DAIRY WASTEWATER TREATMENT USING THREE-STAGE ROTATING BIOLOGICAL CONTACTOR (NRBC)

A. Ebrahimi and M. Asadi

School of Civil-Environmental Engineering, Babol Noshirvani University of Technology
P.O. Box 484, Babol, Iran
atieh.e@gmail.com – asadi.mostafa@gmail.com

G.D. Najafpour*

Faculty of Chemical Engineering, Babol Noushirvani University of Technology
P.O. Box 484, Babol, Iran
najafpour@nit.ac.ir - najafpour8@gmail.com

*Corresponding Author

(Received: November 16, 2008 – Accepted in Revised Form: December 11, 2008)

Abstract Dairy wastewater is enriched in organic matter (about 45-72 g/l, COD) and also contains biodegradable carbohydrates. A three-stage system, NRBC was fabricated as a bench scale unit for lab experiments, to remove organic carbon from the whey. The fabricated NRBC had several advantages, such as quick start-up, high biomass concentration and was additionally able to handle high organic loading rates. In this study, the COD removal efficiencies of 80 and 83 percent were achieved at HRT of 16 and 24 h, respectively. While the HRT was increased to 36 h, the COD removal efficiency was increased to 92 percent. High surface COD loading rate of 38-210 g COD/m^2.day was achieved. The high organic loading rate of whey was successfully treated in the fabricated NRBC. The COD removal efficiency of 96 percent was achieved, while the discs surface was increased by 10 percent.

Keywords Whey, Dairy Wastewater, RBC, COD Removal

چکیده فاضلاب لبنی حاوی مقدار زیادی ترکیبات آلی (COD حدود ۴۵–۷۲ mg/l) و کربوهیدرات تجزیه پذیر است. استفاده از سیستم سه مرحله‌ای NRBC مزایای متعددی دارد که از جمله می‌توان به زمان راه اندازی کوتاه، مقدار بالای بیومس و امکان هضم بار آلی بالا اشاره کرد. در این تحقیق، میزان تصفیه پذیری فاضلاب لبنی با استفاده از سیستم RBC سه‌مرحله‌ای بررسی شد. در زمان‌های ماند ۱۶ و ۲۴ ساعت، کارایی حذف COD برابر ۸۰ و ۸۳ درصد به‌دست آمد. با افزایش زمان ماند تا ۳۶ ساعت، کارایی حذف COD نیز تا ۹۲ درصد افزایش یافت. سیستم NRBC ساخته شده قادر به حذف بار آلی بر حسب واحد سطح برابر با ۳۸–۲۱۰ g COD/m^2 است. افزایش سطح دیسک‌های موجود به میزان ۱۰ درصد، موجب افزایش کارایی حذف COD فاضلاب لبنی تا ۹۶ درصد گردید.

1. INTRODUCTION

The dairy industry, like most other agro-industries, generates large volumes of wastewaters, characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations reflecting their high organic content [1]. Dairy waste effluents are naturally concentrated, and the main contributors of organic load to these effluents are carbohydrates, proteins and fats which were originated from milk [2]. Globaly, cheese whey, a by-product of cheese production, is being generated in enormous quantities as a result of increasing in the trend of cheese production. Disposal of the whey having a high chemical oxygen demand (COD) of about 60,000 to 80,000 mg/l, causes environmental problem. The organic loading rate in dairy wastewater is defined by the amount of lactose, fats and proteins in the whey. The relation between these substances can be extremely varied, that affects their susceptibility to the biological treatment. Wastewater reaction and temperature are other factors that influence the biodegradation efficiency [1,3]. The environmental impact of dairy effluents can be very high, especially due to very large discharge of wastewaters which contain high organic matters and other nutrients including nitrogen and phosphorus. Although all of the whey compounds are biodegradable, some of them such as lactose are readily consumed in a biological treatment. However, the dissolved organic matters in the waste streams pose the greatest threat to the water resources (streams, rivers, and ocean). Discharge of dairy plant effluents to the water resources can lead to destruction of aquatic life and other marine creatures, which can provide more food for microbial consortia and causes further oxygen depletion [3].

