JOURNAL OF ENVIRONMENTAL ENGINEERING AND LANDSCAPE MANAGEMENT
ISSN 1648–6897 / eISSN 1822-4199
2017 Volume 25(03): 234–240
https://doi.org/10.3846/16486897.2016.1223083

EVALUATION OF TREATABILITY OF HIGH STRENGTH WASTEWATER IN A THREE STAGE-ROTATING BIOLOGICAL CONTACTOR

Atieh EBRAHIMI[a], Ghasem D. NAJAFPOUR[b], Manouchehr NIKZAD[c]

[a]*Department of Civil Engineering, Institute of Pardisan Fereidonkenar Iran*
[b]*Biotechnology Research Lab., Faculty of Chemical Engineering, Noshirvani University of Technology, Babol, Iran*
[c]*Faculty of civil Engineering, Noshirvani University of Technology, Babol, Iran*

Submitted 10 May 2015; accepted 25 Jul. 2016

Abstract. Cheese whey effluent contains biodegradable organic compounds in the range of 40 to 80 g. L^{-1}. In this study, a three–stage rotating biological contactor was fabricated as a bench scale experimental unit to remove organic matters from cheese whey. First, the treatability of cheese whey effluent in the three–stage rotating biological contactor (RBC) was evaluated. Then the effect of extended specific surface area (SSA) and recirculation rate on COD removal was investigated. The obtained results showed that the organic removal rate increased with an increase in loading rate, till other limiting parameters affect the process. Prior to application of the designated modifications to the system, maximum COD removal efficiency at HRTs of 24 and 36 h with OLR of 50 gCOD.L^{-1}.d^{-1} was 90 and 92.4%, respectively. The removal efficiency was improved as a result of increasing the SSA and recirculation rate. Also, recirculation rate may assist to increase the DO level of the wastewater, especially at high OLRs. To sum up, obtained results showed that whey effluent has been efficiently treated in a continuous operation of bench scale RBC.

Keywords: cheese whey, COD removal, Rotating Biological Contactor, Recirculation, Organic loading rate.

Introduction

The main priorities for wastewater treatment are effluent quality, cost, energy efficiency and nutrient removal/recovery (Reardon *et al.* 2013). The sustainable development of wastewater treatment technology is essential to improve process efficiency and the long term treatment plant capacity (Hoyland *et al.* 2010, Grady Jr *et al.* 2012).

Cheese whey (CW) is a by–product of the cheese and dairy effluents. Cheese processing effluents exhibit chemical oxygen demand (COD) values in the range of 0.8–102 g.L^{-1} and biological oxygen demand (BOD) values in the range of 0.6–60 g.L^{-1}which leads to a high consumption of dissolved oxygen in water bodies (Carvalho *et al.* 2013; Bylund, Pak 2003; Janczukowicz *et al.* 2008; Ebrahimi *et al.* 2009). It has been reported that cheese whey effluents have pH values in a wide range of 3.3–9.0. Typically, the aforesaid composition has a low pH. Suspended solids (SS), Total Kjeldahl Nitrogen (TKN), and total phosphorus are in the ranges of 0.1–22.0, 0.01–1.7 and 0.006–0.5 g. L^{-1}, respectively.

Whey is a source of protein and lactose; it has high content of organic compounds. Whey as raw material is used for production of lactate and polylactate which is used in packaging industry. Also, it can be used in agriculture, pharmacy and food industry as nutritional supplements and food additives. In the last decades, technological and economic advancement made it possible to recover soluble proteins from cheese whey, but still approximately half of world cheese whey production is not treated, and it is discharged as effluent (Yorgun *et al.* 2008; Smithers 2008). If for any reason such as economic, sanitary, local and lacking enough equipment, whey valorization technologies (such as protein and lactose recovery, spray drying, freeze-concentration, etc.) or direct utilization of whey for animal feed are not applicable, disposal has become an essential issue. In this case, aerobic or anaerobic treatment can be a solution to whey disposal. It is therefore necessary to process the whey even if it may be uneconomic (Kaewkannetra *et al.* 2009). In general, biological and membrane treatment processes are mainly

Corresponding author: Ghasem D. Najafpour
E-mail: najafpour@nit.ac.ir

used to treat cheese whey wastewater, but most of these processes are high energy intensive (Prazeres *et al.* 2012; Carvalho *et al.* 2013).

