Available on line at
Association of the Chemical Engineers AChE
www.ache.org.rs/CICEQ
Chemical Industry & Chemical Engineering Quarterly 16 (2) 175–182 (2010) CI&CEQ

ATIYE EBRAHIMI[1]
GHASEM D. NAJAFPOUR[2]
MAEDEH MOHAMMADI[2]
BABAK HASHEMIYEH[1]

[1]Faculty of Civil Engineering, Noushirvani University of Technology, Babol, Iran
[2]Faculty of Chemical Engineering, Noushirvani University of Technology, Babol, Iran

SCIENTIFIC PAPER

UDC 66.02:637.344

DOI 10.2298/CICEQ100315025E

BIOLOGICAL TREATMENT OF WHEY IN AN UASFF BIOREACTOR FOLLOWING A THREE-STAGE RBC

Biological treatment of a high strength chesses whey wastewater was investigated in a series of aerobic-anaerobic experiments. The aerobic treatment of the wastewater was conducted in a three-stage rotating biological contactor (NRBC), while the anaerobic process was performed in an up-flow anaerobic sludge fixed film (UASFF) bioreactor. Various concentrations of wastewater with influent COD of 40 to 70 g/L were introduced into the NRBC system. Treatability of the samples at various HRTs of 8, 12 and 16 h was evaluated in the NRBC reactor. The effluent streams of the NRBC system were introduced into a UASFF bioreactor. The anaerobic treatment of pretreated samples was investigated in the UASFF at the same HRTs of 8, 12 and 16 h. The obtained results revealed that more than 53, 69 and 78% of the influent COD (50 g/L) were removed in the NRBC reactor at HRTs of 8, 12 and 16 h, respectively. Maximum COD removal efficiencies of 96, 96.8, 97.4 and 96.4% were achieved in the combined systems at total HRT of 32 h for the influent COD of 40, 50, 60 and 70 g/L, respectively.

Key words: cheese whey; chemical oxygen demand; hydraulic retention time; three-stage rotating biological contactor; up-flow anaerobic sludge fixed film.

Dairy industries dominate in the north of Iran. Discharge of inappropriately treated effluents from dairy plants may seriously cause environmental pollution and oxygen depletion for the aquatic organisms.

Generally, there are two distinct trends in the treatment processes of dairy waste streams. In the first trend, which is based on the recovery of valuable compounds, proteins and lactose are recovered in the form of the whey powder. The dried and powdered whey is used as an additive to animal food or in agro-food and pharmaceutical industries [1,2]. In the second trend, which is based on the degradation of untreated whey as pollutants, more attention is paid to the waste treatment processes. Discharge of highly polluted waste streams of dairy industries without further treatments, may seriously cause the environmental pollution and negatively alter the quality of water resources [3,4]. Whey wastewater production is estimated to 145×10^6 t/year and approximately half of that is disposed into the surface water [5]. A disposal of the high COD content of the whey wastewater may lead to the reduction of the dissolved oxygen (DO) level and consequently threaten the aquatic life. Therefore, a whey treatment is very significant from environmental points of view.

Among various wastewater treatment technologies, a biological treatment appears to be most promising. It has been stated that wastewaters with BOD/COD ratios of 0.5 or greater are easily treated by biological treatment processes [6]. A high level of organic matter in whey wastewater may pose a serious problem for conventional wastewater treatment plants. Commonly, a combination of aerobic and anaerobic treatment process is implemented for a dairy wastewater treatment [7]. Among various biological treatment processes, a rotating biological contactor (RBC) is a system that benefits the advantages of both suspended growth and fixed-biofilm. It acts as an alternative bioreactor to treat high strength wastewaters [8,9]. High aeration and oxidation capacity improves the removal process in RBC system [10]. Successive applications of RBC reactor have been found in aerobic treatment processes such as biodegradation of phenol compounds [11,12], a removal of hydrocarbons [13-15], biological decolorization [16-18], bioremediation of heavy metals [19], a treatment of sa-

Corresponding author: G.D. Najafpour, Faculty of Chemical Engineering, Noushirvani University of Technology, Babol, Iran.
E-mail: Najafpour@nit.ac.ir
Paper received: 15 March, 2010
Paper revised: 23 April, 2010
Paper accepted: 27 April, 2010

line wastewater [20-23], a removal of nitrogen [22,24] and a citric acid production [25].

