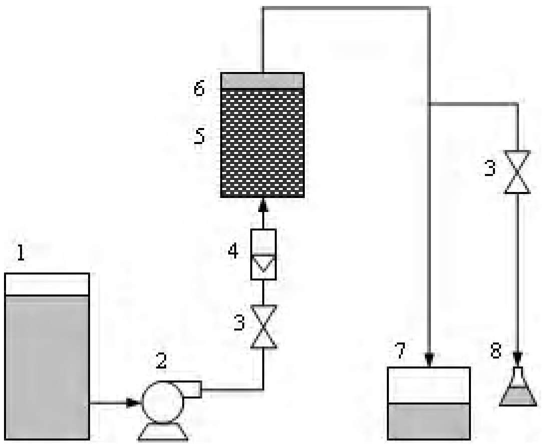

Fig. 1: Experimental setup of the upflow anaerobic packed-bed reactor used in this study: (1) feed storage, (2) peristaltic pump, (3) valve, (4) flowmeter, (5) anaerobic reactor, (6) perforated plate, (7) effluent storage, (8) sampling vessel

Table 1: Quality characteristics of the influent wastewater

Parameter (mg/L)	Samples No.	Average	Standard deviation	Min	Max
BOD_5	50	520	142	354	801
COD	50	1275	137	1022	1511
SS	50	376	64	211	503
$NH_4^+ - N$	25	18.3	7.2	8.2	31
TKN	25	49	13.2	27	87
Phosphorus	25	22	8.1	15.6	36

RESULTS

The performance of the upflow anaerobic packed-bed reactor was evaluated based on the removal of organic matter (BOD_5 and COD) and SS at different HRTs. The operating and performance data of the upflow anaerobic packed-bed reactor during experimentation are summarized in Table 2. Figs. 2,3 show the effluent concentrations of BOD_5 and COD and the removal efficiencies of these parameters in the anaerobic reactor at different HRTs. As illustrated on Fig. 2,3, by increasing HRT from 6 to 24h, the average BOD_5 removal efficiency increased from 79.0 to 89.3% and the average COD removal efficiency increased from 75.7 to 87.2%.

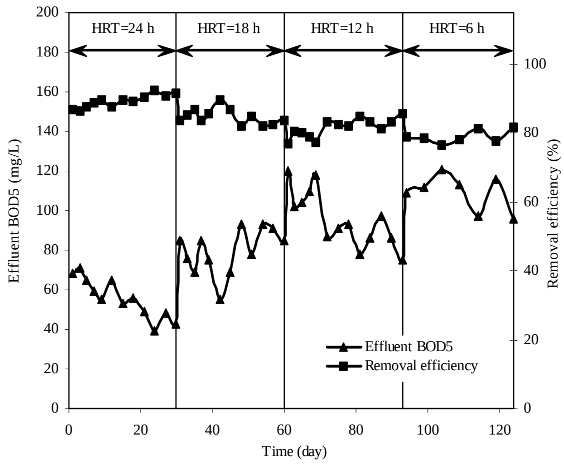

Fig. 2: BOD_5 effluent concentration and its removal efficiency in the upflow anaerobic packed-bed reactor at different HRTs

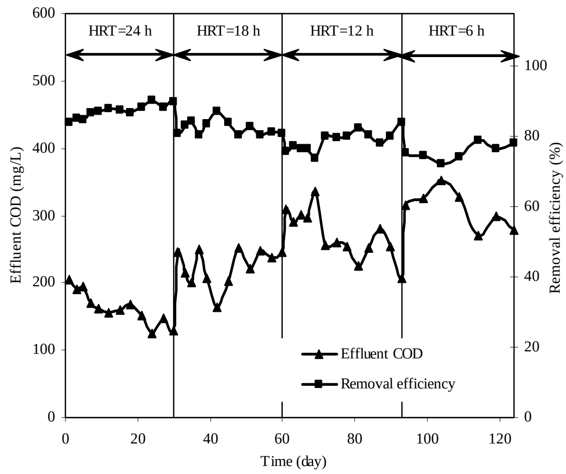

Fig. 3: COD effluent concentration and its removal efficiency in the upflow anaerobic packed-bed reactor at different HRTs

Table 2: Average operating and performance data of the upflow anaerobic packed-bed reactor

HRT (h)	BOD_5 loading rate (kg/ m^3.d)	COD loading rate (kg/ m^3.d)	Effluent BOD_5 (mg/L)	BOD_5 removal efficiency (%)	Effluent COD (mg/L)	COD removal efficiency (%)	Effluent SS (mg/L)	SS removal efficiency (%)
6	2.10	5.14	109.1	79.0	309.9	75.7	64.3	82.9
12	1.05	2.57	95.9	81.6	270.8	78.8	61.5	83.6
18	0.70	1.71	79.5	84.7	223.9	82.4	70.8	81.2
24	0.52	1.29	55.9	89.3	163.0	87.2	47.5	87.4