Rotating biological contactors (RBC) are normally called disc biofilm reactors which are an efficient alternative to wastewater treatment process such as activated sludge. The RBC technology has been widely used for the treatment of both municipal and industrial wastewaters (Mba, Bannister 2007). In this process, microorganism grows by degrading the substrate which causes microbial growth in a static biological film (Hassard *et al.* 2015; Sirianuntapiboon, Chumlaong 2013). In cases of wastewaters with high BOD/COD ratio per day such as cheese whey, some crucial operational challenges like biological clogging emerge, which are unavoidable and quite frequent in biofilters. Correspondingly, the most recognized benefit of rotating biological contactors is prevention of such phenomenon (Vasala *et al.* 2005; Carvalho *et al.* 2013; Rodgers, Zhan 2003). Moreover, high oxygen transfer efficiency in RBC is more cost-effective in the final result in comparison to other processes using diffusers or surface aerators. Other particular advantages such as high capacity to tolerate fluctuations in wastewater characteristics and to dampen shock loadings could also be achieved in a properly designed RBC (Metcalf 2003). Furthermore, it causes higher degradation efficiencies of organic loadings and resistance to toxic shocks than suspended growth process (Najafpour *et al.* 2005, 2006, 2008; Ebrahimi *et al.* 2010). Statistics indicate that RBC demands approximately 70–80% of the energy requirements of a trickling filter system and 40–50% of an activated sludge system (Rodgers, Zhan 2003; Metcalf 2003). In addition, activated sludge process and trickling filter system bring a substantial increase in operation complexity and insufficient efficiency. Therefore, decentralized wastewater technologies like RBC are gaining more attention in order to deal with wastewaters having high organic loading rate such as cheese whey, in terms of both the total cost and energy consumed. Najafpour and his coworkers (Najafpour *et al.* 2005) have investigated the treatability of a high strength organic load of palm oil mill industrial wastewater which contained COD of about 16 $g.L^{-1}$ through a bench scale experiment using a modular RBC reactor. After a five–day HRT, 91, 80 and 89% removal rates were achieved for COD, TKN and SS, respectively. In the most recent studies it was indicated that organic loading rate (OLR) causes a considerable impact on removal rate of biofilm developed on a polyvinyl chloride (PVC) mesh, polyester and polyurethane foam in simultaneously operated RBC reactors (Ercan, Demirci 2013). OLR, stages of RBC, recirculation, hydraulic retention time (HRT), rotation speed, media specific surface area, mass transfer rate and submergence percentage of disks are important parameters in RBC performance. There is considerable relation between some of these parameters which need to be investigated (Hassard *et al.* 2015). Staging has a positive effect on performance of RBC considering wastewater strength and its composition. However, this effect would be insignificant after four stages (Hassard *et al.* 2015). Discharge recirculation also increases the process performance by adjusting the substrate to microorganism ratio. Extensive research has been conducted on the efficiency of biofilm systems for cheese whey treatment; however, not much research was conducted on behavior of RBC systems under various conditions such as excessive daily loading rates, usage of modified extended surface discs as media support and effect of recirculation on removal efficiency in high strength wastewaters.

In the previous work (Ebrahimi *et al.* 2009), the performance of RBC in COD removal of high strength wastewater under various hydraulic loading conditions was experimented. This work is continuation of previous work with more detail studies and evaluation of additional parameters. The effect of increasing SSA and recirculation on COD removal and DO level were compared. In addition to variation of COD and HRT, other effective parameters like dissolved oxygen (DO) and TSS were evaluated. The main objective was to define the most effective process parameter which leads to the highest COD removal.

