Treatment of Industrial Waste Water using Single-Stage Rotating Biological Contactor

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Abstract. This paper presents treatment of industrial waste water using a single-stage Rotating Biological contactor (RBC). A RBC unit typically consists of a series of closely spaced large flat or corrugated discs that are mounted on a common horizontal shaft and are partially or completely submerged in wastewater. The shaft continually rotates by a mechanical motor or a compressed air drive and a bio film is established onto the entire surface area of the media, which metabolizes the organic materials contained in the wastewater. Microorganisms get attached to and grow on these discs. The discs mounted on the surface of a rotating shaft are usually made up of different forms of plastic such as polypropylene or polyurethane. For this study, shaft of RBC is wrapped with polypropylene foam as bio-film medium. From the analysis of results obtained for the present study it has been found that, polypropylene foam as a bio-media can remove organic matter up to 91.2%, nitrate up to 86.2% and phosphate up to 96.3% for 48 hr of hydraulic retention time.

1. Introduction
Industrialization played an important role for scio-economy of the country. Generally, a lot of wastewater are generated from industries due operational processes. Biological processes are best suited for the treatment of effluents that are rich in nutrients, and using these processes, 80–95% reduction in the effluent organic matter can be achieved. Amongst the biological processes, attached growth wastewater treatment processes have shown to be more energy efficient than suspended growth processes. Rotating Biological Contactor (RBC) is one of the attached growth processes. These processes can be carried out aerobically as well as anaerobically. Aerobic rotating biological contactors (RBC) comprise closely spaced circular discs mounted on a rotating shaft. Microorganisms get attached to and grow on these discs. They have been found to be twice more efficient in treating domestic as well as industrial wastewater as compared to the suspended growth. Advantages of using aerobic RBC include short hydraulic retention time (HRT), high biomass concentration, high specific surface area, low energy consumption, operational simplicity, insensitivity to toxic substrate, less accumulation of sloughed bio film and partial stir. Efficiency of the RBC, however, gets affected by various factors such as loading rate, rotational speed, HRT, staging, temperature and disc submergence. A RBC unit typically consists of a series of closely spaced large flat or corrugated discs that are mounted on a common horizontal shaft and are partially or completely submerged in wastewater. A drum filled with some lightweight packed supports can also be used in place of conventional discs. The shaft continually rotates.
by a mechanical motor or a compressed air drive and a bio film is established onto the entire surface area of the media, which metabolizes the organic materials contained in the wastewater. Researcher M. Wallis et. al (2000) [1] had studied the capacity of the bio-film of a 3-stage rotating biological contactor (RBC) for the treatment of wastewater containing cadmium, copper, and zinc. The system effectively removed the metals, in the order Cu > Zn > Cd with removal capacities of 73, 42 and 33% respectively. Vinaíge et.al (2003) [2] studied a lab-scale RBC model and the author has found out that, the rotational speed of shaft plays a vital important role in enhancing the overall performance of RBC. The author had developed a mathematical model of RBC and compared the output with the experimental data obtained. It is found out to be very effective for organic matter removal. Saikaly P. et.al (2003) [3] developed a lab-scale three stage RBC model for studying its effectiveness for the removal of ammonical nitrogen (NH3-N). The step-feed method was adopted for the above experiment and the results obtained were compared with the results of regular-fed RBC model in terms of ammonical nitrogen removal, dissolved oxygen conditions, and HLR and OLR. The result analysis indicates that the step-feed unit has better removal efficiency than the regular-fed one. The percentage of NH3-N removals in the RBC batch-feed stages 2 and 3 were higher than those of the RBC control although the OLR was higher at the RBC step-feed stages and the DO concentrations were found out to be lower. The existence of greater influential NH3-N concentrations in step-feed RBC stages two and three is the main reason for the higher removal percentages. A Tawfik et. al. (2006) [4] conducted an experimental investigation on the treatment of domestic wastewater in the RBC system at a temperature of 12-24 °C. The RBC set-up consisted of a series connected 2-stage system. The prototype was operated at different OLR and HRT to get the best performance of RBC under varying conditions. An increase of 11 g/m2/d in OLR was observed. The effluent quality of soluble COD, however, remains unchanged. Most of the COD was removed in the first stage and in the second stage, nitrification took place. Saikaly P. et. al (2006) [5] proposed and explains the design of a rotating biological system on a lab-scale. To determine design parameters, RBC design criteria were identified and implemented. Locally available stainless steel and polyethylene pipes were used for the fabrication of the model. The designed RBC’s performance proves adequate for the industrial purpose. There was an average rate of loading and removal. Increases in ammonia concentrations improved removal efficiency up to 3.75 mg/l ammonia, after which removal efficiency remained about 40%. Syed E. et., al (2008) [6] conducted a test on a two-stage Rotating Biological Contactor (RBC) laboratory model with provision for varying rotating blade speeds. Gray wastewater was taken for the analysis. The experiment was performed for different COD loadings and varying