Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.846461

53 (2015) 352–359
January

Taylor & Francis
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The combined UASB and MBR system to COD and TSS removal and excess sludge reduction for the treatment of high strength wastewater in various operational temperatures

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Received 18 January 2012; Accepted 20 August 2013

ABSTRACT

There are many activated sludge plants (ASP) in Iran. Most of them are overloaded and as a result their efficiency is very low. A combined laboratory-scale system (5 L reactors) consisting of an up-flow anaerobic sludge blanket (UASB) and aerobic membrane bioreactor (MBR) was operated at 20 and 30˚C with pH between 7.6 and 8.4. The experiment was run to optimize treatment of high-strength enriched municipal wastewater of the Ekbatan treatment plant located in west Tehran. The chemical oxygen demand (COD) of the wastewater was enriched due to the addition of molasses and milk powder. To prevent pH fluctuation of the influent, $NaHCO_3$ and K_2HPO_4 were added to the wastewater. The excess sludge from the MBR was recirculated into the UASB. The system treated fortified municipal wastewater with a volumetric COD loading rate of 600, 1,200, 1,800, and 2,400 mg/L, and temperatures at 20 and 30˚C. The results of the present work indicate an optimum organic loading (7.2–10.8 $kg\,m^{-3}\,d^{-1}$) with COD removal efficiency (RE) between 74 and 85% in both examined temperatures in UASBR. The total combined system efficiency was, approximately, 98% in COD removal and 100% in total suspended solids removal. Furthermore, the nitrate RE was about 80%. Also, excess sludge reduction was over 90%, and the optimum hydraulic retention time for influent COD concentration of 1,200 $mg\,l^{-1}$ is shown to be 4 h. This upgraded system increases the treatment capacity by factor of 5.

Keywords: Enriched municipal wastewater; Temperature; MBR; UASB

1. Introduction

In some cases, domestic wastewater and industrial wastewater, such as dairy sewage discharge into the same collector system. When this happens, high amounts of nutrients such as chemical oxygen demand (COD) must be treated in wastewater treatment plants. A pretreatment stage is necessary to reduce some of the substrates. The anaerobic stage is most efficient in reducing COD, and giving a higher quality effluent to aerobic activated sludge (AS) system.

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On the other hand, high hydraulic retention time (HRT) in secondary sedimentation basins need enormous structures, which are very expensive and often have low efficiency to eliminate total suspended solids (TSS). Furthermore, anaerobic systems such as up-flow anaerobic sludge blanket (UASB) are very sensitive to temperature fluctuation [1]. Another problem is that these systems produce high volumes of excess sludge and poor quality effluent, mainly due to over population and receiving high-strength industrial wastewater. Because of all of this, over 200 activated sludge plants (ASPs) in Iran work at low efficiencies. A proposed solution for these problems is to install a UASB prior to ASP to reduce the biological oxygen demand (BOD) and COD feed, and submit the excess sludge for volume reduction as well as anaerobic digestion [2]. Also, an membrane bioreactor (MBR) installation after the anaerobic stage may allow the elimination of sedimentation basin, while providing more efficient TSS removal, and producing less excess sludge. The MBR process has been extensively studied for its design, operation, and economy [3,4].

The UASB system was designed to retain a high carbon level for denitrification (via nitrate), for methanogensis, and to provide the low C/N ratio effort feeding to the MBR perform the partial nitrification step. Recently, a UASB reactor has been successfully employed for a full-scale dairy treatment application [5]. The use of laboratory-scale UASB at an operational temperature of 30˚C was also previously instigated [6]. The COD_{tot} removal varied between 85 and 88% at HRT of 5.0 h and organic loading rates (OLR) of 8.5 g COD/Ld. Another laboratory-scale investigation indicated that more than 67% COD_{tot} reduction could be achieved at 20˚C using a UASB reactor followed by AS system, with 80% COD removal in the AS systems [7]. The result of combined UASB and MBR system indicated 98% total organic carbon (TOC) removal, while the UASB reactor alone was only 80% efficient in removing TOC at 30˚C [8]. However, the COD, BOD, and TSS concentrations in the effluent of an anaerobic treatment step, generally, do not comply with standards for discharge into the receiving water bodies, and, therefore, a post-treatment is required [9].