1. Materials and methods

1.1. Experimental setup

A three-stage RBC was built similar to that in our previous studies (Ebrahimi *et al.* 2009, 2010). The RBC consisted of three equal-sized compartments (75×35×30 cm), separated by fixed baffle plates with 16 light–weight PVC discs in each compartment. The total volume of RBC was 78.75 L. The discs, mounted on a galvanized metal shaft, had a diameter of 32 cm, 3 mm thickness and interspacing of 8 mm. The total surface area available for microorganism growth on discs was 7.1 m^2. A changeable speed motor (NORD motor, model SK 63/4, Germany) was rotating discs mounted on the shaft. In order to increase the SSA, some rectangular extended thin blades of PVC plates in certain dimensions were attached to the disks surface which increased the surface area by 10%. Five essential factors including HRT, OLR, recirculation, DO level and SSA were evaluated to investigate the impact of RBC operation on overall system performance. Based on steady state condition, the samples were taken for each volumetric flow rate after two times of corresponding retention time. The fresh raw wastewater was collected in a 20-liter container, then transported to the laboratory on a daily basis, refrigerated and stored at 4 °C to prevent any acidification and undesirable changes in their chemical composition. Diluted whey was fed into the reactor at pH 6.5 during the adaptation phase. Several dilutions of CW were prepared using distilled water based on requirements of the tests. In order to adjust the feed pH to 6.5, a 6M sodium hydroxide solution was used. The CW used in this study was obtained from "Gela Dairy Industrial Plant" (Amol, Iran), which was collected from ultra-filtration process for the production of cheese. The whey composition is reported in our previous work (Ebrahimi *et al.* 2009); otherwise, based on experimental conditions, the values are stated.

1.2. Analytical methods

The collected samples were settled for 30 minutes to analyze COD and biomass concentration. Standard methods for examination of water and wastewater was employed to determine TSS and DO concentrations (APHA 2005). In order to measure COD, a colorimetric method with closed reflux method was developed. Spectrophotometer (UNICO 2100, USA) at wavelength of 600 nm was used to measure the absorbance of samples. DO and pH meter (Hanna, HI9024) were used to measure pH and dissolved oxygen. The reactor temperature was basically maintained at room temperature.

2. Results and discussion

2.1. Start-up of the RBC

The RBC reactor was inoculated with 10 L of sludge with MLSS value of 4000 mg. L^{-1}, which was obtained from the mentioned industrial treatment plant. In order to develop initial biofilm, the reactor was fed with raw whey containing 0.4 gCOD.L^{-1}.d^{-1} at rotating speed of 4 rpm and HRT of 36 h. A gradual formation of biofilm on the rotating discs was observed after two weeks and fast biofilm accumulation was observed afterwards. The image of fully developed biofilm on RBC discs is shown in Figure 1.

Fig. 1. The RBC with developed biofilm after start–up

2.2. RBC performance

2.2.1. Effect of OLR and HRT on the efficiency of system

Due to daily variations of dairy effluents, the performance of RBC was investigated in 4 different groups of COD concentrations including 40, 50, 60 and 70 g.L^{-1}. The COD removals were studied at different HRTs (12, 16, 24 and 36 h). The obtained results for COD variations and COD removal in certain OLRs and HRTs are summarized in Table 1.

According to data presented in the Table 1, the maximum removal of organic load using the lowest HRT was about 82%, obtained at HRT of 12 h for COD content of 50 g.L^{-1}. This result is much higher when compared to similar reported data by other researcher which used in a similar RBC process (Hassard *et al.* 2015). The RBC obtained a COD removal efficiency of 92.4% for the COD concentration of 50 g.L^{-1}, when HRT increased to 36 h. However, it is not logical to use long HRTs in order to reach to high levels of treatment, since it would considerably raise the operating costs by decreasing the capacity of system. Also possible fluctuation of loading rate in HRTs of more than 24 h should be considered. Additionally, according to the obtained results, excessive growth of biofilm on the disks is not recommended for achieving more efficiency in the system as this may result in trapping and accumulation of inert materials that do not contribute to the degradation of the organic matters. Oxygen and nutrient passage toward interior layers can also be limited due to generation of thick biofilms on the disks (Ohl *et al.* 2004).

