Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1113143

57 (2016) 20439–20446
September

Taylor & Francis
Taylor & Francis Group

Evaluation of a cost-effective and energy-efficient disc material for rotating biological contactors (RBC), and performance evaluation under varying condition of RPM and submergence

Shamas Tabraiz[a,*], Sajjad Haydar[b], Ghulam Hussain[b]

[a]*Department of Environmental Engineering, University of Engineering, and Technology, Taxila, Pakistan, emails: shamastabraiz28@yahoo.com, shamas.tabraiz@uettaxila.edu.pk*
[b]*Institute of Environmental Engineering and Research, University of Engineering and Technology, Lahore, Pakistan, emails: sajjad@uet.edu.pk (S. Haydar), ghussain@uet.edu.pk (G. Hussain)*

Received 27 March 2015; Accepted 18 October 2015

ABSTRACT

This study was carried out to evaluate the suitability of polyethylene foam as disc material for rotating biological contactors (RBC). Effect on DO levels due to change in RPM and submergence was also investigated. For this purpose, a pilot-scale model of RBC was constructed. The model was operated at 3, 5 and 7 RPM with varying submergence of discs, i.e. 30, 40, 50, 60 and 70%. Domestic sewage was used to run the model. Different parameters like pH, DO, total suspended solids (TSS), BOD and COD were monitored for the influent and effluent of pilot-scale RBC under varying operating conditions. Optimum values of submergence and RPM were found to be 40% and 5 RPM, respectively. BOD and COD removal, under optimum conditions, were 85.7 and 67.6%, respectively. The effluent concentrations for BOD and COD, under optimum conditions, were 42 and 124 mg/L, respectively, meeting the national effluent standards, with DO level of 4.6 mg/L. New disc material used costs US$ 0.38, while conventionally used material, i.e. polystyrene costs US$ 1.91 per square metre. Due to lesser weight energy consumption of newly proposed material is 26 kWh/m^3/year while for Polystyrene it is 96.6 kWh/m^3/year, no wear and tear of material was found after a continuous run of 90 d. Analysis of variance showed that submergence has more dominant role in raising DO levels as compared to RPM.

Keywords: RBC; Disc submergence; Disc RPM; Efficiency; Low-density discs; Energy reduction

1. Introduction

Rotating biological contactors (RBC) is an attached growth bioreactor. It consists of a shaft mounted on closely spaced plates. Plates are partially submerged in wastewater. Rotation provides oxygen for metabolic action of bacteria to utilize organic matter. The first RBC was installed in Germany in 1958. Afterwards, it came to the USA and Canada [1–3]. It is considered to be a prospective alternate of activated sludge process (ASP) due to lesser footprint, simple process and reduced energy requirements [4]. Studies show that the energy requirements of ASP are two to three times more as compared to RBC, to treat the same flow [5].

*Corresponding author.

Factors affecting the efficiency of RBC include; hydraulic loading (HL), hydraulic retention time (HRT), RBC media, staging, organic loading (OL), rotational speed (RPM), submergence, temperature, biofilm characteristics, wastewater characteristics, DO levels in tank, effluent and solid recirculation and step feeding [4,6–14].

A study was conducted to evaluate the effect of RPM of discs of RBC to treat phenolic wastewater. The submergence (50%), HL (23.42 $dm^3/m^2/h$) and OL (3,508 mg $phenol/m^2/h$) were kept constant. Removal of BOD at 40 and 150 RPM was 3,090 and 11,400 mg/m^3, respectively [7]. In another study, effect of RPM on the removal efficiency was evaluated using food cannery wastewater in RBC. OL was kept constant (22.13 g COD/m^2 d). Removal efficiency at 3 and 7 RPM was 62.67 and 93.70%, respectively [15]. Similarly, in another study, food cannery wastewater was treated in RBC to test RPM (15 and 17) affect on removal efficiency by keeping OL constant (210 g COD/m^2 d). Removal efficiency at 15 and 17 RPM was 77 and 78%, respectively [9]. Industrial wastewater was also treated in pilot-scale aerobic RBC, keeping submergence constant (37%). The HL selected was 0.013 and 0.017 m^3/m^2 d. OL rate varied in the range 5.3–17.8 mg $SBOD/m^2$ d. Removal efficiency was same at 8 and 11 RPM [10].