Dairy industry is an important economic sector, but the pollution potential of such activity may be considered high, mainly when recovery of proteins, lipids and lactose is not performed. In many countries, the cost of treatment systems may represent a barrier to achieve high quality wastewater standards. Thus, the search for low-cost, effective techniques may contribute to reduce the environmental impacts generated by the dairy industry [4]. Biological wastewater treatment processes are classified as either attached growth or suspended growth. In an attached growth process, an active thin layer of microorganisms known as biofilm is developed on the solid support. Organic matter, nutrients and oxygen diffuse into biofilm where they are consumed and reacted by the living microorganisms, while the products diffuse out from the biofilm [5-8]. Attached growth processes seem to be more stable than suspended growth processes, especially important when the wastewater has considerable fluctuations in flow rate and organic matter. It has been found that disc biomass plays major role in organic biodegradation [9-11]. In spite of several advantages, the anaerobic processes have not gained popularity in the dairy industry, largely due to the problem of slow reaction, which requires a longer hydraulic retention time (HRT) and exhibits poor process stability in a conventional reactor [11,12].

In general, the rotating biological contactor (RBC) is a fixed biological film reactor system consists of a series of plastic circular discs mounted on a horizontal shaft that rotates perpendicular to the direction of the wastewater flow. In a conventional RBC unit, approximately 40-45 % of the total disc surface area is submerged in the wastewater to be treated [8,13-15]. The RBC with fixed-film and suspended growth systems has been identified as an alternative bioreactor. As the discs rotate, the microorganisms attached as biofilm alternatively immerse in the wastewater, and the biodiscs rotate at a speed that allows adequate attached biofilm development. Transfer of oxygen occur by the exposure and renewal of air-water interfaces, as the contactor rotates, and the wastewater lifted out by the rotating device trickles back down into the sump. This cyclic immersion of the biofilm also provides the opportunity for the adsorption and uptake of organics from the wastewater. The RBC is a proven technology for large-scale wastewater treatment applications, offering several advantages; low-shear environment, easy scale-up, high surface area per unit volume, low maintenance costs, low energy requirements, simple construction and easy operation [14,15]. Many types of proprietary RBC systems have been developed [16-18]. RBC is widely used in aerobic treatment of wastewater. In practice, the discs are arranged in groups and several reactors are used in series. The advantage of RBCs is their relative low energy consumption, simple operation and maintenance with successive treatment of influent contaminants. As an alternative approach to treat hydrocarbons in bioreactors, the RBC appears to be a good choice because of the above reasons. Multi-stages RBC were used by a number of researchers for the degradation and removal of phenol, trichloroethylene and thiocyanate in the wastewater [19-21].

The aim of this research was to study a simple, low cost three-stage RBC system, for the treatment of high-strength dairy wastewater and to evaluate the process performance under various hydraulic loading conditions.

2. MATERIAL AND METHODS

The cheese whey used in this study was obtained from “Gela Factory” (Amol, Iran). For cheese production, Gela Factory is benefited from advanced ultrafiltration process. The whey samples supplied by the factory, were collected in 20 liter containers and daily transported to the laboratory, refrigerated and stored at 4˚C to avoid any changes in chemical composition or acidification of the cheese whey. During the adaptation phase, diluted whey at pH 6.5 was fed into the reactor. Based on necessity of the experiment, various dilutions of cheese whey were prepared using distilled water. The feed pH was adjusted to 6.5, using a 6M sodium hydroxide solution. The notable characteristic of the collected effluent was the high COD content. The characteristics and chemical composition of the obtained whey are summarized in Table 1.

2.1. NRBC Experiments A lab-scale three-stage RBC was fabricated with an acrylic plastic transparent sheet thickness of 8 mm. A schematic experimental setup with auxiliary units is shown in Figure 1.

