Performance of Self-Rotating Discs in Wastewater Treatment

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Abstract: The rotating biological contactor process offers the specific advantages of a biofilm system in treatment of wastewater for removal of soluble organic substances. It is a unique adaptation of the moving-medium biofilm system which facilitates easy and effective oxygen transfer. Two steel channels were constructed on the concrete sump of primary treated wastewater in El-Asloagy WWTP with self-rotating discs in order to investigate the performance of self-rotating discs in wastewater treatment. These discs were freely rotate under the effect of hydraulic discharge of water in the channel without any mechanical power. The effect of flow rates and number of stages of self-rotating discs with the variation of organic loads were assessed, COD removal ratio and DO were assessments tools. Self-rotating disc 230 mm in diameter and five numbers of discs per stage applied in the present study with 35% of disc submergence, with UPVC as a structural discs material. Flow rates ranged (5.5, 6.35, 7.23 and 8.16 l/s) were studied. The highest percentage of COD removal ratio achieved at discharge 8.16 l/s. different number of stages were studied in addition to a front disc at the dropping point of the channel weir. Highest value of COD removal ratio achieved (54.44%) at five stages. Results indicated that, COD removal rate increased from 28.22 to 43.2 kg /m^2.d when COD loading rate increased from 51.85 to 259.25 kg/m^2.d, while COD removal ratio decreased from 54,44% to 16.66 % at the same COD loading rate. Moreover the dissolved oxygen level (DO) increased from (zero, 0.9 mg/l) to (1.5, 2.0 mg/l) respectively. The determination of the number of stages necessary to accomplish a required degree of treatment, as well as determining the effect of each stage on the total treatment scheme, however, requires a stage-by-stage analysis of the RBC. Experimental results of the present study were used for adaptation of RBC mathematical model. Kinetic coefficients constant were estimated. The determinations of the amount of substrate removed per day per unit surface area of each disc which referred to the area capacity constant (P) and the amount of substrate removed per unit surface area of each disc which defined as the removal coefficient (R) were made.

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Keywords: Rotating biological contactors (RBC), wastewater treatment, selfrotating disc, organic load, Flow rate.

1.Introduction

The rotating biological contactor (RBC) has been used for many years in Europe, particularly in Germany, for the treatment of domestic and industrial wastewaters. RBC consists, in essence, of a series of closely spaced discs anchored to a shaft which is supported above the surface of the wastewater. The lower portion of each disc extends into the wastewater, while the upper portion of the disc rotates in the atmosphere. Thus a unit area of biological slime is alternately submerged to absorb nutrients from the wastewater and raised out of the liquid to oxidize the absorbed nutrients as well as maintain dissolved oxygen in the wastewater stream (Clark *et al.,* 1978). Self-rotating discs were used in the present study, which used discharging flow of water for rotating of the discs (without any mechanical power). Chen *et al.,* 2006 studied simultaneous removal of carbon and nitrogen from wastewater using net-like rotating biological contactor (NRBC). Three stages were used; their results indicated that, COD removal ratio increased from 47.4% to78.8 %, when number of stages increased from one stage to three stages. Ismail, 2008, increased self-purification efficiency (COD removal ratio and dissolved oxygen concentration) of water streams (Bilbies stream) in Egypt using self rotating discs (RBC). Elmonayeri*et al.,*2012, studied oxygen transfer in self rotating biological contactors (SRBC), they studied the effect of material/configuration of rips, flow rates, % of disc submergence and reactors size on revolution per minute (rpm) and oxygen transfer coefficient (K_La) of this new form of self-RBC discs. Elmonayeri *et al.,* 2012, studied oxygen modeling of this new form of self-RBC discs, they established self-RBC oxygen model based on dimensional analysis by performing non-linear regression for 45 runs of the experimental values of their study. They also estimated non-dimensional rpm formula as a function of flow rate, diameter and area of disc, working volume, area of tank and immersion factor. At this study, flow rate and number of stages which affecting degree of wastewater treatment were assessed. Adaptation of RBC mathematical model on the freely rotating disc was conducted in the present study. The objective of the model is the prediction of organic loading rate corresponding to maximum removal capacity of the system. A system of equations was solved where the influent substrate concentration and hydraulic loading rates were the main variables. Experimental results of the present study were used in determining the fitting parameters which can be used to design an RBC wastewater treatment system. This aims to achieve the goal of predicting the amount of substrate removed per day per unit surface area of disc which will be referred to the area capacity constant P and the Monod half-velocity coefficient K_s.