In order to meet the environmental regulations and standards for the discharge quality, highly polluting waste streams should be treated before discharging to the surface water. A post aerated system has to be implemented by a suitable treatment process. Anaerobic digestion has the ability to convert most of the remaining organic matters in the aerobic process to biogases such as CH_4 and CO_2 [26]. Most of researches conducted in the wastewater treatment have implemented an anaerobic process followed by and aerobic treatment to reduce the organic load of highly polluted waste streams. In the current experiment, a very high strength wastewater (COD concentration higher than 40 g/L) was planned to be treated. Such a high influent COD is considered as an organic shock for the anaerobic system. In such a high organic load in the anaerobic treatment, very long HRT is required to reduce the COD concentration. Thus, RBC was planned to be used as a primary treatment process in order to reduce the organic load of the wastewater for the subsequent use in an anaerobic system. A similar case, the application of aerobic prior to anaerobic systems used, is reported in the literature [27]. An up-flow anaerobic sludge fixed film (UASFF) bioreactor which is a combination of an up--flow anaerobic sludge blanket (UASB) bioreactor at lower part and an immobilized cell fixed-film (FF) reactor at upper part was used as a suitable choice for post-treatment process [28]. It has been used for the treatment of an industrial wastewater such as dairy and brewery wastewaters and also often used to treat palm oil mill effluents [26,29]. A literature survey showed that overloading of suspended solid at short HRT may create a situation which destabilizes the performance of the UASFF bioreactor [29]. Therefore, a complete digestion of highly polluted waste streams in UASFF requires a pre-treatment process to shorten the HRT.

In the present study, the treatability of cheese whey as a high strength wastewater was initially conducted in a three-stage RBC system and then the effluent was fed to an UASFF bioreactor for further treatment. The performance of the systems at various HRTs and influent COD concentrations was investigated.

MATERIALS AND METHODS

Wastewater preparation

Whey is an important by-product of dairy industries which is generated after separation of fats and casein from the milk. It contains a high level of carbohydrates in the form of lactose (4.5-5% w/v), soluble proteins, mainly casein (0.6-0.8% w/v), fats (0.4--0.5% w/v) and mineral salts (0.5-0.7% w/v) [2]. Therefore, whey is characterized as a stream with a high organic content and a chemical oxygen demand (COD) of 50-70 g/L [1].

The cheese whey used in the experiments as a source of a high strength wastewater was obtained from Gela Factory, Amol, Iran. The whey samples were stored at 4 °C to avoid any changes in a chemical composition or acidification caused by the conversion of lactose to lactic acid. Based on the necessity of the experiments, various dilutions of wastewater were prepared using distilled water. During the adaptation phase, pH of the wastewater was maintained at 6.5, nearly neutral condition, by addition of 1 M sodium hydroxide solution. The characteristics of the whey wastewater are presented in Table 1.

Table 1. Characterization of the waste stream

Parameter	Concentration, mg/L	Mean value, mg/L
COD	50000-70000	60000
BOD	27000-36000	31500
TS	55000-65000	60000
TSS	10000-15000	12500
TKN	20-10	15
Lactose	50000-60000	57500
pH	6.0-6.5	6.25
Alkalinity	200-400	300

Experimental set-up

A lab-scale three-stage RBC with dimensions of 75 cm length, 35 cm width and 30 cm depth was fabricated. The use of three compartments in designing RBC helps the system to behave as a plug flow bioreactor which has reasonably better performance and conversion comparing to a single CSTR bioreactor. The NRBC consisted of acrylic plastic discs which were mounted on a stainless steel shaft. The discs were geared with an electronic motor fixed rotational speed of 4 rpm at a fixed power input (NDRD motor, model SK 63/4, Germany). Generally, the rotational speed of RBC recommended in the literature is 1-1.6 rpm [30]. Kubsad and his co-workers [31] have found a model for the oxygen transfer in a rotating biological contactor, the optimum rotational speed of RBC was defined at 5.3 rpm [31]. The RBC's rotational speed of 4 rpm was in the mid-range recommended in the literature [30,31]. The shaft was passed through the center of the discs and mounted on the bearing attached to the ends of the wastewater container. The substrate feed rate was controlled using a variable speed peristaltic pump (Etatron D.S., model PDP-B-V, Italy). A schematic representation of the NRBC system is shown in Fig. 1. The reactor design and operation parameters are also summarized in Table 2.