From the results it is conducted that at the certain COD concentration from 40 to 60 g.L^{-1}, increasing the HRT enhanced the removal efficiency. Such sensitivity was not observed in COD concentration of 70 g.L^{-1}. In fact in COD content of 70 g/l, the removal efficiency was increased from 45 to 59% due to a shift in HRT from 12 to 24 h, but when the HRT extended to 36 h, COD removal decreased to 52% in contrast with other HRTs. This can be explained by development of microbial layer which lead to reducing the dissolved oxygen required for the growth of the microorganisms. Overall COD removal with COD concentration of 70 g.L^{-1} was significantly lower compared to other groups of COD data presented in Table 1. Insufficient COD removal capacity with COD concentration of 70 g.L^{-1} can be attributed to limitation of oxygen mass transfer and specific surface area for attached microorganisms in relatively high OLR. Moreover, results indicate that the maximum COD removal efficiency of 92.4% was achieved with COD concentration of 50 g. L^{-1} and HRT of 36 h. The obtained results proved that the performance capability of RBC is mostly dependent on OLR rather than on the individual organic concentration or flow rate.

DO variation were monitored for each stage of the reactor. The DO meter probe was placed at the midpoint in each stage. Figure 2 illustrates the DO level regarding the designated HRTs in three stages of the RBC reactor. As it is indicated in this figure, the last stage of the RBC

Table 1. The COD variations and COD removal in certain OLRs and HRTs

COD in (g.L^{-1})	40				50			
HRT (h)	12	16	24	36	12	16	24	36
OLR (g COD.L^{-1}. d^{-1})	80	60	40	26.7	100	75	50	33.3
COD out (g.L^{-1})	10.8	10.13	5.5	4	9.2	6.4	5.2	3.8
COD Removal (%)	73	75	86	90	82	87	90	92.4
COD in (g.L^{-1})	60				70			
HRT (h)	12	16	24	36	12	16	24	36
OLR (g COD.L^{-1}. d^{-1})	120	90	60	40	140	105	70	46.7
COD out (g.L^{-1})	21.6	19	15.5	9.7	38.5	30.5	28.6	33.8
COD Removal (%)	64	68	74	84	45	56	59	52

had the highest content of DO. Very low DO level was observed in the first stage. The averaged DO level in the maximum COD removal condition (COD concentration of 50 g.L^{-1} and HRT of 36 h) were 2.82, 4.5 and 5.2 mg.L^{-1} in the first, second and third stage, respectively. This increase in DO level with increasing the number of stages can be due to the thick biofilm generated on the disks and effectiveness of n-reactors in series. The microorganisms attached to the disks consume oxygen to degrade organic matter which leads to decrease the remained dissolved oxygen level. In fact, staging in RBC can be considered as process enhancement and the physical dividers may separate the flow behavior within the reactor. It causes a gradual reduction in the organic matters so the reactor approaches to a plug-flow regime. This stepwise treatment allows microorganisms to be adapted to each stage condition. This procedure enhances the substrate removal rate and stability of the process. In addition staging can improve the ability of system to manage shock loads as well.

From the results it also can be observed that in a certain COD concentration, as HRT increased, the DO level gradually increased. The increasing trend for DO concentration in all stages was similar; this means for long HRTs, as the concentration of organic matter decreased, the rate of oxygen consumptions slightly declined. For each HRT, as OLR was in an increasing trend; that caused the DO levels to show a slight decrease.

Figure 3 depicts the effect of organic loading rates and number of stages on DO concentration. From the data, it is observed that the DO concentration in the first stage significantly decreased while in the following stages it showed a steady increase. In addition, by increasing the organic loading rates DO concentrations was decreased. As illustrated in Figures 2 and 3, dissolved oxygen profiles mainly followed a pattern of initial decreased in the first stage and then gradually increased in the successive stages. There is a direct correlation between the DO concentration and organic loading rate which is at high organic loading rates; it caused a considerable decrease in dissolved oxygen. It can be a result of heterotrophic uptake of dissolved oxygen in these stages. At the first stage, high utilization of substrate and heterotrophic growth were occurred; which could be related to maximum consumption of dissolved oxygen. As organic substrate is metabolized through the successive stages, heterotrophic growth decreased; that was a result of an expected reduction in oxygen demand in the last stages. The collected data are