2. Materials and methods

The experimental work was carried out in two steel channels constructed in the wastewater treatment plant of El-Asloagy, Zagazig, Sharqia Governorate, Egypt. **Photo (1)** shows the installation of the used self-rotating RBC reactors in the channel. **Figure (1)** shows schematic representation of the two channels relative to the concrete sump of primary treated wastewater. Each channel is 3.0m long in length, 0.40m width and 0.12m of water depth, having upstream and downstream chambers with dimensions of 0.5x0.5x0.6 m. Initially, one submerged pump (maximum power 2.0 HP) was used to raise wastewater to the two channels. One of them for self-rotating discs and the other for overflow condition. Primary treated wastewater was pumped to the channels. **Table 1** shows primary treated wastewater characteristics. Self rotating disc used in this study were fabricated from UPVC as a structural material. **Table 2** shows information related to self rotating disc. Each RBC unit contains five circular discs (230 mm) in diameter and four ribs (1.2) mm thick, 100 mm wide and 270 mm long connected inside disc. Each self-RBC disc contains four ribs as optimized by previous study(Elmonayeri*et al.,* 2009).

Photo 1: Installation of self-RBC discs on the channel

3. Experimental program

Experimental program has been designed as shown in **tables 3 and 4**. Two runs were conducted in the present study based on selecting two major factors that affect COD removal efficiency and dissolved oxygen concentration, which were considered as the main assessment tools. The first run included four cases with the variation of flow rates at four stages (using the average possible value of the experimental setup). The second run included three cases considering the optimum flow rate resulting from the previous (first) run at different number of stages mainly, three, four and five.

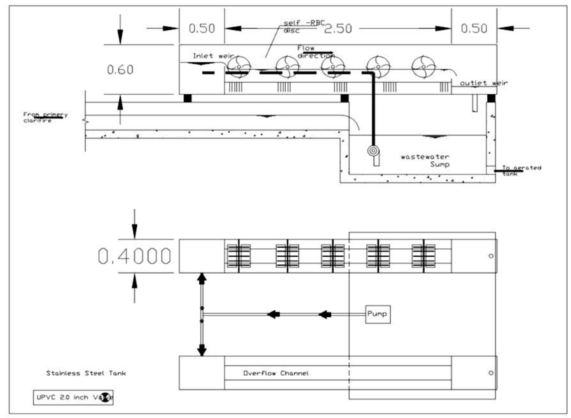

Fig. 1. Schematic representation of the two pilot channels

Table 1: Physical and chemical properties of primary treated wastewater in El-Asloagy WWTP

Parameter	Range
COD	250 - 1000 mg/l
BOD	200 – 350 mg/l
TSS	300 – 400 mg/l
DO	0 – 0.9 mg/l
TDS	750 – 1050 mg/l
PH	7.12 – 7.4
Water temperature	21– 28 ^{o} c

Table 2: Self-RBC disc characteristics

RBC specification	Range
Diameter of disc (mm)	230
No of discs/stage	5.0
Spacing between discs (mm)	54.0
Total surface area /stage (m^2)	0.979
Width of ribs (mm)	100

Table 3: First run conditions for current study

Parameter	Range
COD	250 - 1000 mg/l
BOD	200 – 350 mg/l
TSS	300 – 400 mg/l
DO	0 – 0.9 mg/l
TDS	750 – 1050 mg/l
PH	7.12 – 7.4
Water temperature	21– 28 ^{o} c

Table 4: Second run conditions for current study

cases	Flow rates (Q) l/s	Number of stages
Case no 1	optimum flow rate obtained from first run	3.0
Case no 2		4.0
Case no 3		5.0

After installation of the self-RBC discs along the channel, the formation of the biofilm on RBC discs was observed after three days of operating the model.