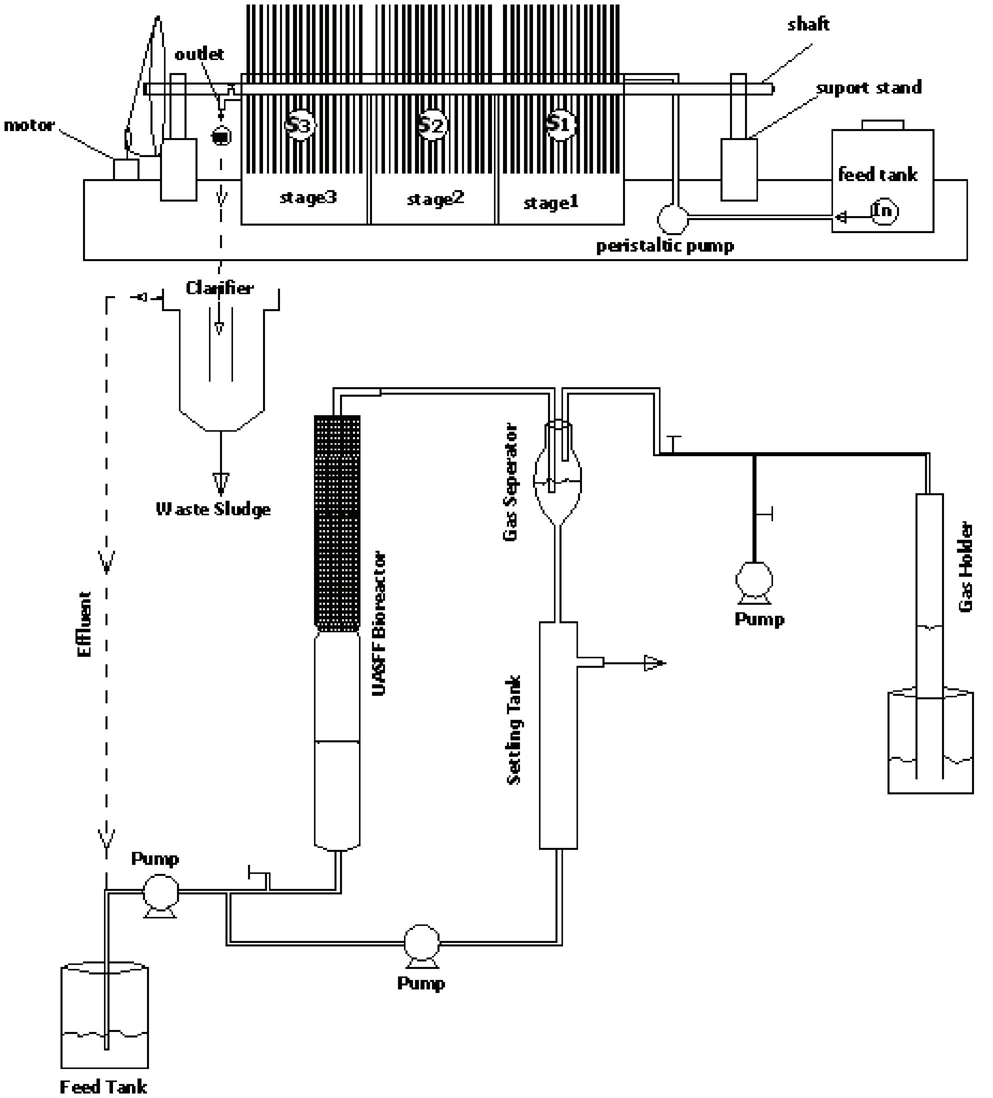

Figure 1. Schematic representation of the UASFF bioreactor fed with effluent of the NRBC system.