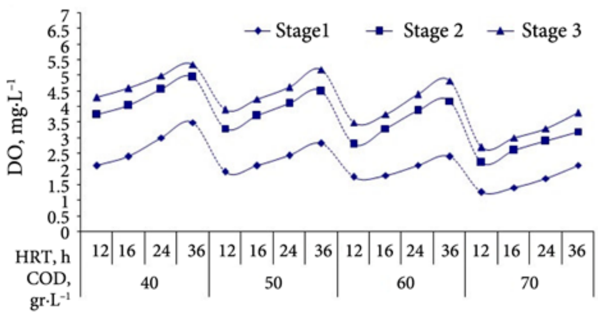

Fig. 2. DO level with respect to HRT and COD in different stages

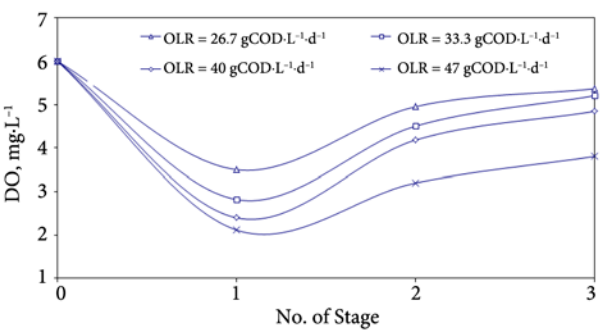

Fig. 3. DO concentration profiles in different stages of RBC with various OLR

in accordance with data reported in the literature (Chen *et al.* 2006).

The effect of organic loading rate and number of stages on TSS concentration is shown in Figure 4. In OLR of 26.7 $gCOD.l^{-1}.d^{-1}$ TSS decreased from 8 in inlet to 3, 2 and 1.2 $g.L^{-1}$ over first, second and third stages, respectively. In OLR of 47 $gCOD.l^{-1}.d^{-1}$, the TSS with the same trend dropped from 15 in inlet to 11.3, 8.9 and 7.8 $g.L^{-1}$ in stage number of 1, 2 and 3, respectively. It showed that increasing the amount of organic loading rate; resulted in an increase in TSS concentration. Also about 66% TSS removal was achieved in the first stage in OLR of 26.7 to 40 $gCOD.l^{-1}.d^{-1}$; in contrary, only 25% TSS removal was attained in OLR of 47 $gCOD.l^{-1}.d^{-1}$ (data is not shown in the figure) which is resulted in an insufficient performance of RBC in TSS removal for high organic loadings compared to low OLRs. The obtained results showed that the most TSS removal completed in the first stage. It is concluded that as the number of the stages proceeded, the TSS concentration decreased. In fact the TSS concentration was strictly dependent on both the organic loading rate and number of stages.