The total and working volume of NRBC were 78.75 and 65.6 L, respectively. The dimensions of the RBC reactor were 75 cm long, 35 cm width and 30 cm depth, which consist of three stages and each stage, had 16 discs, with 32 cm diameter. The interspacing of the discs was 8 mm. The discs were mounted on a stainless steel shaft, geared with a fixed rotational speed (4 rpm) by an electric motor with fixed power input (NDRD Motor, Model SK 63/4, Germany). The shaft passed through the center of each disc and was mounted on the bearing attached to the ends of the wastewater container. The discs were made of blue acrylic plastic sheet with thickness of 3 mm, and the submergence of the discs was 33 percent. The available surface area for the biofilm growth was 7.79 m^2. In the second round of the experiment, total surface area of the discs was extended by 10 percent to improve the COD removal efficiency. In this condition, the working surface area was about 8.57 m^2. The substrate feed rate was controlled by a variable speed (15-150 ml/min) peristaltic pump (Etatron D.S., Model PDP-B-V, Italy). The variables in the rotating biological contactors were surface organic loading rates and hydraulic retention time (volumetric flow rate of the wastewater). Effect of OLR on RBC performance was evaluated by various HRT and variable influent COD in the range of 43000 to 74000 mg/l. The reactor design and operating parameters for the fabricated RBC are summarized in Table 2.

TABLE 1. The Characteristics and Chemical Composition of Cheese Whey.

Characteristic	Unit	Value
COD	g/l	45-72
TS	g/l	55
VS	g/l	49
Proteins	g/l	2.2
Phosphate	g/l	0.6
Ca^{+2}	g/l	0.02
pH	-	5.5-6.6

2.1. Analytical Methods The sampling point positions at inlet, stage 1, 2, 3 (S_1,S_2,S_3) and outlet were fixed as shown in Figure 1. Collected samples were settled for 30 min to analyze COD. The analysis was performed using standard methods [22]. The COD concentration was measured according to standard methods using close reflux method. COD was determined using colorimetric method by color absorption at wave length of 600 nm using spectrophotometer (2100 SERIES, UNICO, U.S.A.).

3. RESULT AND DISCUSSION

Whey was yellowish with negligible amount of TSS but enriched with carbohydrate (Lactose) and high COD (45-72 g/l) continuously fed into the RBC. The supplied whey from ultrafilteration (UF) Gela plant was directly used in the NRBC without any pretreatment or dilution. One of the developed techniques for the treatment of whey was continuous treatment using attached growth microbial film on a biological contactor (NRBC). Based on special criteria of the attached-growth process, NRBC retained massive amount of biomass as biofilm,