The performance of the reactor was also evaluated in terms of the organic removal rate expressed as kg BOD_5/m^3.d (or kg COD/m^3.d). Since the influent wastewater applied to the reactor had an organic content which varied within a very limited range (i.e., could be considered essentially constant for practical applications), the organic loading rate varied by changing the liquid flowrate (i.e., HRT). Fig. 4 illustrates the relationship between the organic loading rate and organic removal rate which appears to be linear within the range of loading rates studied, with a very high correlation coefficient (R^2>0.999). The maximum organic removal rate was 1.66kg BOD_5/m^3.d (or 4.70kg COD/m^3.d) which was at organic loading rate of 2.10kg BOD_5/m^3.d (or 5.14kg COD/m^3.d) and the HRT of 6h.

Fig. 5 presents the SS effluent concentration and its removal efficiency in the anaerobic system at different HRTs. The average efficiency of SS removal at different HRTs ranged between 81.2 to 87.4%. Also the average effluent concentrations of SS at HRTs of 6, 12, 18 and 24 h were obtained to be 64.3, 61.5, 70.8 and 47.5 mg/L, respectively.

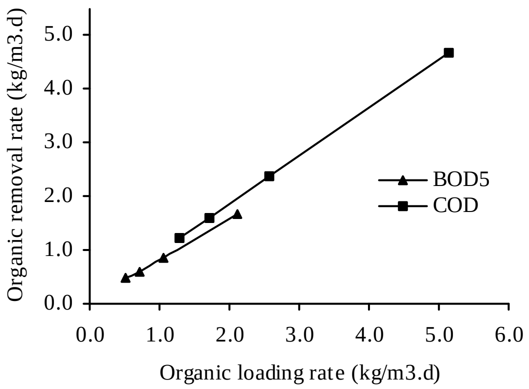

Fig. 4: Effect of organic loading rate on the organic removal rate

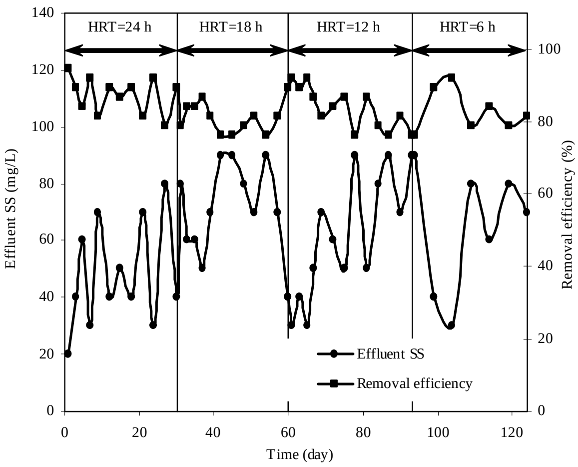

Fig. 5: SS effluent concentration and its removal efficiency in the upflow anaerobic packed-bed reactor at different HRTs

DISCUSSION

According to Figs. 2, 3, the organic matter removal efficiency increased slightly as the HRT increased from 6 to 24 h. The average effluent concentrations of BOD_5 and COD at differet HRTs were found to be in the ranges of 55.9-109.1 and 163.0-309.9mg/L, respectively. The results indicated that the reactor in combination with existing aerobic treatment process (completely mixed aerated lagoon) can produce a high quality effluent. In other tropical countries, anaerobic reactors for domestic wastewater treatment have also found wide acceptance. There are several full-scale plants already in operation in Colombia, Brazil, Indonesia, India and Egypt and COD removal efficiencies above 70% have been observed in these WWTPs. The effluent quality at these installations is reported to be 140mg COD/L, 75mg BOD_5/L and 30mg SS/L (Souza and Foresti, 1996; Chernicharo and Cardoso, 1999; Kalogo and Verstraete, 2000). The COD to BOD_5 ratio of the process effluent was higher than that of the influent wastewater, so the ratios in the influent wastewater and the reactor effluent were determined 2.5 and 2.9, respectively. The higher COD to BOD_5 ratio of the effluent is most likely contributed by the non-biodegradable portion of the organic matter escaping biological treatment (Metcalf and Eddy, 2003).

According to Fig. 4, the anaerobic reactor achieved higher organic removal rates as long as the mass transfer limitations for substrate were not reached. However, the maximum organic loading rate beyond which the process might fail to attain higher organic removal rate was not reached in the range of loading rates studied. The relationship between the organic loading rate and organic removal rate was linear within the range of loading rates studied.

The average SS removal efficiencies at HRTs of 6, 12, 18 and 24h were obtained to be 82.9, 83.6, 81.2 and 87.4%, respectively. Therefore, the range of HRTs had not significant influence on the SS removal efficiency of the reactor.

The results showed that the upflow anaerobic packed-bed reactor was a feasible process for the upgrading of Parkandabad WWTP by observing removal efficiencies of organic matter and suspended solids.

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