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Optimizing OLR and HRT in a UASB Reactor for Pretreating High- Strength Municipal Wastewater

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This study was carried out for examination of a lab-scale UASB reactor for optimization of organic loading rate and hydraulic retention time. The total volume of the reactor was 5 l with an effective height of 160 cm and diameter of 5 cm. This reactor was used to treat fortified municipal wastewater at volumetric organic loadings of 3.6, 7.2, 10.8, and 14.4 kg m^{-3} d^{-1} at temperature 30℃. The result of present work indicated an optimum range for organic loading (7.2 to 10.8 kg m^{-3} d^{-1}) with COD removal efficiency of about 85%. Moreover, optimum HRT for influent COD concentration of 1200mg/l is shown to be only 4 hours. Furthermore nitrate removal efficiency was about 80% at optimized organic loading range, with a sharp decrease beyond this range (e.g. up to 30% decrease for 14.4 kg/m^3.d and up to 45% decrease for 3.6 kg/m^3.d)

1. Introduction

There are over 200 Activated Sludge Plants (ASPs) in Iran most of them working at low efficiencies. The major problems with these systems are high production of excess sludge and poor quality of their effluents, which are mainly due to over population and receiving extra high-strength industrial wastewater. To solve these problems, it is thought to install up-flow anaerobic sludge blanket reactor (UASBR) prior to ASP to reduce the BOD feed and also to admit the excess sludge for volume reduction as well as anaerobic digestion.

UASBR is widely used for sewage treatment in tropical countries, such as India and Brazil (Aiyuk et al, 2006). The current challenge in anaerobic technology is to develop the system to treat municipal sewage in extreme situations. For instance, in Palestine and Jordan sewage is characterised with high COD concentrations of more than 1000 mg/l with high fraction of suspended COD (CODs of up to 70%) and fluctuating temperature in the range of 15–25 ℃ (Halalsheh et al., 2005). Previous researches had demonstrated that the performance of one-stage UASB reactors at low temperatures (5–20 ℃) is severely limited by the slow hydrolysis of entrapped solids that accumulate in the sludge bed when high loading rates are applied (Zeeman and Lettinga, 1999). The solids accumulation will impose a more frequent sludge discharge. Consequently, the excess sludge will increase, leading to a low solids retention time (SRT) and a

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concomitantly less stabilised sludge bed with a low specific methanogenic activity (SMA).

Due to high rate of population growth in Iran and thus increasing the flow and loading rate of municipal wastewater, most of existing ASPs need to be retrofitted. As mentioned before, the aim of this work was to optimize the hydraulic retention time (HRT) and organic loading rate (OLR) for such retrofitted system.

2. Material and methods

2.1 Reactor

A plexiglass lab-scale UASB reactor was built for this study (Fig. 1). The total volume of the reactor was 5 l and had three sections: feed entrance section with conical shape of 5 cm height, sludge bed and blanket zone with 5 cm diameter and 160 cm effective height and settling zone with 10 cm diameter and 20 cm height. A gas-liquid-solid separator (GLS) device was installed in the top portion of sludge bed.

2.2Influent wastewater

For this study, the main source of wastewater was from Ekbatan Wastewater Plant located in west of Tehran. The COD of this wastewater was fortified by molasses and milk powder. So the total COD could reach to 600, 1200, 1800 and 2400 mg/l. To prevent pH fluctuation of the influent, $NaHCO_3$ and K_2HPO_4 were added to wastewater. Influent wastewater characteristic is presented in Tab. 1

2.3 Seed

For startup, the reaction was filled with anaerobic sludge taken from Pegah Diary Company and then fed continuously with municipal wastewater from Ekbatan Wastewater Treatment Plant.

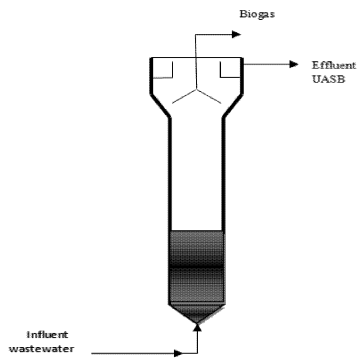

Figure 1: Schematic diagram of UASB reactor

Table 1: Influent wastewater characteristics

parameter	unit	quantity
pH	mg/L	7-8
COD	mg/L	600 -2400
TSS	mg/L	190 -250
nitrate	mg/L	4-25
TKN	mg/L	60-80
phosphor	mg/L	15-25
SO_4^{-2}	mg/L	120 -200
alkalinity	mg $CaCO_3$/L	1200-3140
temperature	˚C	30

2.4 Chemical analyses

All chemical analyses for determination of wastewater quality parameters were conducted according to Standard Methods (APHA, 1992). UV-Vis Spectrophotometer (DR 5000) was used for measuring of nitrate, Total Kjeldahl Nitrogen (TKN) and total phosphor. Methane content in biogas was measured by gas chromatograph (model: PR 2100). The quantity of produced gas was estimated by water displacement method.