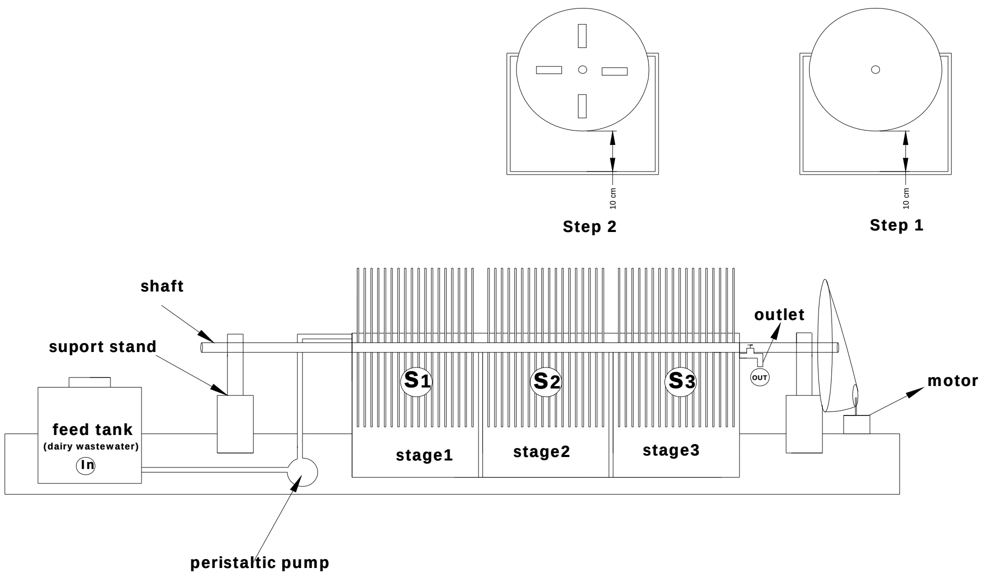


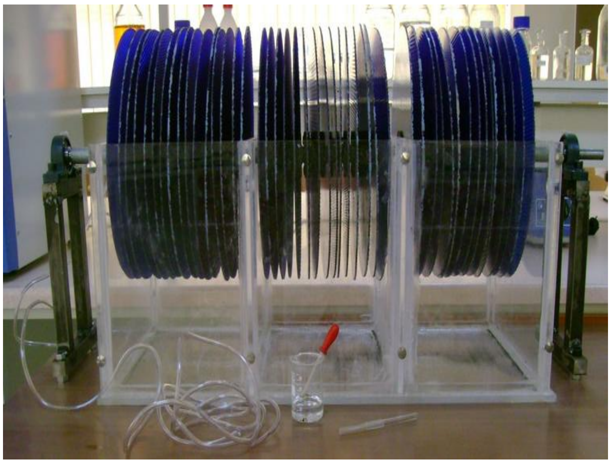
Figure 1. Schematic experimental setup.

TABLE 2. Reactor Design and Operating Parameters for the Laboratory Scale NRBC.

SPECIFICATION	VALUES
Number of Stages	3
No. of Disc/Stage	16
Diameter of the Disc (mm)	320
Spacing Between the Disc (mm)	8
Cross-Sectional Area of Tank (m^2)	0.105
Total Surface Area of Discs (m^2)	7.79
Total Surface Area of Discs After Extension (m^2)	8.57
Working Volume (L)	65.6
Submergence (%)	33
Rotations Per Minute	4

therefore it had the capacity to treat very high strength of COD (influent) also could tolerate high organic loading rate and hydraulic shocks. In the first week of operation, considerable film of biomass was quickly developed on the discs surface and then the process was operated in full capacity after 3-4 days of start up period.

The NRBC was continuously operated with HRT of 16 to 36 h. Low HRT (8h) was also experimented, in terms of treatment process the results were unreliable. The fabricated pilot is shown in Figure 2a. Figure 2b depicts the established biofilm on the surface of discs after 2 days. Considerable amount of biomass was



(a)

(b)

(c)

Figure 2. Development of thick biofilm on the surface of discs.

developed as the biofilm on the discs after 4 days of operation. Figure 2c presents the fully developed thick and active biofilm after 7 days of operation. One can observe that the surface of the discs was totally covered by the film of active biomass.

Figure 3 shows the COD concentration at various sampling point locations for HRT of 16 hours. Based on the availability and supply of whey for feeding the NRBC, the inlet COD concentrations were varied from 45000 to 62000 mg/l. The decreasing trends of COD concentration for a defined retention time (16 h) for operation time of 1-8 days were about the same. Maximum removal efficiency of 80 percent was achieved in the first seven days of operation with COD concentration of 60000 and 12000 mg/l at inlet and outlet effluent, respectively. For each selected HRT, the system was operated for sufficient time in order to establish steady state condition. The collected data were in triplicates and the mean value was reported.