Wastewater was allowed to flow through the self rotating discs for 10 days as a start up period to develop the biofilm. During the study, samples were collected following inlet weir and in between each disc in addition to the outlet point.

4. Results and discussion

During this study, the used RBC units were fixed on the channel and immersed in the wastewater by 35% of their total surface area. In order to increase the total biomass area of the self-RBC discs, UPVC granules were pasted on the surface of plastic discs, this aimed to supply a large area for biomass accumulation, and causes turbulence near the interface of bulk liquid to facilitate efficient mass / oxygen transfer**.**

4.1. Effect of flow rates on % of COD removal ratio

Collected water samples were filtered using paper filters before analysis in order to avoid sloughing action of self-RBC discs which produced an increase of suspended solids concentration.

Figure 2 illustrates flow rates versus % of COD removal ratio. Results indicated that, with the increased of flow rates from 5.5 l/s to 8.16 l/s, % of COD removal increased from 13.86 % to 37.82 %.

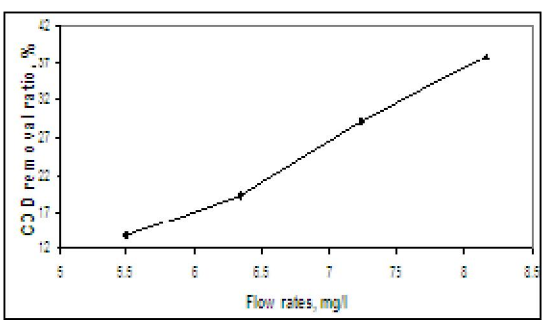

Fig. 2. Flow rates versus %, COD removal ratio at first run.

Mechanism of self-RBC reactor allows rotation to occur due to hydraulic contact of discharged water with ribs at RBC surfaces. Degree of rotation depends upon the velocity of water and is affected by the variation of flow rate. Increase of flow rates increase the number of revolution per minute and the turbulence. Increase of turbulence thus increases the dissolved oxygen concentration consequently COD removal ratio increases.

Ismail, 2008 studied the effect of flow rates on COD removal efficiency. Results of the first phase indicated that, COD removal efficiency increased with increased flow rate from 20 to 30 l/s. This complies with the results of the present study. In the conventional use of RBCs in the sewage treatment, these rotate with mechanical power which occurred due to the revolution of motor. Chan and Stnstrom, 1979, used 7.0 rpm,Chen *et al.,*2006**,** used 5.0rpm.

4.2. Effect of number of stages on the performance of self-rotating discs (sRBC)

Figure 3 illustrates results concerning COD removal for the second run.

Results indicated that COD removal ratio increased from 37.82 to 54.44% with the increased of number of stages from three to five stages respectively.

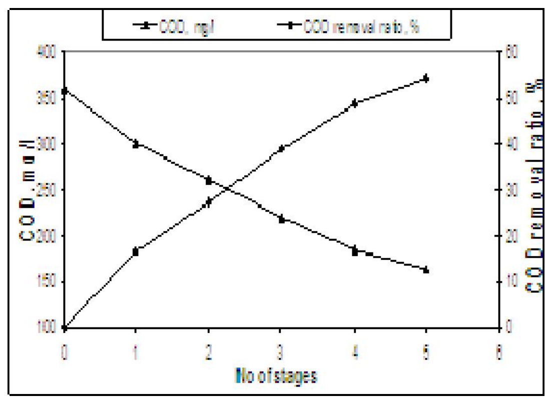

Fig. 3. Effect of number of stages on COD removal ratio.

This may be attributed to that; each stage of self-RBC discs is really a separate filter which acts as secondary treatment unit where the increase of number of stages achieved more surface area. These results comply with the previous studies of many investigators such as, Chan and Stnstrom, 1979 who used four stages RBC units. Results indicated also that COD concentration decreased gradually with the increase of number of stages; also in agreement with Ayoub and Saikaly, 2004 who applied three stage RBC units. Results produced COD concentration (635, 117, 107 mg/l) with three stages respectively, where as the influent concentration were 1200 mg/l. Results of the present study also comply with the results of Elmonayeri*et al.,*2009 where used self-RBC discs in enhancement of self-purification of water streams, their results indicated that, COD removal achieved 65.32% at ten number of stages. Chen *et al.,*2006 used three stage of RBC, their results indicated that COD removal ratio increased from 47.4% to 78.8% by increasing the number of stage from one stage to three stage.