3. Results and discussion

3.1 Results of COD measurements

Initial influent COD was around 200mg/l during startup period for 20 days and then increased to 2400 mg/l with few step changes (Fig 2). The COD Removal Efficiency (RE) was very poor (45% based on unfiltered effluent (total COD) and 70% based on filtrated effluent (soluble COD)). After formation of granules (about 40 days after startup) the reactor reached to the steady state and the sludge washout was decreased sharply, the COD RE was improved to 85% regardless of effluent filtration.

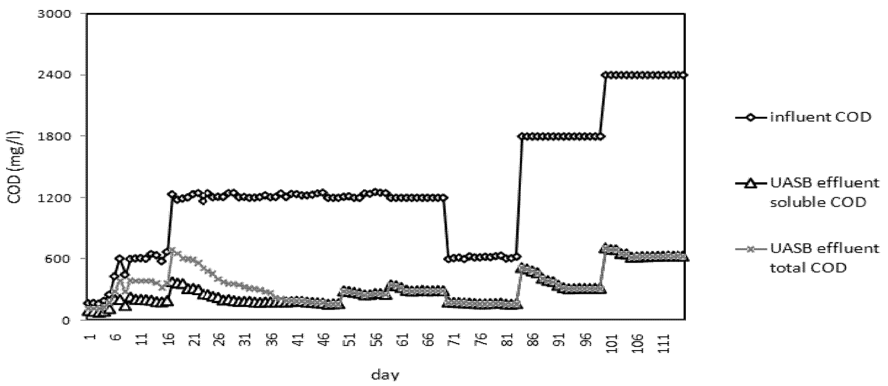

Figure 2: Temporal variation of influent- COD, effluent soluble COD and effluent-total COD

3.2 Results of HRT variations

The effect of various retention times (RTs) of 3, 4, 5, and 6 hours on COD, TSS, and sulfate RE were investigated to determine the best HRT (results are shown in Fig. 3). As can be seen, the COD RE is the highest at the RTs of 4 and 5 hours.

The reason for decrease in efficiency while reducing the HRT, in spite of increasing the turbulency in the reactor, is that the contact time of wastewater with sludge granules will be decreased, so less organic matters are utilized. The efficiency was also decreased by increasing the RT, because of lesser mixing due to reduction of upflow liquid velocity. Mixing in the reactor is caused by rising gas bubbles and the upflow liquid velocity. The TSS RE in steady state conditions for different RTs is also shown in Fig. 3. As can be seen, the TSS RE is increased by increasing the RT up to 4 hours, but very little increase (about 1%) was observed for higher HRTs. The sulfate RE was also 80% on the retention times of 4 to 5 hours, but it reduced sharply beyond this range. The reduction of sulfate RE at retention times of 3 and 6 hours, shows that parameters such as mixing and wastewater contact time with bulked sludge are important factors for SRB bacteria, like methanogens.

The methane gas and its fraction in the total gas production in HRT of 4 hours and OLR of 10.8 kg/m^3.d was determined 194.3 [ml CH_4/g COD removed at standard temperature and pressure (STP) condition] and 56% respectively. As can be seen, the amount of methane gas produced is less than the expected value of 250-350 [ml CH_4/g COD removal] range. This happens is because of high sulfate concentrations, which makes SRB more active. The more active SRB, the less active methanogens, so less methane is produced. It should be noted that the methane production can be improved, if the ratio of COD/sulfate is increased. For example, the methane production at 4 hour HRT and OLR of 7.2kg/m^3.d, was increased to 306.6 [ml CH_4/g COD removed at STP condition].

3.3 Results of OLR variation

The RE of COD, nitrate, sulfate, and TSS (Total Suspended Solids) for different organic loadings of 3.6, 7.2, 10.8, and 14.4 [kg COD/m^3.day] (for COD concentrations of 600, 1200, 1800, and 2400, respectively and HRT=4 hours) is shown in Fig. 4.