A submerged MBR system with a membrane submerged in the aeration tank treating the effluent of UASB was investigated. The integrated system achieves more than 98% removal of COD_{tot} and 100% of TSS at a wide temperature range. The COD_{tot} removal rate was reduced from 85 to 70%, when the operational temperature was reduced from 30 to 20˚C in a UASB reactor.

The aim of the present study is to evaluate the effectiveness of a system consisting of a UASB-MBR system for treating high-strength wastewater in cold and warm weather conditions, and comprise them. Emphasis is given to the removal efficiency (RE) of $COD_{tot,}$ BOD_s, and TSS. An important aspect in this study is to assess the effectiveness of the combined system at both low and high temperatures.

2. Material and methods

2.1. Lab scale experimental setup

The experimental work was carried out over two successive periods at Ekbatan wastewater treatment plant in Tehran—Iran. Fig. 1 depicts experimental setup consisting of two parts. This is a UASB and aerobic MBR.

2.2. UASB reactor

A Plexiglas laboratory-scale UASB reactor was built for this study (Fig. 1). The total volume of the reactor was 5 L and had three sections:

(1) feed entrance section with conical shape of 5 cm height;
(2) sludge bed and blanket zone with 5 cm diameter and 160 cm effective height;
(3) settling zone with 10 cm diameter and 20 cm height.

An inverse-conical gas-liquid-solid separator device was installed at the top portion of sludge bed and inside the settlement section [10,11]. The diameter of its inset is designed 6 cm for produced gas total in a portion of sludge bed. The gas is removed from the process using a gas outline, and gas did not enter the settlement section.

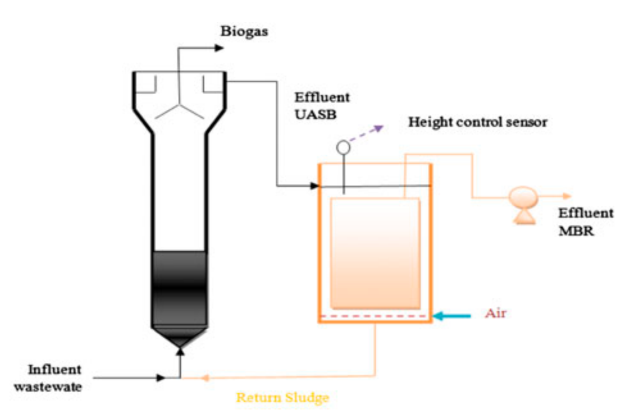

Fig. 1. Schematic of laboratory-scale experimental setup.

2.3. The MBR

The MBR was designed and built with dimensions of $65 \times 22 \times 5\,cm^2$. The useful volume in the reactor was 5 L, and it was composed of 4 main sections:

(1) Sides—the designed MBR was made of two layers. The inner part forms the main reactor basin in which the biological reactions took place, and in the outer part the warm water flows and is used to investigate the process temperature variations. All of the biological processes were performed at set room temperature.
(2) Membrane—the membrane used in this study was microfiltration type produced by the Kubota Company. It had an effective area of $0.1\,m^2$, pore nominal diameter of 0.4 μm, and A4 sheet size. The membrane was made of PVDF (Fig. 2).
(3) Conductor blade—the aeration process in an MBR occurs for two purposes: to supply the oxygen required for biological processes, and to clean the membrane surface and reduce the fouling rate [12–14]. To achieve the second goal, a polymethylmetacrylate plate was used as a blade to keep the air bubbles near the membrane surface. This way they will make proper tensions with the membrane surface and wash the sediment from the surface [15,16]. The distance of blade from the membrane and the basin side was set to 7 and 2.5 mm, respectively.
(4) The height control sensor—the main bar length of the sensor was about 20 cm, and was installed on the MBR in a place, which indicates 5 L volume of the basin.