4.3. Effect of number of stages on dissolved oxygen concentration

Figure 4 illustrates relation between number of stages and the concentration of dissolved oxygen (DO) at the studied two runs. Results indicated that dissolved oxygen concentration increased with the increase of number of stages. Each stage acts as an aerator in the self-RBC channel. Degree of rotation of each stage depends upon the velocity of water. It should be noticed that, as the rotational speed of self-RBC discs increased turbulence and then, the aeration increased. In which the front stage has a higher rotational speed of self-RBC disc. Hence the dissolved oxygen concentration and oxygen transfer increase.

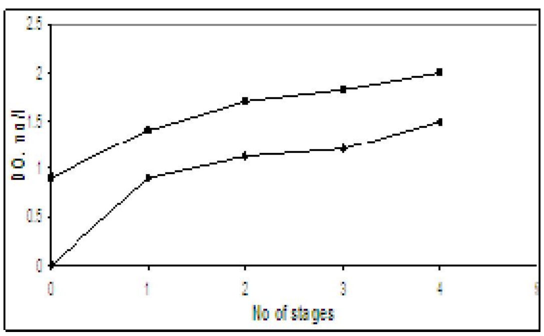

Fig. 4. No of stages versus dissolved oxygen concentration at first and second runs.

This result agreed with,Surampalli*et al.,*1994 that usedfour stage RBC units. Results indicated that, dissolved oxygen after each stage were (4.0 mg/l) /stage one, (5.0 mg/l) /stage two, (8.2 mg/l) /stage three, and (9.3 mg/l) /stage four. Also this complies withAyoub and Saikaly, 2004; who's applied three stages of RBC units. Their results indicated that, dissolved oxygen concentrations (DO) increased from 1.65, 2.10 to 5.8 mg/l, with the three stages respectively. Ismail, 2008 used self-RBC discs in enhancement of stream self-purification. Results indicated that, dissolved oxygen concentration increased with the increase of number of stages.

4.4. Effect of COD loading rates on the performance of self-rotating discs

Figures 5 and 6 illustrate relation between COD loading rates versus removal efficiency of COD (removal rate, (kg/m^2.d) and removal ratio, %) for first and second runs respectively. At first run, results indicated that, COD removal rate increased from 18.18 to 26.64 kg/m^2.d when COD loading rate increased from 48.06 to 192.27 kg/m^2.d, and COD removal ratio decreased from 34.82% to 13.85%. On the other hand, COD removal rate increased from 28.22 to 43.2 kg/m^2.d when COD loading rate increased from 51.85 to 259.25 kg/m^2.d, and COD removal ratio decreased from 54,44% to 16.66 % at second run. Results indicated that, when COD loading rate increased, COD removal rate increased and COD removal ratio decreased.

This reduction in COD was an indication of insufficient elimination capacity, and referred to the limitation in oxygen mass transfer and disc surface area of attached microorganisms. Results of the present study comply with many researchers such asGupta and Gupta, 2001.

Removal ratio and COD removal rate (second run).

Theystated that, "when COD loading rate increased from 10.0 to 32.0 g /m^2.d, COD removal rate increased from 8.7 to 25.9 g/m^2.d", and also, Nahid*et al.,*2001 who used Biopack (RBC) system. Results indicated that, when the surface organic loading of COD increased from 629.2 to 1030.4 g/m^2.d, this resulted in a decreased of the efficiency percentage of COD removal from 94.9% to 77.4%. This also complies with the results of Elmonayerie*et al.,*2009, when applied self-RBC discs in wastewater treatment in streams. Results indicated that, COD removal rate increased from 0.09 to 12.37 kg/m^2.d when COD loading rate increased from 5.225 to 28.52 kg/m^2.d, and COD removal ratio decreased from 65.32% to 44.6%.