Aerobic lab-scale RBC, having acrylic discs of 0.25 m diameter was used in 3 stages having 42 discs and high-strength municipal wastewater. HL rate was varied between 20 and 32 dm^3/m^2 d. OL rate was varied between 10 and 32 g COD/m^2 d Rotational speed was kept constant at 5 RPM. The removal efficiency was observed at different retention times. For hydraulic retention time of 24 h, removal was 66.67% (20 g COD/m^2 d removed) [16].

OL rate and HRT affect on the removal efficiency were evaluated using RBC. The RPM (10), submergence (30%) and HL (1.1–6 dm^3/h) was kept constant. Removal efficiency of COD at 38 g COD/m^2 d and HRT of 10 h was 88%, while at 210 g COD/m^2 d and HRT of 55 h was 35%. The increase in OL decreased the removal efficiency even at higher HRT [8].

Furthermore, studies have revealed that more HRT increased the contact time of the wastewater to biomass on discs. The organic matter diffuses more deep increasing the removal efficiency [15]. Similarly, other works on RBC have also been reported [13,17,18].

It can be concluded from the above review that in some studies RPM was kept constant and other factors affecting efficiency (submergence, HRT, HL and OL) were varied to study the effect on performance. While in some studies, submergence was kept constant and other factors affecting efficiency (RPM, HRT, HL and OL) were varied. However, no study could be found where RPM and submergence were varied by keeping all other factors constant.

Disc material used for RBC is another important factor affecting the cost and energy consumption [19]. The heavier is the disc material, the higher is the energy consumption to rotate it. Studies were conducted on disc materials, which were both lighter and cheaper, to make the system economical and less energy intensive. Material investigated were; stainless steel, lightweight clear plastic, propylene pall rings, hard polythene discs, acrylic plastic discs, cylinder with wooden slats, PVC and polystyrene [7,9,15,20–24]. However, no study has so far been conducted to evaluate the feasibility of using polyethylene foam, which is both cheaper and lighter than the above-mentioned disc materials.

Thus, the present study was conducted with the objectives: (1) to study effect of varying RPM and submergence on RBC performance keeping other parameters constant (i.e. OL and HL); (2) to test suitability of a new disc material, i.e. polyethylene foam for its use in RBC; and (3) compare operational cost of RBC using new material with other conventionally used material and ASP.

2. Materials and methods

2.1. Description of pilot-scale RBC

A pilot-scale model of rotating biological contactor was designed and constructed. It had three main parts; primary clarifier, RBC tank and secondary clarifier. Peristaltic pump was used to control flow. Motors with adjustable rods were used to vary RPM and submergence of discs. Fig. 1 shows a concept diagram of the pilot-scale model. The working volume of the RBC reactor was 0.3 m^3 (300 L). A flow rate of 3.6 m^3/d was maintained that gave a detention time of 2 h in RBC tank. The working volume of primary and secondary clarifier was 0.225 m^3 (225 L). The pilot RBC was continuously operated for 91 d. The start-up period was 7 d during which the plant was operated at 7 RPM and 30% submergence. The complete operational plan after the initial start-up is given in Table 1.

2.2. Sampling and experimental analysis

To evaluate the performance of pilot RBC, composite samples for 12 h were collected from the outlet of the primary sedimentation tank (S-1), outlet of secondary sedimentation tank (S-2) and from RBC reactor (S-3) S-1 and S-2 were used to evaluate the