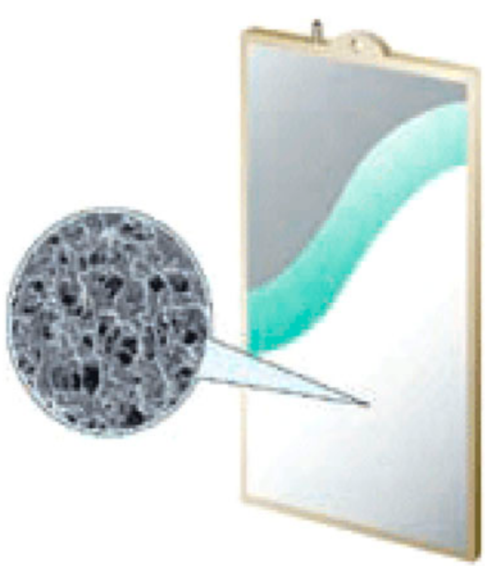

Fig. 2. Schematic of the used membrane.

2.4. Operation and start-up of reactors

The anaerobic seed sludge was collected from Pegah Dairy wastewater facility, and then fed continuously with municipal wastewater from the Ekbatan wastewater treatment plant. The one-stage UASB reactor was started up during an especially the hot period of the Iranian summer with average temperature of 30˚C.

After sedimentation, sludge with a volatile suspended solid content of 30 g/L was employed in the UASB with an inoculum volume of $1{,}000\,cm^3$. The UASB culture was operated with an initial HRT of 6 h, and reached steady-state condition in terms of TOC removal and gas production and biomass granulation. As the HRT was further shortened to 4 h, the MBR was filled up with the UASB effluent.

Daily monitoring (including ambient air temperature, biogas production, and grab) was started at the onset of the experiment. Influent and effluent wastewater samples were analyzed daily for COD_{total} and TSS over both the hot and cold periods of investigation. After 210 days of operation, 36 influent and effluent samples were collected, and analyzed to provide 120 days worth of data for BOD, total kjeldal nitrogen (TKN), and NH4 content at regular intervals [17]. The combined system was also operated for 210 days, of which the first 55 days were considered as a “start-up period”. The first 120 days operated at 30˚C and last 90 days at 20˚C.

Suction and aeration was conducted continuously to reduce cake resistance from the membrane surface, while the MBR process was being operated [18–20]. The operation proceeded for 210 days and comprised of three stages. Operation conditions of the combined system are shown in Table 1.

2.5. Characterization of wastewater

The main source of the influent wastewater for this study was from Ekbatan Wastewater Treatment Plant located in west of Tehran. The COD of this wastewater was enriched with molasses and milk powder, so that the total COD would reach to 600, 1,200, 1,800, and 2,400 mg/L. To prevent pH fluctuation of the influent, estimated quantities of $NaHCO_3$ and K_2HPO_4 were added to wastewater. Influent wastewater characteristics are presented in Table 2.

Table 1
Operational condition in this study

	Run 1	Run 2
HRT (h) [both reactor]	4	4
Temperature (c)	30	20
Aeration rate (L/min) [MBR]	4	4
UASB up-flow velocity (m/h)	0.4	0.4
Operational period (days)	120	90
PH [UASB]	7.6–8.4	7.6–8.4

Table 2
Influent wastewater characteristics

Compositions/parameters	Quantity
pH	7.6–8.4
COD_{total}, (mg/L)	600–2,400
BOD 5, mg/L	400–1,600
SS, 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	1,200–3,140
Temperature, ˚C	20,30

2.6. Sampling and analytical methods

A chemical analysis for the determination of wastewater quality parameters was conducted according to standards methods [21]. Spectrophotometer (model: DR 5000) was used for the measurement of nitrites and TKN. Methane content in the biogas was measured by gas chromatograph (model: PR 2100). The quantity of gas product was estimated using the water displacement method. Grab samples of the influent and the effluent of the UASB reactor and MBR were analyzed for pH, five days BOD, COD, TSS, VSS, and TKN, according to the APHA and analysis were carried out in accordance with standard methods [22–24].