blade speeds. From the result analysis, it was found out that 3rpm speed gives maximum COD removal that is, 95.07% as compared to the 4.5 and 6rpm speed that is, 95.04% and 94.96% removal efficiencies respectively. A. Ebrahimi and M. Asadi (2008) [7] had analyzed a three-stage RBC system for the removal of organic content from whey. The analysis was done under different detention periods such as 8h, 16h, 24h, and 36h and also under varying disc surface area. The acrylic sheets were used as disc material and submergence of 33% was kept during the experiment. The treated effluent was analyzed for COD, TS, VS, Phosphate, pH, and proteins. From the result analysis, it was found out that, the COD removal efficiency was 80 and 83% at the detention period of 16 and 24h respectively and at HRT 36h the removal efficiency was increased to 92%. The COD removal efficiency was increased to 96% when the disc surface area was increased by 10%. Dolores et, al (2009) [8] conducted the technology of set biomass, and bio disk, for sewage treatment in big and medium-sized reactors. The structure of bio-films and the interaction of microorganisms were vital parameters for effective system function and regulate. Bio-film size and complete dry weight were commonly used for characterizing bio-films but were not enough to define bio-film pattern. The availability of nutrients in the bio-film is one of the controlling parameters for the effectiveness of bio-film. So it is better to develop a small, stable and active bio-film for getting the best treatment of water and sewage. Joanna Rodziewicz et. al (2010) [9] had prepared a lab-scale RBC model and conducted the research under both conventional conditions (without current) and under different current flow conditions such as 0.2A, 0.8A, and 1.5A. The results were analyzed for organic content and ammonical nitrogen on municipal wastewater. The highest nitrogen removal efficiency was observed with the passage of electrical current.
at a density of 0.2A. The system was found out to be 64% efficient for denitrification and 93.4% efficient in nitrification. Kapoor et al. (2011) [10], they researched the common use of RBC technology for municipal and industrial effluent therapy. In the mining sector, RBCs have also been used effectively to remove pollutants such as ferrous iron (Fe2+), cyanide and its different species, oxalate, and selenium from mining waste effluents. This article represents the result of two continuing study projects being conducted at Natural Resources Canada's Mining and Mineral Sciences Laboratory. Using a three-stage RBC, the research efficiently oxidized Fe2+ to Fe3+ at 80C. Oxidation levels of Fe2+ varying from 63.0 g to 146.0 g Fe2+/m2/day were noted under different flow rates, temperature, and Fe2+ concentration working circumstances. Kader et. al. (2011) [11], had developed a mathematical model to analyze RBC’s capacity to treat grey water. The whole setup was consisting of three units such as the RBC unit, settling tank unit, disinfection tank unit. After the optimization of the RBC model, three different gray water batches were prepared for the treatment such as low, medium and high levels of gray water. Using the data obtained from the mathematical model the lab scale set-up was done. The result analysis showed that the removal efficiency of BOD was between 93 to 96% and TSS removal was between 84 to 95%. Pathan et al. (2011) [12], Grey water’s features differ from nation to nation and depend on the respective country's cultural and social behaviour. The grey water had to be characterized and recycled considerably. Grey water has been isolated from black water in this respect and analyzed for different physiochemical parameters. RBC (Rotating Biological Contactor) is a more efficient therapy method for COD (Chemical Oxygen Demand) removal and organic matter removal, among numerous grey water recycling treatment techniques. But in Pakistan, this technology has not been implemented and tested. Before implementing on a mass scale, there was a considerable need to measure the effectiveness of the RBC technology for small scale greywater recycling. A single-stage RBC reactor was fabricated for the treatment of grey water in the laboratory. The rotational speed of simulator was 1.70 rpm. The RBC's disk region was submerged in the grey water by about 40%. At each HRT (Hydraulic Retention Time) water specimens were gathered and analyzed using conventional techniques for parameters such as “pH, conductivity, TDS (Total Dissolved Solids), salinity, BOD5, COD, and suspended solids”. The findings are encouraging with 53% and 60% removal of BOD5 and COD respectively. Kadu et. al (2013) [13], the author had analyzed the effectiveness of the RBC unit for the removal of soluble biodegradable substances from wastewater. The result analysis showed that the RBC successfully removes BOD up to 89.8% and a COD removal up to 80% had been achieved. The TSS removal rate was found out as nearly 80. Jayamala and Nitin A. Deshpande (2016) [14], had developed a partially submerged three stage rotating biological contactor for treatment of sewage. The RBC model was operated at a speed of 6 rpm and the effluent was tested for BOD removal efficiency. The results obtained, showed a BOD removal of 98.32% and indicated that rotating biological Contactors can treat organic and inorganic waste efficiently, cost-effectively and effectively. Rana et. al [15] had researched the removal of phenol from the industrial wastewater by using the RBC system. Parameters such as the concentration of mixed liquor suspended solids (MLSS), original phenol concentration, hydraulic retention time (HRT), disk submergence, rotation per minute (RPM) were optimized to improve the efficiency of phenol removal. The test result showed that, when synthetic wastewater containing 1g/l C6H12O6 and 250g/l phenol was treated through the reactor with 40% disc submergence, 30rpm rotational speed and 14h retention time, more than 56% phenol removal was achieved.