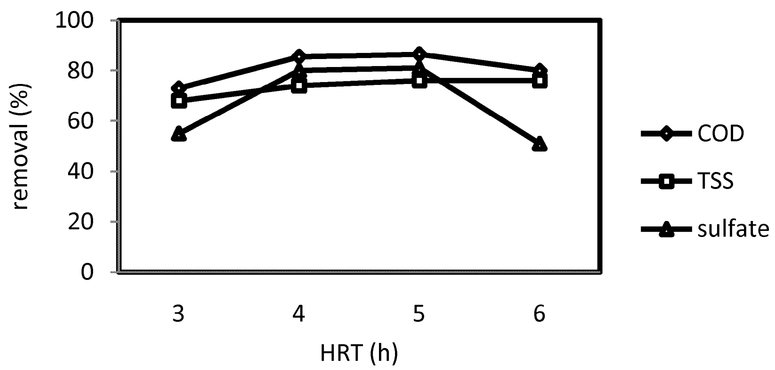

Figure 3: Removal efficiency of COD, TSS and sulphate with HRT

As it can be seen, the COD RE is at maximum in the organic loading range of 7.2 to 10.8 [kg COD/m^3.d]. The COD RE in this range is about 85 percent, but it reduces to 74 percent while decreasing the OLR to 3.6 kg COD/m^3.d, and 73 percent while increasing the organic loading to 14.4 [kg COD/m^3.d], representing an optimum OLR of 7.2 to 10.8 [kg COD/m^3.d] in 30ºC for this reactor. By increasing the COD from 1800 to 2400 mg/l (increasing organic loadings from 10.8 to 14.4 kg COD/m^3.d), the COD RE was decreased. The reason for this RE reduction is because of higher sulfate concentration (from 120 to 200mg/l) due to addition of molasses to increase COD from 1800 to 2400). This makes the substrate utilization competitive between SRB and methanogenous bacteria, therefore the methanogens activities reduce with respect to previous condition. The competitive domination of sulfate reduction over methane production in sulfate-rich environments has been demonstrated by different researchers (Abram, 1978). It should be noted that increasing the COD from 1200 to 2400 mg/l, yields in a sharp reduction in nitrate removal, from 80% to 30%. This reason for their reduction might be because of lesser activities of nitrifying bacteria at higher CODs.

3.4 Sludge physical characteristics

The mixed liquor suspended solid (MLSS) concentration in the sludge bed zone increased from 10g/l to 29g/l and mixed liquor volatile suspended solid (MLVSS)/MLSS ratio increased from 0.5 to about 0.85 at the end of the operation period. The sludge volume index (SVI) decreased from 55 to about 12 ml/g.

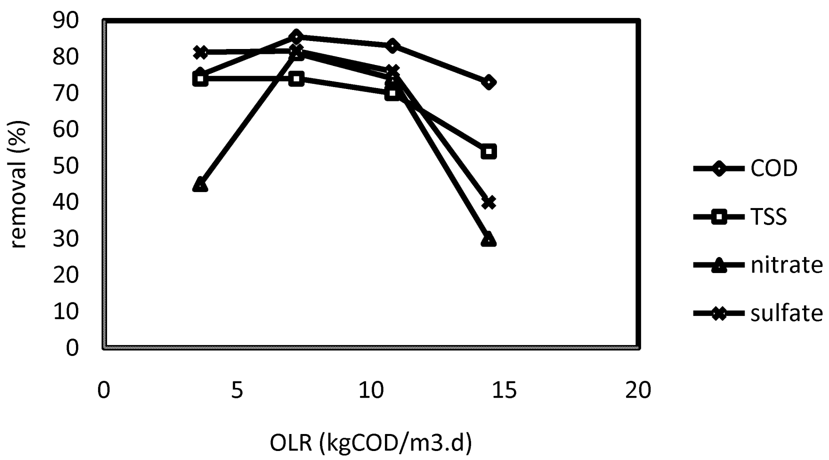

Figure 4: Removal efficiency of COD, nitrate, sulphate, and TSS in different OLR

4. Conclusion

1. Existing ASPs in Iran could be easily retrofitted by adding a UASBR before aeration basin. This will increase the total influent capacity by a factor of 10 (BOD efficiency of about 90% was achieved for UASBR)
2. The UASBR was very stable when granules appeared after 40 days from startup. Sludge washout was reduced to almost zero. Worth mentioning that SVI was less than 12.
3. As was noticed, the COD concentration of UASBR influent should be around 1200 to 2400 mg/l. for some cases the which the incoming COD is not as much, the COD may be increased by admitting excess sludge to UASBR resulting a significant reduction of excess sludge volume.
4. The optimum OLR was easily in the range of 7.2 to 10.8 $kg/m^3.d$. However, this range could easily be expanded if the sulfate content of UASBR feed will be reduced.
5. HRT of 4 hour was found to be the optimum. Nevertheless, this could be reduced if the amount of granules are increased

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