2.7. Anaerobic seed

For startup the reactor was filled with sludge taken from the Pegah dairy company, and fed continuously with municipal wastewater from the Ekbatan treatment plant.

2.8. Aerobic seed

The aerobic sludge used in the MBR basin was supplied from the returned AS of the Ekbatan wastewater treatment plant. It should be noted that because the MBR influent was from the UASB effluent (which defers from the Ekbatan wastewater) it took about 20 days for aerobic sludge to adapt to the new feed stream (UASB reactor effluent).

2.9. Sludge return

The MBR sludge retention time was set to be 10 days, accounting for 50 mL of aerated sludge being returned to the UASB reactor each day [25]. Because of this there was no excess sludge from the MBR tank.

3. Results and discussion

3.1. Results of HRT variation

The effect of various HRT of 3, 4, 5, and 6 h on COD and TSS RE was investigated at 30˚C to determine the best HRT for the set to resume research (results are shown in Fig. 3). As observed, the COD RE is the highest in the RTs of between 4 and 5 h bacteria.

The reason for the decreased efficiency while reducing the HRT, in spite of increasing the turbulence in the reactor, is that the contact time of the wastewater with sludge granules is decreased, and, therefore, less organic matters is utilized by micro-organism [26,27]. The efficiency also was lowered by increasing the RT, because of lower amount of mixing due to a reduction in up-flow liquid velocity. Rising gas bubbles and the up-flow liquid velocity causes mixing in the reactor. The TSS RE in steady-state condition for different RTs is also shown in Fig. 4. It shows that the TSS RE is has risen, when the RT is increased to 4 h, but very smooth reduction (about 1%) was observed for higher HRTs. Therefore, optimum HRT for COD removal (about 80%) can be considered 4 h at 30˚C. Fig. 4 also shows that increasing the retention time from 5 to 6 h has almost no effect on COD RE reduction. This may be due to

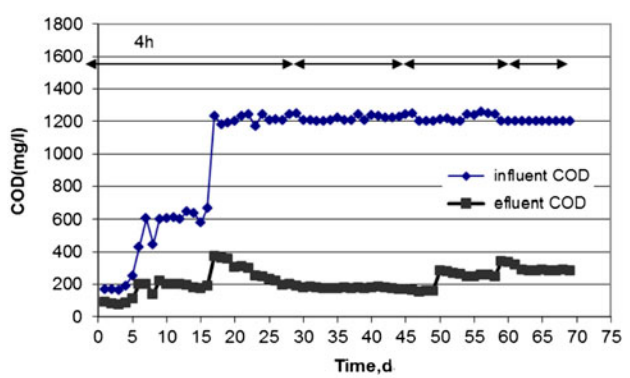

Fig. 3. HRT investigation.

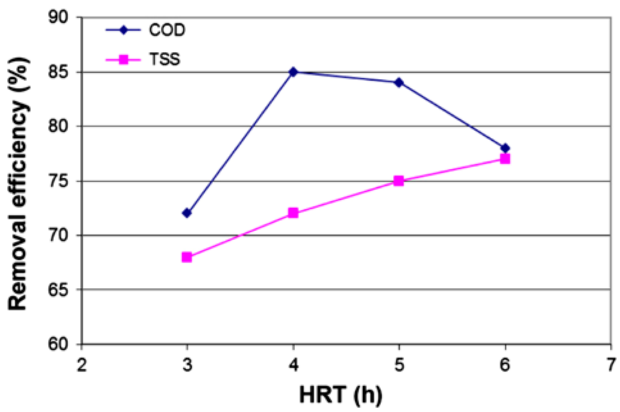

Fig. 4. COD and TSS RE with HRT (OLR of 1,200 mg l^{-1}, at 30˚C) (UASB reactor).

reduction in sulfate reduction bacteria (SRB) activities, which is a good factor for methanogenic bacteria. Because of this, the effect of a decrease in mixing is reduced.