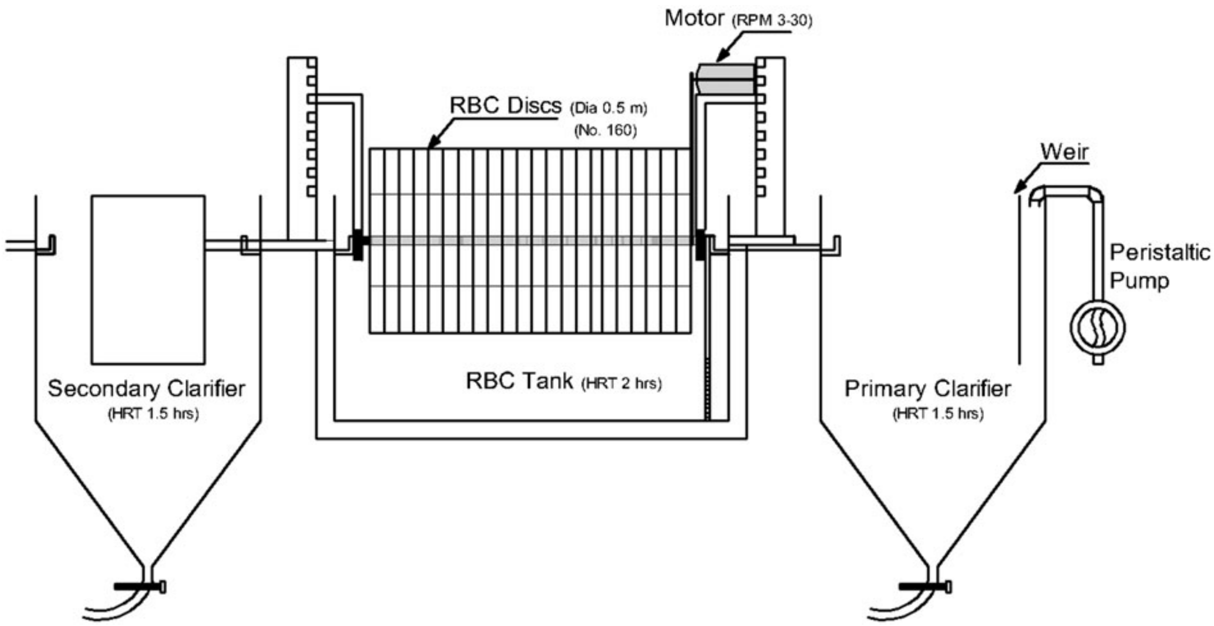

Fig. 1. Concept diagram of pilot scale.

Table 1
Operational plan of pilot-scale RBC

Operation days	RPM	Submergence (%)
7	7	30
6	7	40
6	7	50
6	7	60
6	7	70
6	5	30
6	5	40
6	5	50
6	5	60
6	5	70
6	3	30
6	3	40
6	3	50
6	3	60
6	3	70

performance, while S-3 was used to study the pH, temperature and DO levels in RBC tank.

2.2.1. Tests conducted for evaluating the performance of RBC

For performance evaluation, tests conducted on S-1 and S-3 and testing procedure [25] (standard method no.) are listed in Table 2.

Table 2
Tests performed for performance evaluation and test procedures used

S. no.	Test	Test procedure
1	DO	4,500-O
2	TSS	2,540 D
3	BOD	5,210 B
4	COD	5,220 D
5	Total phosphorus (TP)	4,500 P E
6	Total Kjeldahl Nitrogen (TKN)	4,500 N_{org}

2.2.2. Energy consumption analysis

Energy calculations for different options were carried out for an assumed community of 500,000 persons. Water consumption adopted per person per day was 190 litres. Eighty per cent of the water consumed was taken as wastewater flow. Thus, total wastewater flow came out to be 76,000 m^3/d. Wastewater characteristics of typical domestic wastewater were used (Table 3). Energy consumption for RBC plant using six different disc materials was computed. In addition, energy consumption for activated sludge using the above data was also evaluated.

Energy required for RBC shafts was computed using the following procedure and equations.

Net weight on shaft = weight of discs and shaft + weight of attached biomass on discs − uplift force of water.

Table 3
Wastewater characteristics

S. no.	Parameters	Mean value[n]	Standard deviation
1	BOD	288.09	±61.2
2	COD	370.18	±55.81
3	TSS	332.93	±125.54
4	TP	16.36	±2.55
5	TKN	22.5	±3.2
6	pH	6.8–7.9	–

The biomass from the discs was weighed after its removal from the discs.

$$P = T\omega \quad (1)$$

where "T" is the torque (weight × radius of shaft).

$$\omega = (2\pi N/60)\ \text{rad/s} \quad (2)$$

where "N" the is revolution per minute.

Power calculations for the ASP were carried out using Eq. (2) for oxygen requirement and then energy requirement was calculated for mechanical aerators to supply that oxygen. Oxygen transfer rate of aerators was taken 1 kg O_2/kWh. For ASP, energy required for sludge recirculation was also included [5].

$$O_2\ \text{required} = Q(S_o - S) - 1.42\,P_x \quad (3)$$

where "Q" is the wastewater flow, "S_o" is the influent BOD, "S" is the effluent BOD and "P_x" is the sludge produced.