Table 2. Design specifications of the fabricated NRBC

Specification	Description
Support medium	Acrylic plastic disc
Disc diameter, m	0.32
Disc area, m^2	7.93
Percent of immersion	40
Number of stages	3
Disc number per stage	16
Distance among discs, mm	8
Reactor volume, L	65.6
Influent concentration, g COD/L	40-70
Rotational speed, rpm	4
Hydraulic retention time, h	8, 12 and 16

The UASFF bioreactor was followed by NRBC system. The effluent stream of the NRBC was introduced into the UASFF for further treatment. The pilot scale of the UASFF bioreactor was fabricated with total volume of 960 ml, the internal diameter of 2.76 cm and the height of 160 cm. The top part of a glass column was randomly packed with seashells so that the voidage was 85%. At first, both bioreactors (RBC and UASFF) were operated at room temperature (22 °C). Although the RBC system showed a very good performance at this temperature, the UASFF bioreactor did not suitably perform in terms of a biogas production at 22 °C. Thus, an external circulation of the warm water bath was applied to control the UASFF's temperature at 36 °C. Such a temperature dependence of the two bioreactors may refer to the growth and activity of various aerobic and anaerobic organisms at different operational conditions.

The pretreated wastewater was continuously fed into the reactor using a peristaltic pump (Thomas, model SR25, Germany). The feed was introduced from the bottom of the column reactor and distributed through the column using a perforated plate. The schematic diagram of the UASFF bioreactor is also shown in Fig. 1.

Bioreactor operation

A sample of whey wastewater was used to culture a suitable biomass for the process start-up. The wastewater which was supplied from the ultrafiltration unit of the cheese production plant was enriched in COD and lactose. Initially, a diluted wastewater with the concentration of 4000 mg COD/L was continuously fed into the NRBC system. The system was operated at HRT of 24 h and the disc rotational speed was set at 4 rpm. A permanent film of the biomass was gradually established on both sides of the discs after 5-7 days (Fig. 2). Then, the process was operated at various HRTs of 8, 12 and 16 h. The effect of various influent COD and HRT on the performance of NRBC reactor and COD removal efficiency was investigated. The samples were taken from each stage of the RBC system. The collected samples were analyzed for the COD concentration using a standard method [30]. A spectrophotometer (Unico, model 2100, USA) at the wavelength of 600 nm was used to measure the absorbance of the samples. The effluent samples were collected in a settling basin and the clear effluent was further treated in a lab-scale UASFF bioreactor.

The UASFF bioreactor was inoculated with 500 ml of a seed culture which was originated from an anaerobic sludge sample of the cheese wastewater treatment plant. For the acclimation of microbial consortium, the bioreactor was batch-wise fed with diluted cheese whey (7000-20000 mg COD/L). For the first eight days of a start-up operation, the bioreactor was continuously fed in a full recycle mode. Then the feed tank was gradually loaded with the pretreated wastewater obtained from the NRBC system. Similar experiments were conducted at the selected HRTs of 8, 12 and 16 h and then COD removal efficiencies were calculated.

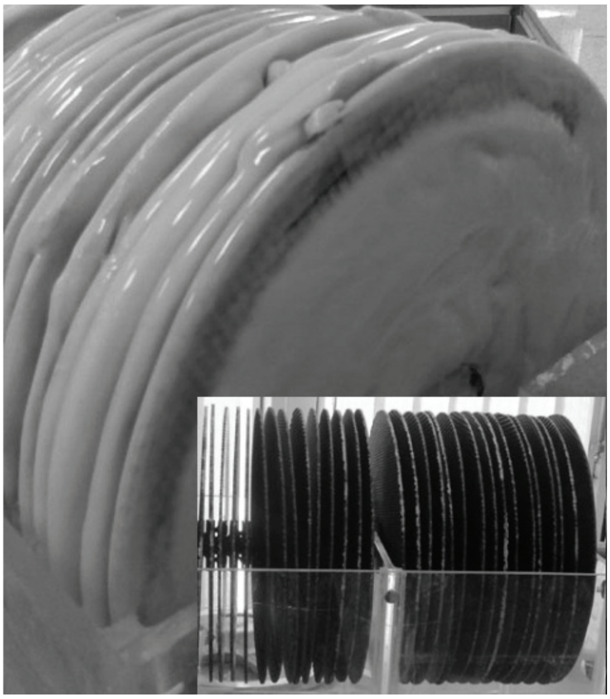

Figure 2. Biofilm developed on rotating discs of the NRBC system.

RESULTS AND DISCUSSIONS

An aerobic treatment of cheese whey as a highly polluted wastewater was investigated in a three-stage RBC system. According to the high strength wastewater, RBC was selected to conduct the continuous treatment process. The attached growth microbial film on the biological contactors enables the RBC to retain high concentrations of the biomass. Therefore, RBC has the ability to treat high strength influents and resists against high organic and hydraulic shocks [9,28,32].