The three stage RBC was operated with selected HRT of 24 hrs for duration of 6 days. The collected data at five different locations are plotted in Figure 4. The inlet COD concentrations were varied from 51000 to 72000 mg/l. At the end of the third day of operation, the inlet COD was quite high (72000 mg/l) and the effluent COD was measured 31000 mg/l, only 57 percent of COD was removed. Maximum removal efficiency of 83 percent was achieved in the 6th day of operation with an inlet COD concentration of 55000 mg/l. In the first stage of NRBC, more than 35 percent of COD concentration was removed. Because of the high organic load introduced in the first stage, the rate of removal of COD in the first stage was higher than the other stages of the NRBC. The progressive removal efficiency of 72 and 75 percent were achieved in the second and third stages, respectively.

Figure 5 depicts the COD concentration for the HRT of 36 h. The collected data are categorized as high and mid range of COD concentration. As the HRT increased to 36 h, the COD removal efficiency for high COD concentration (72000 mg/l) was not at satisfactory level. The inappropriate action of the bioprocess was most probably due to the biofilm toxication at high organic loading rate. Then the biofilm went under recovery for the first few days of operation. The system behaved

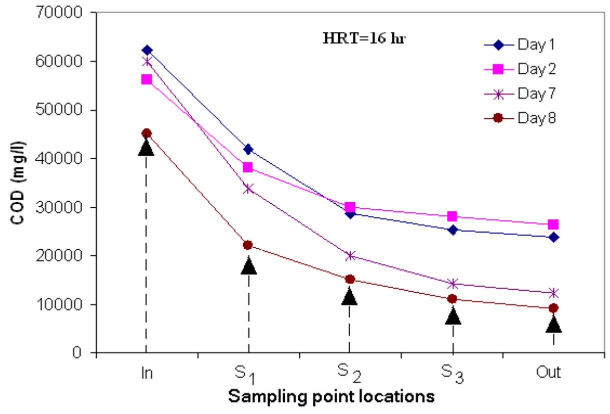


Figure 3. COD concentrations at various stages for HRT of 16h.

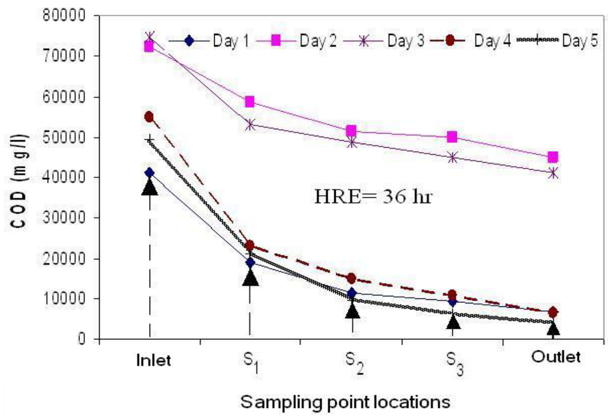


Figure 5. COD concentrations at various stages for HRT of 16h.

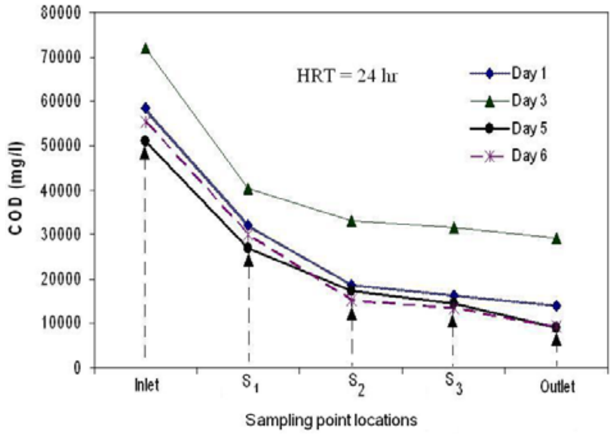


Figure 4. COD concentrations at various stages for HRT of 16h.