The methane gas production at standard temperature and pressure (STP) conditions and methane fraction in different HRT at steady-state condition is shown in Fig. 5. The amount of methane produced gas is less than the acceptable range of 250–350 mL $CH_{4/g\ COD}$. This is because of high sulfate concentrations, which make SRB more active. The more active SRB and less active methanogens result in less methane production.

3.2. Results of COD RE variation by OLR at various temperatures

The RE of COD and TSS at different OLR of 3.6, 7.2, 10.8, and 14.4 kg COD/m^3 d (for COD concentrations of 600, 1,200, 1,800, and 2,400 mg/L, respectively, (HRT = 4 h) at three various operational temperatures are shown in Figs. 6 and 7.

The COD RE is at a maximum with the OLR of 7.2–10.8 kg COD/m^{3}d. The COD RE in this range is about 85, 81, and 75% at 30, 25, and 20˚C, respectively, but it is reduced to 72, 66, and 59%, while decreasing the OLR to 3.6 kg COD/m^{3}d. These values are reduced, while increasing the OLR to 14.4 kg COD/m^{3}d to 78, 72, and 62%. The results representing an optimum OLR of 7.2–10.8 kg COD/m^{3}d are seen at 30, 25, and 20˚C for the UASB reactor. By increasing the COD RE from 1,800 to 2,400 mg/L, the COD RE was decreased. The reason for this RE reduction is because of a higher sulfate concentration, (from 120 to 200 mg/L) due to the addition of molasses to increase COD from 1,800 to 2,400). SRB and methanogenic bacteria compete to use the substrate.

The methanogens' activities are reduced with respect to the previous condition. Various researches

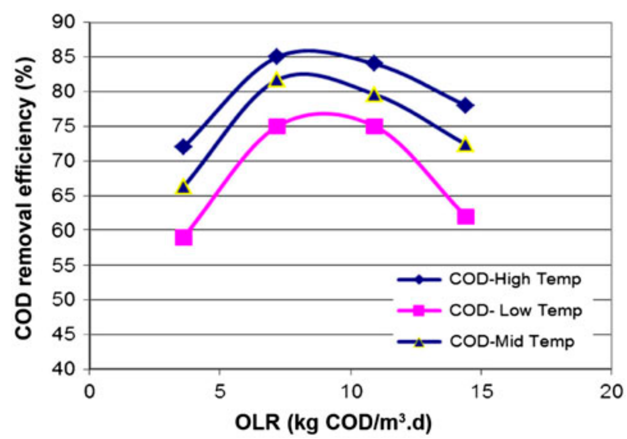

Fig. 6. COD RE variation in various OLR by temperature fluctuation (UASB reactor).

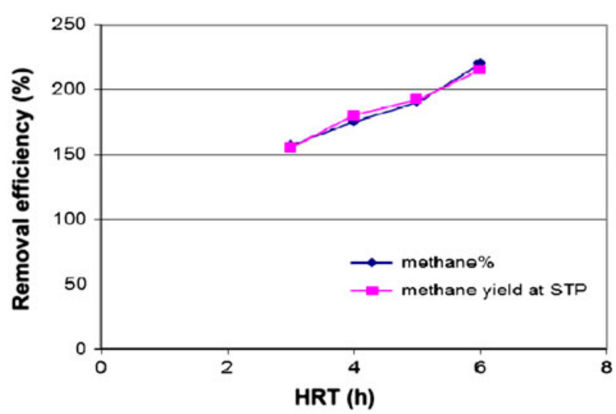

Fig. 5. The methane gas production on STP condition and methane fraction in different HRT in steady-state condition (30˚C).