The fabricated NRBC system was initially operated with diluted cheese whey with the concentration of 4000 mg COD/L at the flow rate of 2.7 l/h, HRT of 24 h and disc rotational speed of 4 rpm. The system was continuously operated until a permanent film of the biomass was gradually created on the discs. After 10 days of the operation, the system became stable and was ready for full capacity exploitation. Table 3

Table 3. Characterization of the wastewater after 12 days of operation at COD = 4000 mg/L, HRT= 24 h and ω = 4 rpm

Place	Temperature, °C	pH	DO, mg/L	COD, mg/L	COD removal, %
Reservation tank	22	7.6	3.8	4000	-
First stage	22	7.3	2.8	1340	67
Second stage	22	7	4.5	1110	74
Third stage	22	6.9	5.6	820	81

summarizes the characteristics of the wastewater after the start-up period.

It was observed that the DO level was reduced at the first stage of the NRBC system and then gradually increased. This was due to the fact that microorganisms utilize the nutrients in the wastewater and grow rapidly to form a thick biomass which consequently resulted in a reduction in a DO level of the wastewater. Since most of the nutrients had been consumed by microorganisms at the first stage, a biomass formation was not so strong at the next steps. This may cause a reduction in the oxygen consumption rate. Besides, the rotation of the discs was a significant parameter to increase the DO content of the wastewater.

After the development of a permanent and uniform biofilm on both sides of the discs, the system was operated in full capacity. In order to investigate the effects of influent COD and HRT on the COD removal efficiency, various influent COD (40, 50, 60 and 70 g/L) and HRT (8, 12 and 16 h) were selected. The system was operated in sufficient time at each selected HRT to establish the steady condition. The effect of HRT on the COD removal efficiency is described in Fig. 3. It was observed that for all influent COD concentrations, the COD removal efficiency increased as the HRT was gradually increased from 8 to 16 h. Maximum COD removal efficiency of 80% was obtained at HRT of 16 h and influent COD of 50 g/L. As the influent COD was increased to 60 and 70 g/L, the COD removal efficiency gradually decreased which was due to a high organic load and hydraulic shocks. The high organic load may have caused toxication of the biofilm which consequently resulted in depletion of the COD removal.

The effluent stream of the NRBC was introduced into UASFF bioreactor to conduct further treatment processes. In order to evaluate the effect of HRT on the COD removal efficiency in the UASFF bioreactor, the same HRTs of 8, 12 and 16 h were examined. The effluent wastewater obtained from the RBC pretreatment process was introduced into the UASFF bioreactor. The effluent COD of the UASFF bioreactor at various HRTs of 8, 12 and 16 h are tabulated in Table 4.

Figure 4 represents the effect of total HRT (NRBC and UASFF) on total COD removal efficiency. Figures 5a, 5b and 5c refer to the wastewater samples which were pretreated at HRT of 8, 12 and 16 h in the NRBC system, respectively. The achieved data revealed that the COD removal efficiency increased as the HRT was gradually increased. Figure 5a shows that maximum total COD removal efficiencies of 95.7, 96.9, 96.6 and 97.1% at total HRT of 24 h (8 h in NRBC and 16 h in UASFF) were obtained for influent COD of 40, 50, 60and 70 g/L, respectively. As Figs. 5 b and 5cdepict, similar trends were followed for the samples which were pretreated for 12 and 16 h in the NRBC reactor.

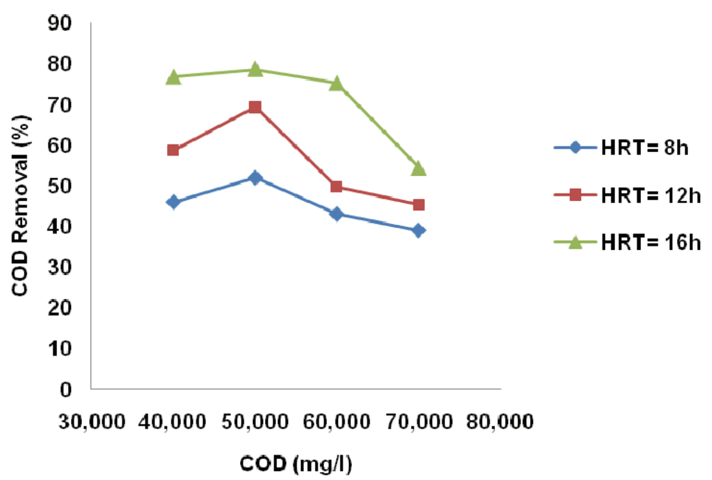

Figure 3. Effect of HRT on COD removal efficiency in the RBC system.