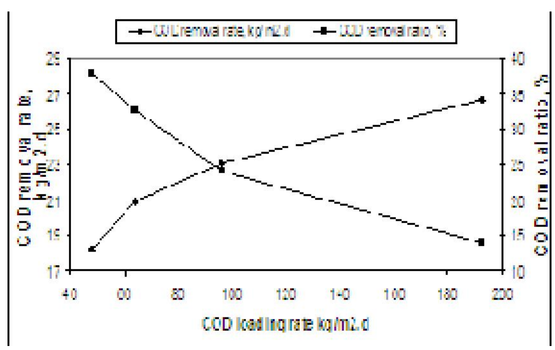

Fig. 5. Effect of COD loading rate on, % of COD removal ratio and COD removal rate (first run).

5. Applicable Rbc Models

A mathematical model developed by Grieves, 1972 was tested by Torpey*et al.*(1974) using the data from a ten-stage pilot plant. The model used depth of submergence, disc rotational speed, and disc area as parameters and was developed by making mass balances on substrates in the liquid film, in the organism film beneath the liquid film, in the organism film submerged in the bulk liquid, and in the completely mixed reactor.

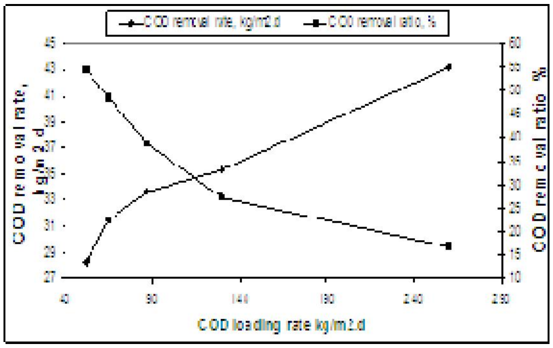

Fig. 6. Effect of COD loading rate on, % of COD

Williamson and McCarty, 1976 developed and tested a mathematical model in which substrate utilization within biofilms was described as a process of molecular diffusion with simultaneous biochemical reactions. The model is straightforward and easily applicable to the present pilot-plant study. Clark *et al.,*1978 applied some modifications to the model where complete mixing in the liquid volume is assumed because of the intensity of mixing in each RBC stage, and organism decay is neglected because the decay rate is small compared to the growth rate. Therefore, the mathematical expression can be written as

$V\,(ds/dt) = (FS_0 - FS_1) - (\mu_a/Y_a)\,A_wX_a - (\mu_s/Y_s)\,X_s\,V$ ----- (1)

Where:-

V = liquid volume in the reactor (m^3)

ds/dt = change of substrate concentration with respect to time (mg/l.s)

F = wastewater flow rate (1/s)

S_0 = influent substrate concentration (mg/1)

S_1= effluent substrate concentration (mg/1)

μ_a = specific growth rate of the attached biomass/day

Y_a= apparent yield of the attached biomass (kg biomass produced/ kg substrate consumed)

A_w = wetted area of biodisc (m^2)

X_a= mass of attached active biomass per unit area of biodisc (g/m^2)

μ_s = specific growth rate of the suspended organisms/day

Y_s= apparent yield of suspended organisms (kg biomass produced/ kg substrate consumed)

X_s= concentration of suspended organisms (mg/1)

The consumption of substrate due to the suspended growth can be neglected, and thus the previous equation is simplified to

$V\,(ds/dt) = FS_0 - FS_1 - (\mu_a/Y_a)\,A_wX_a$ ---------- (2)

Using the Monod growth function in the form of

$\mu_a = \mu_{max}\,[S_1/(K_s+S_1)]$ -------------------------- (3)

μ_{max} = maximum specific growth rate for the attached biomass/day

K_s = the Monod half-velocity coefficient (mg/1)

The previous equation becomes

$V\,(ds/dt) = FS_0 - FS_1 - (\mu_{max}/Y_a)\,A_wX_a\,[S_1/(K_s+S_1)]$ ------ (4)