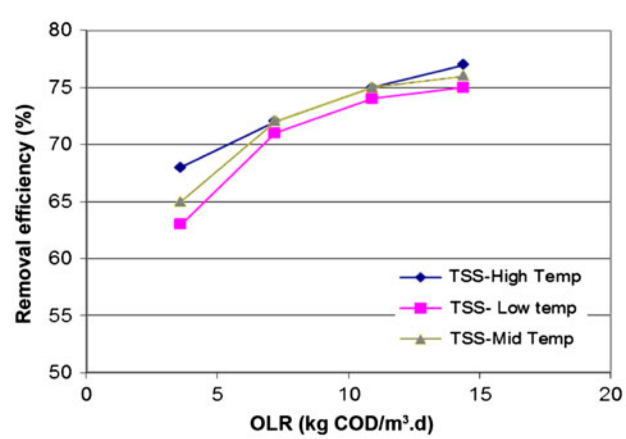

Fig. 7. The RE of TSS in different OLR (UASB reactor).

has demonstrated the competitive domination of sulfate reduction over methane production in sulfate-rich environments [28,29]. It should be noted that increasing the COD from 1,200 to 2,400 mg/L yields a sharp reduction in nitrite removal from 80 to 45% at 30˚C. The reason for this reduction may be because of fewer activities involving nitrifying bacteria at higher CODs. Fig. 7 depicts that the TSS RE has a positive trend when increasing OLR, but is relatively independent of temperature fluctuation.

3.3. Efficiency of COD removal in the UASB reactor

The UASB reactor operated at a constant HRT of 4 throughout the study, while OLRs were 3.6, 7.2, 10.8, and 14.4 kg $m^{-3}d^{-1}$ due to the changes in influent composition. UASB reactor operated at two operational temperatures. At the first stage, the reactors efficiency was investigated at 30˚C for various OLR mentioned above.

Despite the variation, 73% COD removal was observed with an OLR of 3.6 and 14.4 kg COD/m^3 d, whereas the UASB reactor achieved 85% COD RE for OLR 7.2 and 10.8 kg COD/m^3 d.

In the second stage, the UASB reactor operated at 20˚C for the above OLR, and COD RE decreased, approximately, 13 and 16% for OLR of 14.4 and 3.6. COD RE had higher performance with an OLR rate of 7.2 to 10.8, where it was only reduced by 10%.

This relatively good performance could attribute to the long solid retention time (80 days), which could effectively increase efficiency of hydrolysis of particulates matters, and subsequent digestion to soluble organic matters. The results clearly show that the UASB reactor achieved a substantial reduction of TSS resulting in an average removal of 80%. These results indicated that UASB performance in TSS removal is independent of temperature.

Also, standard deviations in results by percentage in examined temperatures and OLR are presented in Fig. 8. The results presented in Figs. 4 and 8 reveal a high temperature dependence of process performance. During the start-up stage the reactor was started without inoculation. The COD effluent quality was almost stable, with a slightly improving trend, during the first step of operation at 30˚C. This operation period coincided with the hot period of experiment. During the second step, the temperature dropped down, accompanied by deterioration in effluent quality and RE.

The NH4 and TKN removal in both reactors were low. The results clearly show that UASB reactors are not sufficient for removing nutrient from wastewater [30]. In the UASB reactors only a change in the chemical forms of nitrogen and phosphorous take place as reported by Bogte et al. [31–33]. Therefore, a nutrient removal, when necessary, can be achieved in separate post-treatment step [31].

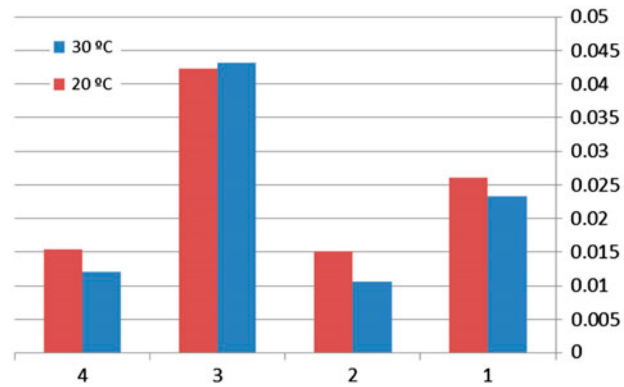

Fig. 8. Standard deviations of results in percentage.