Table 4. Effluent COD of the UASFF bioreactor

HRT in RBC, h	COD_{out}, RBC, COD_{in} and UASFF mg/L	COD_{out} and UASFF, mg/L		
		HRT, h		
		8	12	16
8	21600	13610	8990	1730
	24000	14400	9310	1540
	34200	22570	12410	2050
	42700	29040	14090	2010
12	16520	9420	8590	2630
	15350	8140	7520	1950
	30120	16570	10600	2110
	38220	22170	11730	2290
16	9280	5860	5380	1590
	10650	6600	5640	1600
	13680	8300	6020	1560
	31850	10510	8410	2550

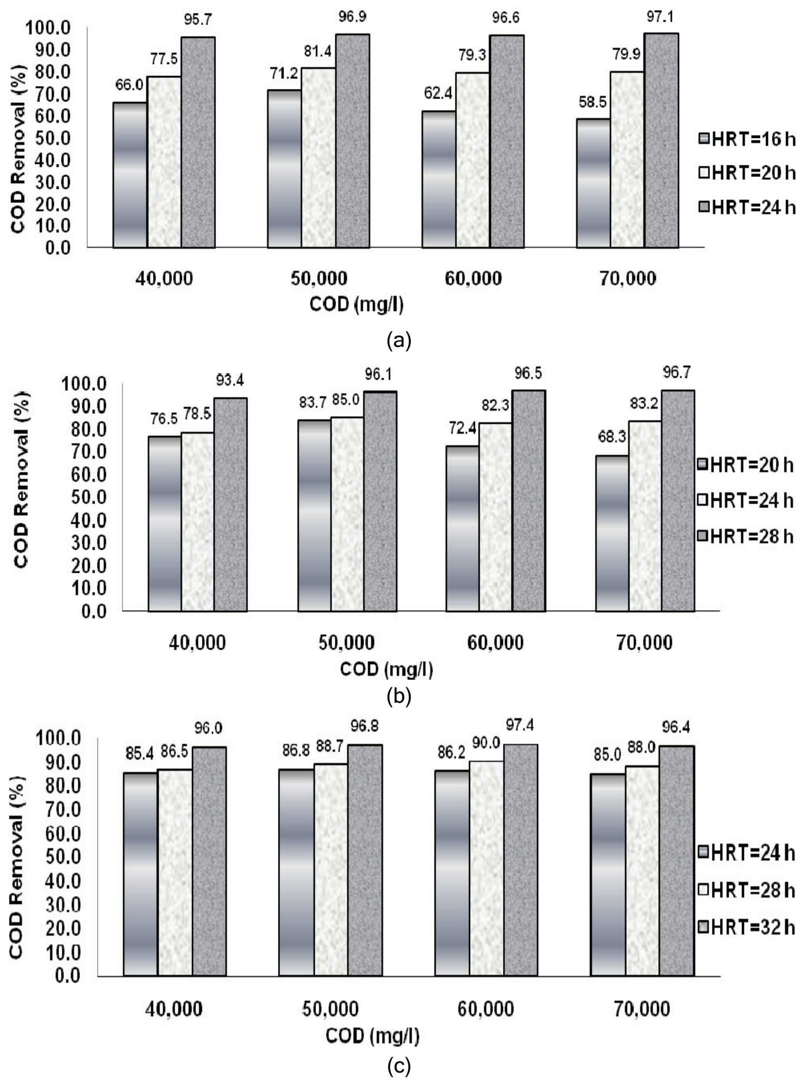

Figure 4. COD removal efficiency with respect to HRT in the UASFF bioreactor; a) pretreated samples at HRT= 8 h, b) pretreated samples at HRT= 12 h and c) pretreated samples at HRT= 16 h.