For both ASP and RBC, energy required for equalization, primary clarifier sludge pumping, secondary clarifier sludge pumping was also calculated.

2.2.3. Disc material cost

The disc material cost share a major parts in the cost of RBC constructions. Different materials, disc material cost, conventionally used for the RBC discs (PVC, polyacrylic, propylene, hard polyethylene, polystyrene) and new proposed disc material (polyethylene foam), cost was collected from the local industries.

2.3. Wastewater characteristics and operation conditions

The pilot plant was operated at OL of 12–15 g soluble BOD/m^2 d and HL rate was 0.11 m^3/m^2 d. The temperature of the ambient air was 33–37°C, while the influent temperature varied from 25 to 30°C. The influent wastewater characteristics are given in Table 3.

3. Results and discussions

3.1. Effects of RPM and submergence on DO levels

DO variation in RBC tank, with RPM and submergence, is presented in Fig. 2. It can be seen that both parameters affect DO levels. The maximum DO observed was 5.3 mg/L at 7 RPM and submergence of 30%. DO levels fell with increasing submergence; keeping RPM constant. However, increase in RPM at the same submergence raised DO levels in RBC tank. Minimum DO observed was 2.6 mg/L at 3 RPM and 70% submergence. As the submergence increased, keeping the RPM constant, DO decreased. It was due to the decrease in area of discs exposed to air. Increase in RPM at the same submergence causes increase in DO content of the wastewater. It was due to more turbulence and increased frequency of wet discs exposure to air. A study was conducted in which the pharmaceutical industrial wastewater was treated in RBC. The COD and BOD_5 concentrations were 300 and 160 mg/L, respectively, while operating temperature was 10–12°C. The RPM and submergence was 4 and 45%, respectively. DO concentration in effluent was reported 4.6–7.2 mg/L [26]. In the present study, DO level at 40% submergence and 5 RPM was 4.6 mg/L, at 25–30°C influent temperature. In the present study, different BOD, COD and temperature are higher which resulted in the reduced DO concentration as compared to reported study.

In another study, the sewage was treated in RBC with disc speed 8 rpm and submergence of 30%. The

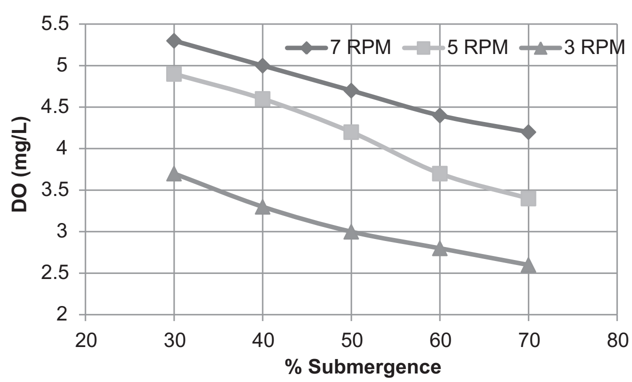

Fig. 2. DO concentration at different RPM and submergences.

Table 4
ANNOVA results

Source of variation	SS	df	MS	F	p-value	F crit
Rows (submergence)	6.949333	2	3.47	251.18	6.04E−08	4.46
Columns (RPM)	2.957333	4	0.739	53.44	8.22E−06	3.84
Error	0.110667	8	0.0138			

DO level reported, 9.3–14.3 mg/L, were quit higher as compared to the DO levels of present study. Difference in DO concentration was due to the low temperature, i.e. 13˚C, in reported study [27]. Similarly, in another study, self-rotating RBC was operated at 35% submergence. The influent temperature was 21–28˚C and OL was 51 kg COD/m^2 d. The concentration of DO in the first stage was reported 1.65–2 mg/L. The low DO concentrations can be attributed due to lower disc speed and high OL [28].

The concentration of DO in the RBC depends upon the many parameters, i.e. HL, OL, disc RPM, disc submergence, temperature and type of wastewater [20].

To check which parameter (submergence or RPM) has more significant role in varying DO levels, ANNOVA analysis with two factors without replication, was carried out on the data, at an α value of 0.05. The null hypothesis used was that "the variance among columns and rows is equal i.e. both parameter have equal role in enhancing DO levels". Analysis of variance results are given in Table 4.