The consolidated parameters, $(\mu_{max}/Y_a)\,X_a$ in Equation 4, give the amount of substrate removed per day per unit surface area of disc, and will be referred to as the area capacity constant, P. The term $[F\,(S_0 - S_1)]\,/\,A_w$ gives the amount of substrate removed per unit surface area of each disc, and is defined as the removal coefficient, R. At a steady-state condition, ds/dt is zero, and Equation 4 can be written as

$(1/R) = (K_s/P)\,(1/S_1) + (1/P)$ ---------- (5)

Which plots as a straight line with a slope of K_s/P and intercept of 1/P when $1/S_1$ is plotted against 1/R. This gives a method of evaluating K_s and P for the attached biomass on the disc for each stage.

6. Application To Design

By performing linear regression on the experimental results of the present study which varied in flow rates (5.5, 6.35, 7.23 and 8.16 l/s) and number of stages (3, 4 and 5) with the variation in organic loads, fitting parameters estimated as shown in **table 5. Figure 7** shows the actual data points for the entire system stages 1, 2, 3 and 4 based on the results of the present study.

Table 5: Best estimation of area capacity constant, P, Monod half-velocity coefficient, Ks, for the four stages

Stages	P,(m^3/m^2.d)(mg/l)	Ks, mg/l
Stage 1	31.05	405.49
Stage 2	17.73	369.13
Stage 3	19.92	427.23
Stage 4	8.16	279

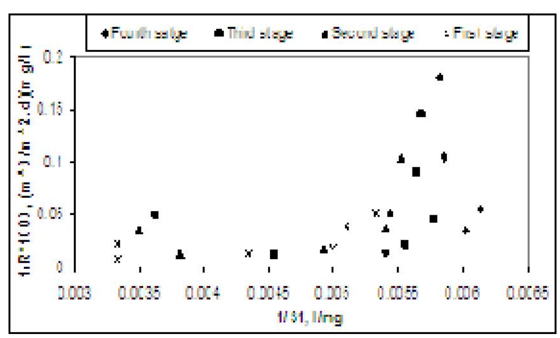

Fig. 7. Four stages data based on the experimental results in the present study

The kinetic model can be applied in design to determine the disc surface area required for a necessary degree of wastewater treatment of RBC system. The previous equation estimated for each stage as,

For stage one,

$A_w / [F (S_0 - S_1)] = (405.49 / 31.05) (1/ S_1) + (1/ 31.05)$

For stage two,

$A_w / [F (S_0 - S_1)] = (369.13 / 17.73) (1/ S_1) + (1/ 17.73)$

For stage three,

$A_w / [F (S_0 - S_1)] = (427.23 / 19.92) (1/ S_1) + (1/ 19.92)$

For stage four,

$A_w / [F (S_0 - S_1)] = (279 / 8.16) (1/ S_1) + (1/ 8.16)$

Based on the literature, apparent yield of the attached biomass (kg biomass produced/ kg substrate consumed) $Y_a$were, (0.96) and mass of attached active biomass per unit area of biodisc (g/m^2), X_a(35863, 30594, 24403 and 9851.8 mg/(m^2) for the four stages respectively (Clark et al, 1978), maximum specific growth rate for the attached biomass/day (μ_{max}, day^{-1}) calculated were, μ_{max} for stage 1(0.831 day^{-1}), stage 2 (0.5563 day^{-1}), stage 3 (0.7836 day^{-1}) and for stage 4 (0.7951 day^{-1}).

7. Conclusions

Based on the current study and its described conditions, the following conclusions can be demonstrated:

- COD removal ratio increase with the increase of number of stages, where COD removal ratio achieved 54.44% with five stages of self rotating discs.
- COD removal rate increased from 28.22 to 43.2 kg/m^2.d when COD loading rate increased from 51.85 to 259.25 kg/m^2.d, and COD removal ratio decreased from 54,44% to 16.66 %.
- Dissolved oxygen level (DO) increased from (zero, 0.9 mg/l) to (1.5, 2.0 mg/l).
- Flow rate, 8.16 l/s achieved high value of COD removal efficiency
- The present study shows how the kinetic model can be used to design self-rotating discs in wastewater treatment system under a steady state condition using pilot-plant data.

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