This investigation was operated with a low circulation ratio of 25% from MBR to UASB. At the low circulation ratio high methane production indicates that the main pathway of carbon resource degradation was methanogenesis [8,34]. With the increase in the recirculation ratio, complete denitrification caused high nitrogen with low methane production [8].

3.4. Efficiency of COD removal in the MBR

The effluent COD at all retention times and temperatures in the MBR were very similar. When reducing organic loadings in UASB reactors, the MBR has fewer organic loadings so its RE rises above 90% efficiency of the system removal that exceeds 98% as shown in Fig. 9. The TSS RE in the MBR is nearly 100% as shown in Fig. 10.

3.5. Volume reduction of system and excess sludge

Typically, AS systems such as the one of Ekbatan are designed with 20 h HRT. By upgrading these systems using pretreating UASB reactors and replacing the secondary settling tanks with membranes, the effluent quality becomes higher using a shorter retention time (4 h); therefore, the volume of the AS system can be reduced by up to 5 times.

It is necessary to mention that the retention time of MBR solids was set at 10 days, and the excess sludge was returned to the UASB reactor. This means that during 210 days of a reactor operation, 105 L of excess sludge was returned to the UASB reactor, but only about 10 L of sludge was brought out from the reactor This means the sludge volume reduction factor was

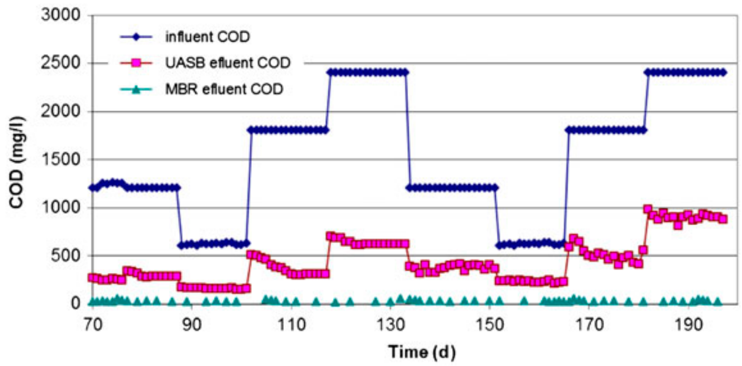

Fig. 9. COD RE in both run time.

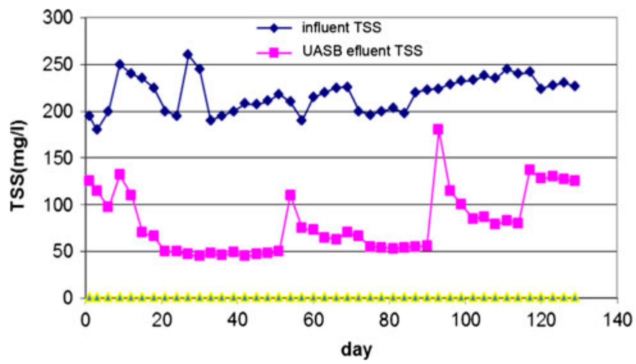

Fig. 10. TSS RE.

almost 10. It was mentioned above that determining the HRT is a very important factor, due to the increase in Iran's population and wastewater generated. This study shows that the optimum detention time is about 4 h with a RE of 98% for COD, 100% for TSS, and 80% for sulfate.

4. Conclusion

(1) The AS systems can be upgraded by UASB as pretreatment and a membrane as substitute for a secondary sedimentation time.
(2) Granular sludge appeared after 40 days of start-up in UASB reactor. Since then, the reactor was in a steady-state condition and the sludge wash-out stopped. The SVI was also dropped to 12.
(3) As was shown, for the UASB reactor, the optimum HRT is 4 h and the optimum OLR is 7.2–10.8 kg COD/m^3 d. In this condition, the reduction efficiency for COD were about 85% at 30℃, 81% at 25℃, and 74% at 20℃, respectively.
(4) Such a system upgrade increased the treatment capacity by a factor of 5, and decreased the wasted quantity of sludge by 90%.

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