From Table 4, it can be seen that, for submergence, the p-value ($6.04 \times 10^{-8} < 0.05$) is less than α, i.e. 0.05 and $F > F_{crit}$ i.e. ($251.18 > 4.46$). Thus, the null hypothesis is rejected. For RPM; it was found that the p-value ($8.22 \times 10^{-2} < 0.05$) is less than α, i.e. 0.05 and $F > F_{crit}$, i.e. ($53.44 > 3.84$). For submergence, the values of α is lesser and value of F is higher when compared with RPM. This shows that submergence affect DO levels more than RPM, although both are instrumental in changing DO levels.

3.2. *Effects of submergence and RPM variation on BOD and COD removal*

Fig. 3 presents the BOD removal efficiencies at different RPM and submergences. It is obvious that the removal efficiencies are higher at the 5 RPM as compared to 3 and 7. The highest removal efficiency observed was at 5 RPM and 40% submergence. Same was the case with COD removal efficiencies (Fig. 4).

Maximum efficiencies observed at other RPM, i.e. 3 and 7, were also at the 40% submergence. These results show that the optimum submergence was 40%. And, the optimum RPM was 5. As the submergence was increased the oxygen transfer efficiency decreased, i.e. the oxygen level of RBC tank decreased (Fig. 2) [12,14]. Decrease in DO level could be a possible reason of decrease in removal efficiency.

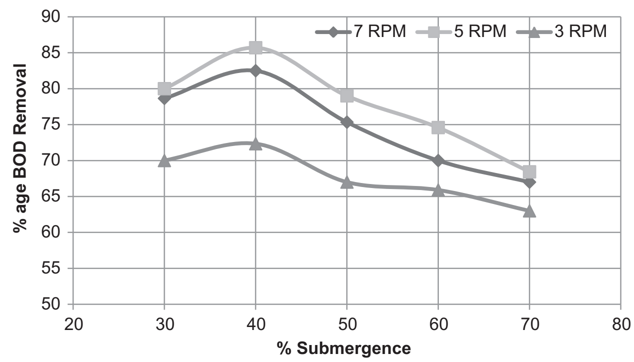

Fig. 3. BOD removal efficiencies at different RPM and submergences.

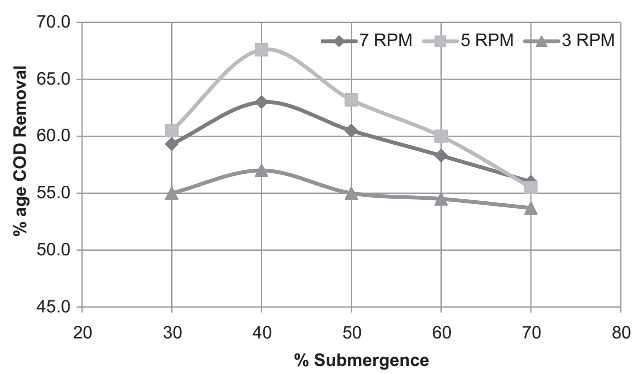

Fig. 4. COD removal efficiencies at different RPM and submergences.

The BOD removal was maximum at optimum submergence and RPM of 40% and 5, respectively, and it was 85.7%. When RPM was increased to 7 RPM at the same submergence the removal efficiency dropped to 72.3%. Decrease in removal efficiency, at higher RPM, was due to sloughing off the biofilm from the discs which reduced the biomass concentration [29,30].

Fig. 5. Disc material after completion of the study.

More submergence increased dipped disc area (more micro-organisms exposed to wastewater to take up food) and decreased the biofilm exposure to air. It resulted in a decrease in DO levels. At 30% submergence, 70% area was exposed to the air. DO uptake from air was higher. While less portion of biofilm was exposed to wastewater. At 40% submergence, exposure of biofilm to wastewater increased and exposure to air decreased. Exposure to air was enough to get required DO to oxidize the organic matter. Efficiency at 40% submergence was thus maximum. When submergence increased from 40 to 50%, the exposure of biofilm to air reduced. It resulted in deficiency of DO to oxidize the organic matter. Therefore, efficiency reduced at 50% submergence. Further reduction was observed at higher submergences, i.e. 60 and 70%. In summary, DO level, number of micro-organisms on biofilm, biofilm area exposed to wastewater and the time discs remain in wastewater and air, all these factors decide stoichiometric ratios required for all reactants in oxidation reaction in bioreactor.