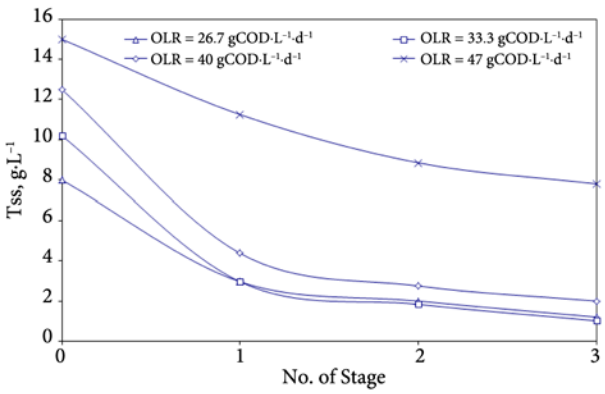

Fig. 4. TSS concentration profiles in different stages of RBC at various OLR

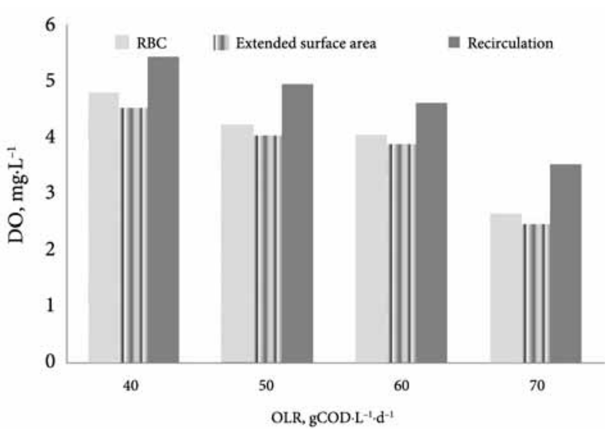

Fig. 5. DO level with respect to OLR for RBC, extended surface and recirculation

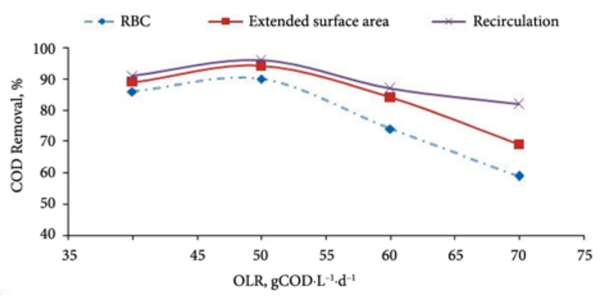

Fig. 6. COD removal with various OLR in RBC, with extended surface and recirculation at HRT of 24 h

2.2.2. Effect of the modified specific surface area and recirculation on the efficiency of the system

Figure 5 shows the effect of extended SSA and recirculation on average DO concentration for OLR values ranging from 40 to 70 $gCOD.L^{-1}.d^{-1}$. From the obtained results it can be observed that recirculation enhanced the average DO level. In particular, for OLR of 70 $gCOD.L^{-1}.d^{-1}$, recirculation seems to have a more positive impact on the DO concentration. Also it is observed that the DO level decreased slightly after increasing SSA in compare to initial condition (as shown in Fig. 5). It could be result of sufficient thickness of biofilm as to the formation of new biofilm and also more dissolved oxygen utilization.

As it was mentioned, we can conclude that increasing the SSA can enhance the capability of the treatment system to remove organic substrate. In order to increase the efficiency of the system in case of a high strength wastewater, a 50% recirculation were performed and the SSA was also extended. Figure 6 shows the COD removal efficiency for the given OLRs at HRT of 24, after increasing the surface area and applying the recirculation in compare to initial setup (see Fig. 6).

The COD removal efficiency at HRT of 24 was investigated after the SSA was increased by 10%. From the illustrated data in this figure it can be observed that for the high OLRs, the tolerance between the initial results and those obtained after modification has increased, which is an indication of the improvement of RBC performance at high OLRs. According to the presented data, the maximum COD removal efficiency at OLR of 50 $gCOD.L^{-1}.d^{-1}$ and HRT of 24 in initial RBC, after increasing surface area and recirculation were 89, 94.2 and 96% respectively.

After increasing the surface area, in OLRs lower than 50 $gCOD.l^{-1}.d^{-1}$, the COD removal efficiency had a slight improvement (about 4%), but in OLR higher than 60 $gCOD.L^{-1}. d^{-1}$, the removal efficiency was enhanced by about 10%. Also recirculation improved COD removal rate by 12% in OLR of 70 $gCOD.L^{-1}.d^{-1}$. This could be attributed to the dilution of the substrate concentration applied to the system. More improved efficiency at high OLR is attributed to the presence of high concentrations of DO in the three stages of the system with recirculation compared to the system without recirculation.

Conclusions

From the results it is concluded that a properly operated RBC can effectively be employed for dealing with cheese whey effluents. The maximum COD removal efficiency in the initial configuration was 92.4% which was operated at COD concentration of 50 $g.L^{-1}$ and HRT of 36 h. An increase in OLR (50 to 70 g $COD.L^{-1}.d^{-1}$), a drop (90 to 59%) in percentage of the COD removal was observed. It shows that oxygen transfer rate through biofilm would cause a limiting effect on the efficiency of substrate degradation. Hence, maximum organic removal rate is attained at the highest loading before exceeding of biofilms mass transfer restrictions. Both modification of SSA of the discs and recirculation had positively improved the COD removal efficiency, especially in higher OLRs. Although increasing the surface area slightly reduced the average DO level, recirculation had evidently enhanced the DO level. Thus, the findings of the present study well demonstrated that the recirculation may be beneficial when the inlet organic loading rate is extremely high.