Figure 5 represents the COD of the effluent samples with respect to total HRT. From the obtained results it is clear that the combined system (three--stage RBC + UASFF) is quite effective in removing the COD because of the low concentration of COD (1.5-2.5 g/L) obtained at total HRT of 32 h. However, it should be mentioned that the wastewater treated in this way still does not meet a suitable limit for discharge (COD < 100 mg/L) and further post treatment processes should be applied to reduce the COD concentration to the limit stated as a standard for safe discharge.

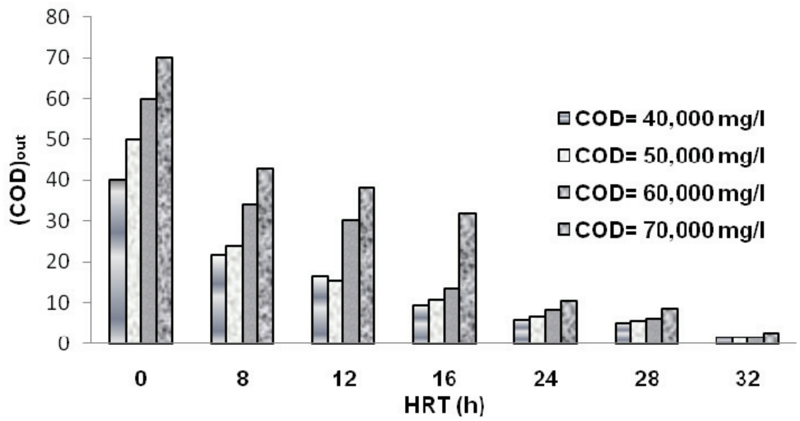

Figure 5. COD of the effluent samples with respect to total HRT.

CONCLUSION

Aerobic-anaerobic treatment of cheese whey wastewater was conducted in a NRBC system and then the effluent fed to an UASFF bioreactor. Treatability of the wastewater with respect to HRT and influent COD was investigated in both systems. It was observed that the NRBC reactor effectively removed more that 50% of the COD at HRT of 12 h. The obtained results showed that the UASFF bioreactor was suitable for the post-treatment process and the achieved COD removal efficiencies were more than 96% for all influent CODs at HRT of 32 h.

Acknowledgements

The authors gratefully acknowledge the research committee of Noushirvani, University of Technology, for support and facilities to conduct the present research in Biotechnology research lab. Special thanks go to Gela Factory for their collaboration and supply of effluent from the UF unit.

REFERENCES

[1] J. Frigon, J. Breton, T. Bruneau, R. Moletta, S. Guiot, Bioresour. Technol. **100** (2009) 4156-4163

[2] P. Seesuriyachan, A. Kuntiya, K. Sasaki, C. Techapun, Process Biochem. **44** (2009) 406-411

[3] F. Carta-Escobar, J. Pereda-Marin, P. Alvarez-Mateos, F. Romero-Guzman, M. Duran-Barrantes, F. Barriga-Mateos, Biochem. Eng. J. **21** (2004) 183-191

[4] J. Rajesh Banu, S. Anandan, S. Kaliappan, I. Yeom, Solar Energy **82** (2008) 812-819

[5] G. Güven, A. Perendeci, A. Tanyolac J. Hazard. Mater. **157**(1) (2008) 69-78

[6] Y. Chan, M. Chong, C. Law, D. Hassell, Chem. Eng. J. **155** (2009) 1-18

[7] I. Sengil, J. Hazard. Mater. **137** (2006) 1197-1205

[8] C. Lu, A. Yeh, M. Lin, Environ. Int. **21** (1995) 313-323

[9] G. Najafpour, H. Yieng, H. Younesi, A. Zinatizadeh, Process Biochem. **40** (2005) 2879-2884

[10] L. Di Palma, N. Verdone, Bioresour. Technol. **100** (2009) 1467-1470

[11] E. Sahinkaya, F. Dilek, Biochem. Eng. J. **31** (2006) 141--147

[12] I. Alemzadeh, F. Vossoughi, M. Houshmandi, Biochem. Eng. J. **11** (2002) 19-23

[13] S. Brar, S. Gupta, Water Res. **34** (2000) 4207-4214

[14] T. Suzuki, S. Yamaya Process Biochem. **40** (2005) 3429--3433

[15] T. Yamaguchi, M. Ishida, T. Suzuki Process Biochem. **35** (1999) 403-409

[16] C. Guimaraes, P. Porto, R. Oliveira, M. Mota, Process Biochem. **40** (2005) 535-540