In a study, two-stage RBC was operated to treat sewage. The study reported 77% COD removal efficiency at OLR of 22 g COD/m^2 d, 5 h HRT, 5 RPM and 40% submergence [31]. In another study, polypropylene corrugated cylinders were used instead of discs in RBC to treat sewage. OLR was 5.5 g COD/m^2 d, hours HRT, 5 RPM and 30% submergence. The COD removal efficiency was 76%. Similarly, a study was conducted to treat grey water in RBC. The textured plastic sheet was used as a disc material with 40% submergence at 1.7 RPM. The removal efficiency of BOD and COD was 60 and 53%, respectively, at 1.5 h HRT [32]. In the present study, removal efficiency of BOD and COD, at 40% submergence and 3 RPM, was 72 and 57%, respectively. A study was conducted on municipal wastewater using Plexiglas as disc material in RBC. Submergence of discs was kept 35% and RPM was 8. The removal efficiencies of BOD and COD was 86 and 82%, respectively, at HRT of 22.5 h [27]. The present study BOD and COD removal efficiency at 30% submergence and 7 RPM was 78.65 and 59.3%, respectively. Removal efficiencies in the reported study were higher due to higher HRT as compared to the present study. Similarly, in another study the winery effluent was treated using polyurethane discs with 40% submergence and 6 RPM. HRT of the bioreactor was kept 1 h. Only 23% COD removal efficiency was reported [33].

The new disc material was found in satisfactory condition after a continuous use of 91 d. Fig. 5 gives a photograph of the disc material after completion of the study.

3.3. Cost comparison with other disc materials

PVC, polystyrene, polyacrylic, propylene and hard polyethylene materials are conventionally used as the disc materials for RBC. Polystyrene is the most commonly used material. A comparison of density and cost of the above materials with polyethylene foam is given in Table 5. It is obvious that polyethylene foam is lighter and cheaper than the other materials. PVC and polyacrylic have the highest costs. Polyethylene foam disc cost is only 7, 20, 9 and 29% of the cost of PVC, polystyrene, polyacrylic, propylene and hard polyethylene, respectively.

The comparison of the energy requirement for newly proposed RBC disc material with others and ASP is given in Fig. 6.

Energy requirement is the major component of O and M cost of RBCs. It is obvious from Fig. 5 that the

Table 5
Comparison of newly proposed disc material with others

S. no.	Name of material	Thickness (mm)	Density (kg/m^3)	Cost/m^2 (PKR)
1	PVC	3	1,350	576
2	Polystyrene	3	1,050	200
3	Polyacrylic	3	1,200	450
4	Propylene	3	855	136
5	Hard polyethylene	3	915	136
6	Polyethylene foam	3	30	40

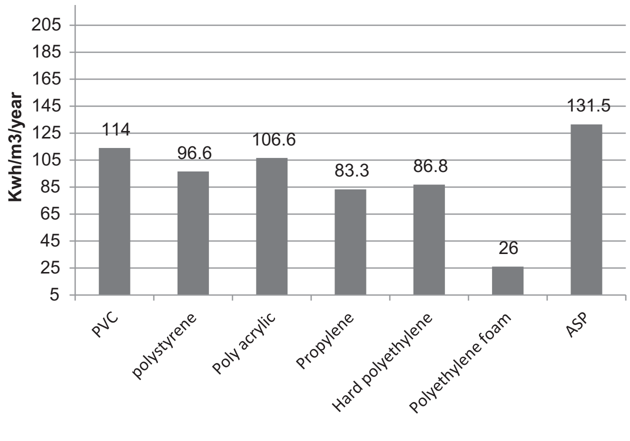

Fig. 6. Energy consumption for different RBC disc materials ASP.

energy requirement (kWh/m^3/year) for polyethylene foam discs is minimum due to its low density as compared to other materials and ASP. Energy requirement for RBC, using polystyrene as a disc material, is four times more as compared to RBC, using polyethylene foam. RBC energy requirement is less as compared to ASP [5,34,35]. ASP requires five times more energy when compared with RBC using polyethylene foam as disc material.