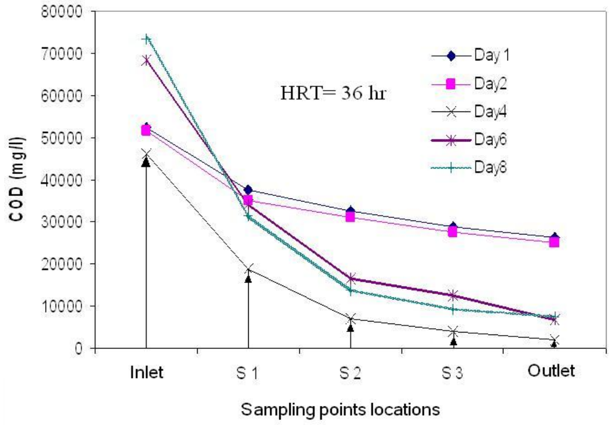


Figure 6. COD concentration profiles with the extended surface area of RBC for HRT of 36h.

excellently in the midrange of COD concentration. Maximum COD removal efficiency of 92 percent was achieved at fifth day of operation. The organic load on first stage of the NRBC was considered to be high, about 57 percent of COD was removed in the first stage of NRBC.

Disc surface area in RBC plays major role in oxidation of the organic matters. The data presented in Figure 6 were obtained after addition of the disc surface area by 10 percent. Since the biofilm was disturbed due to mounting the surface extension, the data for the first two days of operation was not promising. Maximum removal efficiency increased to 96 percent at HRT of 36 hours for the duration of 4-8 days of operation. About 60 percent of COD concentration was removed in the first stage of NRBC. The percentages of COD removal in the second and third stages of NRBC were lower than the first stage. That was due to high concentration gradient of incoming COD at each stage.

The three stage RBC was successfully operated for the whole experimental duration course of 8 months without any system failure. During the long experimental runs, there was no report of system interruption and the system was very reliable, never confronted to any serious problem. Therefore NRBC biological process is recommended for industrial wastewater treatment. The experience of

Gela's UF plant effluent treatment was a successful case.

4. CONCLUSION

The three-stage lab-scale rotating biological contactor was successfully operated, while treating the dairy wastewater. A 96 percent COD removal efficiency was achieved at HRT of 36 h. The sequential stage COD removal efficiency gradually decreased with an increase in number of stages. About 55-60 percent of organic compounds were removed in the first stage of aerobic NRBC. This three-stage RBC system was aerobically experimented as an efficient process for treating high-strength organic wastewater under fixed rotational speed of the biodiscs (4 rpm) and submergence of 33 percent.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledged Gela plant manager and the R and D board of Babol, Noshirvani University of Technology, for their cooperation and support. Also special thanks to our Biotechnology Research Center for providing research facilities to carry out quality research.