Acknowledgements

The authors are gratefully acknowledged Biotechnology Research Lab. Noushirvani University of Technology (Babol, Iran) and the Institute of Pardisan Fereidonkenar for the support and facilities provided to conduct present work.

References

APHA. 2005. *Standard methods for the examination of water and wastewater.* American Public Health Association (APHA), Washington, D.C., USA.

Bylund, G.; Pak, T. 2003. *Dairy processing handbook.* Tetra Pak Processing Systems AB Lund.

Carvalho, F.; Prazeres, A. R.; Rivas, J. 2013. Cheese whey wastewater: characterization and treatment, *Science of the Total Environment* 445: 385–396. https://doi.org/10.1016/j.scitotenv.2012.12.038

Chen, Z.; Wen, Q.; Wang, J.; LI, F. 2006. Simultaneous removal of carbon and nitrogen from municipal-type synthetic wastewater using net-like rotating biological contactor (NRBC), *Process Biochemistry* 41(12): 2468–2472. https://doi.org/10.1016/j.procbio.2006.06.003

Ebrahimi, A.; Asadi, M.; Najafpour, G. 2009. Dairy wastewater treatment using three-stage rotating biological contactor (NRBC), *International Journal of Engineering* 22(2): 107–114.

Ebrahimi, A.; Najafpour, G. D.; Mohammadi, M.; Hashemiyeh, B. 2010. Biological treatment of whey in an UASFF bioreactor followed a three-stage RBC, *Chemical Industry and Chemical Engineering Quarterly* 16(2): 175–182. https://doi.org/10.2298/CICEQ100315025E

Ercan, D.; Demirci, A. 2013. Current and future trends for biofilm reactors for fermentation processes, *Critical Reviews in Biotechnology* 35(1): 1–14. https://doi.org/10.3109/07388551.2013.793170

Grady JR, C. L.; Daigger, G. T.; Love, N. G.; Filipe, C. D. 2012. *Biological wastewater treatment*. CRC Press.

Hassard, F.; Biddle, J.; Cartmell, E.; Jefferson, B.; Tyrrel, S.; Stephenson, T. 2015. Rotating biological contactors for wastewater treatment – a review, *Process Safety and Environmental Protection* 94(3): 285–306. https://doi.org/10.1016/j.psep.2014.07.003

Hoyland, G.; Vale, P.; Rogalla, F.; Jones, M. 2010. A new approach to nutrient removal using the HYBACS process, *Proceedings of the Water Environment Federation* 14(7): 81–94. https://doi.org/10.2175/193864710798208421

Janczukowicz, W.; Zieliński, M.; Dębowski, M. 2008. Biodegradability evaluation of dairy effluents originated in selected sections of dairy production, *Bioresource Technology* 99(10): 4199–4205. https://doi.org/10.1016/j.biortech.2007.08.077

Kaewkannetra, P.; Garcia-Garcia, F.; James, A.; Chiu, T. 2009. Effect of surfactants on the stability and filterability of whey suspensions, *Separation and Purification Technology* 66(2): 362–367. https://doi.org/10.1016/j.seppur.2008.12.017

Mba, D.; Bannister, R. 2007. Ensuring effluent standards by improving the design of Rotating Biological Contactors, *Desalination* 208(1): 204–215. https://doi.org/10.1016/j.desal.2006.04.079

Metcalf, E. 2003. *Inc., Wastewater Engineering, Treatment and Reuse*. New York: McGraw-Hill.

Najafpour, D. G.; Naidu, P. N.; Kamaruddin, A. H. 2008. Rotating biological contactor for biological treatment of poultry processing plant wastewater using Saccharomyces cerevisiae, *ASEAN Journal of Chemical Engineering* 2(1): 1–6.