4. Conclusions

Submergence of discs and RPM affect the efficacy of RBC process. From the pilot plant study, the optimum values for submergence and RPM was found to be 40% and 5, respectively, for domestic wastewater. BOD and COD removal efficiency observed under optimum conditions was 85.7 and 67.6%, respectively; DO level was 4.6 mg/L; and effluent concentrations for BOD and COD were 42 mg/L and 124 mg/L, respectively, meeting NEQS. ANNOVA analysis revealed that both submergence and RPM are instrumental in changing DO levels; however, submergence plays more significant role when compared with RPM. New disc material tested, polyethylene foam, was found satisfactory. It is cheaper than all the previously used material. It is 80% cheaper than the conventional and most commonly used material, i.e. polystyrene. It uses less energy, being lighter than the conventionally used disc material. Energy requirement using new disc material, conventional material and ASP is 26, 96.6 and 131.5 Kwh/m^3/year, respectively. No wear and tear of material was found after a continuous run of 91 d. However, study with longer time period is suggested to evaluate the durability of the polyethylene foam as a disc material. Furthermore, the polyethylene foam-packed ring could be a feasible low-energy and cheap option.

Competing interest

The authors declare that they have no competing interests.

Authors' contributions

ST carried out literature review, construction of model, operation of model, and paper writing. SH suggested the methodology, guided about the construction and operation of model, reviewed the manuscript. GH reviewed the manuscript.

Acknowledgements

The funding for this research was provided by UET Taxila. The help of my undergraduate students; Salman Fakhar, Lauqman Akhtar, Bilal Ahmed Khan, Adeel Younus, Muhammad Ahmad, Abdul Sarmad and Bilal Tahir is acknowledged.

References

[1] B. Metcalf, G. Eddy, Wastewater Engineering: Treatment Disposal Reuse, Central Book Company, New Delhi, 1980.
[2] M. Rodgers, X.-M.Zhan, Moving-medium biofilm reactors, Rev. Environ. Sci. Biotechnol. 2 (2003) 213–224.
[3] D. Mba, R. Bannister, G. Findlay, Mechanical redesign of the rotating biological contactor, Water Res. 33 (1999) 3679–3688.
[4] F.A. Nasr, N.M. Badr, H.S. Doma, Industry wastewater management case study, Environmentalist 26 (2006) 31–39.
[5] S.E. Williams, Energy usage comparison between activated sludge treatment and rotating biological contactor treatment of municipal wastewater, 2012. Available from: <www.williams-works.com>.
[6] A. Tawfik, B.F. Klapwijk, F. El-Gohary, G. Lettinga, Treatment of anaerobically treated domestic wastewater using rotating biological contactor, Water Sci. Technol. 45 (2002) 371–376.
[7] S.H. Israni, S.S. Koli, A.W. Patwardhan, J.S. Melo, S.F. D'souza, Phenol degradation in rotating biological contactors, J. Chem. Technol. Biotechnol. 77 (2002) 1050–1057.
[8] G. Najafpour, H.A. Yieng, H. Younesi, A. Zinatizadeh, Effect of organic loading on performance of rotating biological contactors using palm oil mill effluents, Process Biochem. 40 (2005) 2879–2884
[9] P. Nahid, M. Vossoughi, I. Alemzadeh, Treatment of bakers yeast wastewater with a Biopack system, Process Biochem. 37 (2001) 447–451.
[10] A. Torkian, K. Alinejad, S. Hashemian, Posttreatment of upflow anaerobic sludge blanket-treated industrial wastewater by a rotating biological contactor, Water Environ. Res. (2003) 232–237