6. REFERENCES

1. Janczukowicz, W., Zielinski, M. and Debowski, M., "Biodegradability Evaluation of Dairy Effluents Originated in Selected Sections of Dairy Production", ***Bioresource Technology***, Vol. 99, (2008), 4199-4205.
2. Patel, C. and Madamwar, D., "Biomethanation of Salty Cheese Whey using an Anaerobic Rotating Biological Contact Reactor", ***Journal of Fermentation and Bioengineering***, Vol. 83, No. 5, (1997), 502-504.
3. Bae, T.H, Han, S.S. and Tak, T.M., "Membrane Sequencing Batch Reactor System for the Treatment of Dairy Industry Wastewater", ***Process Biochemistry***, Vol. 39, (2003), 221-231.
4. Dugba, P.N. and Zhang, R., "Treatment of Dairy Wastewater with Two-Stage Anaerobic Sequencing Batch Reactor Systems-Thermophilic Versus Mesophilic Operations", ***Bioresource Technology***, Vol. 68, (1999), 225-233.
5. Kargi, F., "Empirical Models for Biological Treatment of Saline Wastewater in Rotating Biodisc Contactor", ***Process Biochemistry***, Vol. 38, (2002), 399-403.
6. Brar, K.S. and Gupta, S.K., "Biodegradation of Trichloroethylene in Rotating Biological Contactor", ***Water Resource***, Vol. 34, No. 17, (2000), 4207-4214.
7. Teixeira, P. and Oliveira, R., "Denitrification in a Closed Rotating Biological Contactor: Effect of Disc Submergence", ***Process Biochemistry***, Vol. 37, (2001), 345-349.
8. Najafpour, G.D., Yieng, H.A., Younesi, H. and Zinatizadeh, A., "Effect of Organic Loading on Performance of Rotating Biological Contactors using Palm Oil Mill Effluents", ***Process Biochemistry***, Vol. 40, (2005), 2879-2884.
9. Ndegwa, P.M., Venkata, L.W. and Vaddella, K., "Potential Strategies for Process Control and Monitoring of Stabilization of Dairy Wastewaters in Batch Aerobic Treatment Systems", ***Process Biochemistry***, Vol. 42, (2007), 1272-1278.
10. Mba, D. and Bannister, R., "Ensuring Effluent Standards by Improving the Design of Rotating Biological Contactors", ***Desalination***, Vol. 208, (2007), 204-215.
11. Tawfik, A., Klapwijk, A., Gohary, F. and Lettinga, G., "Treatment of Anaerobically Pre-Treated Domestic Sewage by a Rotating Biological Contactor", ***Water Research***, Vol. 36, (2002), 147-155.
12. Tawfik, A., Klapwijk, A., Gohary, F. and Lettinga, G., "Potentials of using a Rotating Biological Contactor (RBC) for Post-Treatment of Anaerobically Pre-Treated Domestic Wastewater", ***Biochemical Engineering Journal***, Vol. 25, (2005), 89-98.
13. Hsu, C.L., Ouyang, C.F. and Weng, H.T., "Purification of Rotating Biological Contactor (RBC) Treated Domestic Wastewater for Reuse in Irrigation by Biofilm Channel", ***Resources, Conservation and Recycling***, Vol. 30, (2000), 165-175.
14. Castillo, E., Vergara, M. and Moreno, Y., "The Combined Effect of Step-Feed and Recycling on RBC Performance", ***Waste Management***, Vol. 27, (2007), 720-726.
15. Demetrios, N.H., Manariotis, I.D. and Grigoropoulos, S. G., "Organic and Nitrogen Removal in a Two-Stage Rotating Biological Contactor Treating Municipal Wastewater", ***Bioresource Technology***, Vol. 93, (2004), 91-98.
16. Najafpour, G.D., Zinatizadeh, A.A.L. and Lee, L.K., "Performance of a Three-Stage Aerobic RBC Reactor in Food Canning Wastewater Treatment", ***Biochemical Engineering Journal***, Vol. 30, (2006), 297-302.
17. Najafpour, G.D., Naidu, P.N. and Harun, A., "Rotating Biological Contactor for Biological Treatment of Poultry Processing Plant Wastewater using Saccharomyces Cerevisiae", ***Asean Journal of Chemical Engineering***, Vol. 2, No. 1, (2002), 1-6.
18. Najafpour, G.D. and Naidu, P.N., "Biological Wastewater Treatment using RBC", Regional Symposium on Chemical Engineering (RSCE) 2000, PDD4.5, Singapore, (December 11-13, 2000).
19. Alemzadeh, I., Vossoughi F. and Houshmandi M., "Phenol Biodegradation by Rotating Biological Contactor", ***Biochemical Engineering Journal***, Vol. 11, (2002), 19-23.

20. Sirianuntapiboon, S., "Treatment of Wastewater Containing Cl_2 Residue by Packed Cage Rotating Biological Contactor (RBC) System", ***Bioresource Technology***, Vol. 97, (2006), 1735-1744.
21. Suzuki, T. and Yamaya, S., "Removal of Hydrocarbons in a Rotating Biological Contactor with Biodrum", ***Process Biochemistry***, Vol. 40, (2005), 3429-3433.
22. APHA-AWWA-WEF (American Public Health Association, American Water Works Association, Water Environment Federation), "Standard Methods for the Examination of Water and Wastewater", 21st Ed., APHA-AWWA-WEF Washington DC, U.S.A., (2005).