[17] I. Karapinar Kapdan, F. Kargi, Enzyme Microb. Technol. **30** (2002) 195-199

[18] B. Van Driessel, L. Christov, J. Biosci. Bioeng. **92** (2001) 271-276

[19] S. Costley, F. Wallis, Water Res. **35** (2001) 3715-3723

[20] K. Windey, I. De Bo, W. Verstraete, Water Res. **39** (2005) 4512-4520

[21] F. Kargi, Process Biochem. **38** (2002) 399-403

[22] A. Gupta, S. Gupta, Water Res. **35** (2001) 1714-1722

[23] A. Dincer, F. Kargi, Process Biochem. **36** (2001) 901-906

[24] S. Wyffels, K. Pynaert, P. Boeckx, W. Verstraete, O. Van Cleemput, Water Res. **37** (2003) 1252-1259

[25] W. Jianlong, Bioresour. Technol. **75** (2000) 245-247

[26] A. Zinatizadeh, H. Younesi, H. Bonakdari, M. Pirsaheb, M. Pazouki, G. Najafpour, M. Hasnain Isa, Renewable Energy **34** (2009) 1245-1251

[27] E. Castillo, M. Vergara, Y. Moreno, Waste Manage. (Oxford) **27** (2007) 720-726

[28] G. Najafpour, A. Zinatizadeh, A. Mohamed, M. Hasnain Isa, H. Nasrollahzadeh, Process Biochem. **41** (2006) 370--379

[29] A. Zinatizadeh, A. Mohamed, M. Mashitah, A. Abdullah, M. Isa, Biochem. Eng. J. **35** (2007) 226-237

[30] A. Eaton, L. Clesceri, E. Rice, A. Greenberg, American Public Health Association, Washington, DC, 2005

[31] V. Kubsad, S. Chaudhari, S. Gupta, Water Res. **38** (2004) 4297-4304

[32] G. Najafpour, A. Zinatizadeh, L. Lee, Biochem. Eng. J. **30** (2006) 297-302.

ATIYE EBRAHIMI[1]
GHASEM D. NAJAFPOUR[2]
MAEDEH MOHAMMADI[2]
BABAK HASHEMIYEH[1]

[1]Faculty of Civil Engineering, Noushirvani University of Technology, Babol, Iran
[2]Faculty of Chemical Engineering, Noushirvani University of Technology, Babol, Iran

NAUČNI RAD

BIOLOŠKA OBRADA SURUTKE U POSTROJENJU SA TROSTEPENIM ROTIRAJUĆIM BIOLOŠKIM KONTAKTOROM I BIOREAKTOROM UASFF

Biološka obrada otpadne vode sa surutkom iz proizvodnje jakih sireva je ispitivana u aerobno-anaerobnim eksperimentima. Aerobna obrada otpadne vode je sprovedena u trostepenom rotirajućem biološkom kontaktoru (NRBC), dok je anaerobni proces sproveden u bioreaktoru sa nepokretnim filmom anaerobnog mulja i proticanjem naviše (UASFF). U NRBC reaktor se uvođene otpadne vode sa različitim vrdnostima hemisjke potrošnje kiseonika (HPK) u opsegu od 40000 do 70000 mg/l. Uspešnost obrade uzoraka je ispitivana pri različitim vremenima zadržavanja (HRT) od 8, 12 i 16 h u NRBC reaktoru. Izlazni tok iz NRBC sistema je uvođen u UASFF bioreaktor. Anaerobna obrada prethodno obrađenih uzoraka je ispitivana u UASFF reaktoru za iste vrednosti HRT od 8, 12 i 16 h. Dobijeni rezultati su pokazali da je 53, 69 i 78 % ulazne HPK (50 g/l) bilo uklonjeno u NRBC reaktoru pri vremenu zadržavanja od 8, 12 i 16 h, respektivno. Maksimalne efikasnosti uklanjanja HPK od 96,0, 96,8, 97,4 i 96,4% su postignute u kombinovanom sistemu sa ukupnim HRT 32 h za ulazne vrednosti HPK od 40, 50, 60 i 70 mg/L, respektivno.

Ključne reči: surutka; hemijska pottrošnja kiseonika; vreme zadržavanja; rotirajući biološki kontaktor; bioreaktor sa nepokretnim filmom anaerobnog mulja.