[11] C. Lu, H.-C. Li, L.Y. Lee, M.-R. Lin, Effects of disc rotational speed and submergence on the performance of an anaerobic rotating biological contactor, Environ. Int. 23 (1997) 253–263.
[12] O. Hanhan, D. Orhon, K. Krauth, B. Gnder, Evaluation of denitrification potential of rotating biological contactors for treatment of municipal wastewater, Water Sci. Technol. 51(2005) 131–139.
[13] T.A. Schwingle, A.J. Lepak, R.J. Wenta, Refining applications, Hydrocarbon Eng. (2005).
[14] P.A. Kadu, Y. Rao, Rotating biological contactors: A critical review, Int. J. Sci. Eng. Res. 3(9) (2012).
[15] G. Najafpour, A. Zinatizadeh, L. Lee, Performance of a three-stage aerobic RBC reactor in food canning wastewater treatment, Biochem. Eng. J, 30 (2006) 297–302.
[16] A. Gupta, S. Gupta, Simultaneous carbon and nitrogen removal from high strength domestic wastewater in an aerobic RBC biofilm, Water Res. 35 (2001) 1714–1722.
[17] P. Teixeira, R. Oliveira, Denitrification in a closed rotating biological contactor: Effect of disk submergence, Process Biochem. 37 (2001) 345–349.
[18] S. Sirianuntapiboon, C. Chuamkaew, Packed cage rotating biological contactor system for treatment of cyanide wastewater, Bioresour. Technology 98 (2007) 266–272.
[19] S. Cortez, P. Teixeira, R. Oliveira, M. Mota, Rotating biological contactors: A review on main factors affecting performance, Rev. Environ. Sci. Bio/Technol. 7 (2008) 155–172.
[20] P. Mathure, A. Patwardhan, Comparison of mass transfer efficiency in horizontal rotating packed beds and rotating biological contactors, J. Chem. Technol. Biotechnol. 80 (2005) 413–419.
[21] J. Ramsay, M. Shin, S. Wong, C. Goode, Amaranth decoloration by Trametes versicolor in a rotating biological contacting reactor, J. Ind. Microbiol. Biotechnol. 33 (2006) 791–795
[22] B.L. Brazil, Performance and operation of a rotating biological contactor in a tilapia recirculating aquaculture system, Aquacult. Eng. 34 (2006) 261–274.
[23] I. Alemzadeh, M. Vossoughi, Biodegradation of toluene by an attached biofilm in a rotating biological contactor, Process Biochem. 36 (2001) 707–711.
[24] S.S. Enayathali, V. Nehru Kumar, Effect of rotational speed of blades for treating grey water in rotating biological contactors, Int. J. Eng. Res. Appl. 2(3) (2012) 2294–2297. Available from: <www.ijera.com>.
[25] A.A. Wef, Standard Methods for the Examination of Water and Wastewater, Washington, DC, 1998.
[26] R. Su, G. Zhang, P. Wang, S. Li, R.M. Ravenelle, J.C. Crittenden, Treatment of antibiotic pharmaceutical wastewater using a rotating biological contactor, J. Chem. 2015 (2015) 8 pp., Article ID 705275. Available from: <http://dx.doi.org/10.1155/2015/705275>.
[27] D.N. Hiras, I.D. Manariotis, S.G. Grigoropoulos, Organic and nitrogen removal in a two-stage rotating biological contactor treating municipal wastewater, Bioresour. Technol. 93 (2004) 91–98.
[28] D. El Monayeri, N. Atta, D. Ahmed, S. Daif, Performance of self-rotating discs in Wastewater Treatment, J. Am. Sci. 9 (2013) 45–50.
[29] P. Griffin, G. Findlay, Process and engineering improvements to rotating biological contactor design, Water Sci. Technol. 41 (2000) 137–144.
[30] J.N. Hochheimer, F. Wheaton, Biological filters: Trickling and RBC design, in: Proceedings of the Second International Conference on Recirculating Aquaculture, Roanoke, VA, 1998, pp. 16–19.
[31] A. Tawfik, H. Temmink, G. Zeeman, B. Klapwijk, Sewage treatment in a rotating biological contactor (RBC) system, Water, Air, Soil Pollut. 175 (2006) 275–289.
[32] A.A. Pathan, R.B. Mahar, K. Ansari, Preliminary study of greywater treatment through rotating biological contactor, Mehran Univ. Res. J. Eng. Technol. 30 (2011) 531–538.
[33] G. Coetzee, L. Malandra, G. Wolfaardt, M. Viljoen-Bloom, Dynamics of a microbial biofilm in a rotating biological contactor for the treatment of winery effluent, Water SA 30 (2004) 407–412.
[34] B.K. Sovacool, K.E. Sovacool, Identifying future electricity–water tradeoffs in the United States, Energy Policy 37 (2009) 2763–2773.
[35] C.W. King, A.S. Holman, M.E. Webber, Thirst for energy, Nat. Geosci. 1 (2008) 283–286.