Najafpour, G.; Yieng, H. A.; Younesi, H.; Zinatizadeh, A. 2005. Effect of organic loading on performance of rotating biological contactors using palm oil mill effluents, *Process Biochemistry* 40(8): 2879–2884. https://doi.org/10.1016/j.procbio.2005.01.002

Najafpour, G.; Zinatizadeh, A.; Lee, L. 2006. Performance of a three-stage aerobic RBC reactor in food canning wastewater treatment, *Biochemical Engineering Journal* 30(3): 297–302. https://doi.org/10.1016/j.bej.2006.05.013

Ohl, A. L.; Horn, H.; Hempel, D. 2004. Behaviour of biofilm systems under varying hydrodynamic conditions, *Water Science and Technology* 49(11–12): 345–351.

Prazeres, A. R.; Carvalho, F.; Rivas, J. 2012. Cheese whey management: a review, *Journal of Environmental Management* 110(3): 48–68. https://doi.org/10.1016/j.jenvman.2012.05.018

Reardon, R.; Davel, J.; Baune, D.; Mcdonald, S.; Appleton, R.; Gillette, R. 2013. Wastewater treatment plants of the future: current trends shape future plans, *Florida Water Resources Journal* 1(5): 8–14.

Rodgers, M.; Zhan, X.-M. 2003. Moving-medium biofilm reactors, *Reviews in Environmental Science and Biotechnology* 2(2–4): 213–224. https://doi.org/10.1023/B:RESB.0000040467.78748.1e

Sirianuntapiboon, S.; Chumlaong, S. 2013. Effect of Ni2+ and Pb2+ on the efficiency of packed cage rotating biological contactor system, *Journal of Environmental Chemical Engineering* 1(3): 233–240. https://doi.org/10.1016/j.jece.2013.04.019

Smithers, G. W. 2008. Whey and whey proteins—from "gutter-to-gold", *International Dairy Journal* 18(7): 695–704. https://doi.org/10.1016/j.idairyj.2008.03.008

Vasala, A.; Panula, J.; Neubauer, P. 2005. Efficient lactic acid production from high salt containing dairy by-products by Lactobacillus salivarius SSP. salicinius with pre-treatment by proteolytic microorganisms, *Journal of Biotechnology* 117(4): 421–431. https://doi.org/10.1016/j.jbiotec.2005.02.010

Yorgun, M.; Balcioglu, I. A.; Saygin, O. 2008. Performance comparison of ultrafiltration, nanofiltration and reverse osmosis on whey treatment, *Desalination* 229(1): 204–216. https://doi.org/10.1016/j.desal.2007.09.008

Atieh EBRAHIMI. She is a lecturer on water and wastewater treatment engineering at Institute of Pardisan Fereidonkenar, Iran. She has completed her MSc degree and also is PhD candidate at School of Civil engineering, Babol Noshirvani University of Technology, where she furthers her research on advanced water and wastewater treatment and waste minimization. She has presented 10 papers on various biological treatment processes at conferences both home and abroad and published 3 ISI journal articles.

Ghasem D. NAJAFPOUR. Professor Ghasem D. Najafpour is a distinguished professor in Chemical Engineering and Chairman of Biotechnology Research Center, Babol Noshirvani University of Technology, Iran. He is an educated scholar with PhD Degree from University of Arkansas, USA with strong background in biological processes. He is deeply involved in research and teaching in biochemical engineering subjects and he has conducted many practical researches in enzyme technology, fermentation processes, biodiesel, biofuel, wastewater treatment and biochemical engineering. In past decades, he has supervised more than 165 master and 28 PhD students. He has published more than 360 papers in international journals and has written 10 books in the field of Chemical Engineering and Biotechnology. In year 2006, he has published his 1st edition of his book with Elsevier entitled "Biochemical Engineering & Biotechnology". The 2nd edition of "Biochemical Engineering & Biotechnology" with 20 chapters is published by Elsevier in Feb. 2015.

Manouchehr NIKZAD. He is graduated, having BSc degree in civil engineering and currently is M.Sc. student in environmental engineering at Babol Noshirvani University of Technology. He has presented 3 research papers on environment engineering subjects at conferences both home and abroad. His research interests include Geoenvironmental Engineering technologies, Environmental Modeling and Optimization, and Green Building Modeling.