From the detailed study on previous work done it has been clear that the RBC system is very effective for the treatment of wastewater containing of organic waste products. The shaft rotational speed plays a very important role in achieving the best removal efficiency. Other important parameters that influence the overall performance of RBC are the detention period, bio-film material, percentage of submergence, and availability of oxygen for the microorganisms. From the above study, it also has been clear that the shaft rotational speed of 2-6rpm and submergence of 35-45% gives the optimum removal efficiency. As few research has been carried out on bio-film materials that are naturally available, so for this project polypropylene has been considered as a bio-film medium. The wastewater has been treated separately in batches by using both polypropylene as bio-film medium.
2. Details of Experimentation

2.1. Methodology
A prototype of single-stage RBC reactor was fabricated and the whole assembly consists of different parts such as reactor, rotating shaft, motor for rotation of the shaft, cylinder for placing the media profile, media profiles, pulley for achieving the required rotational speed and stand for supporting the whole set-up. The properties of the lab-scale model are tabulated below

Table 1. Properties of reactor

| Specification                        | Values                             |
|--------------------------------------|------------------------------------|
| Number of stages                     | 1                                  |
| The diameter of the central cylinder | 0.0762 m                           |
| Length of the central cylinder       | 0.3048 m                           |
| The total surface area of the central cylinder in use | 0.14 m² |
| Working volume of the reactor        | 22.5 litre                         |
| Number of pulleys                    | 2 (used for controlling the rotational speed) |
| Media profile and its thickness      | Polyurethane foam with 4mm thickness |
| Rotation per minute                  | 4 rpm                              |
| Submergence (%)                      | 43%                                |
| Motor used                           | One single phase induction motor   |

2.2. Properties of polypropylene foam
This is otherwise called as biochemical sponge. This is a porous material and very flexible in nature and provides the breeding ground for the cultivation of fine nitro bacteria. This foam can be reused after every set of treatment up to approximately six months and is easily available in the market. It is very economical in nature.

Figure 1. Polypropylene foam

Figure 2. RBC set-up
2.3 Working principle of the reactor
The reactor works on the principle of the attached growth system. The central cylinder has been wrapped up with the media profile. The central cylinder was kept 43% submerged throughout the experiment and the rotation of the cylinder with media profile was kept at 4rpm. The rotation was achieved by the setup of two pulleys and a single phase motor.

2.4 Mechanism
When the central cylinder with active bio-film in 43% submerged state rotates at 4rpm speed through the wastewater, the active bacteria present in the bio-film consume the organic matter as their food and grows in presence of nutrients thereby leaving the wastewater-free from organic loading and excessive nutrient. The rotation helps in oxygen transfer to the microbes which help for their growth. When the organic matter is subjected to degradation in the presence of oxygen, then carbon dioxide, water, and nutrients are released and new cells are formed. If the bio-film layer is brown in colour then the microbes present are healthy and if the colour is grey, then they are unhealthy in nature.

3. Reactor operation
3.1 Acclimatization
Before processing the synthetic wastewater through the reactor, the reactor was subjected to acclimatization. It is the process by which the microorganism grows on the media surface to form an active layer of bio-film. The reactor was supplied with tap water, glucose, cow dung (20%) and drain water (10%) for this purpose. The acclimatization was done for 5days. After the formation of active bio-layer, the water present in the reactor was released and the prepared synthetic wastewater samples were supplied to the reactor for treatment in batches one after another.

![Figure 3. Processing of waste water through the reactor](image)

All total of five batches of synthetic wastewater was processed through the reactor. The sample waters were collected at an interval of 1h, 3h, 8h, 24h and 48h for each batch separately. The reactor was constantly in running state up to 8h and after that, the wastewater was left for settling and the sample water was collected in 48h. The water samples were then tested for various parameters such as COD, nitrate and organic content, phosphate, ammonia, pH, and TDS. Then that batch wastewater was released from the reactor and the reactor was provided with the next batch of synthetic wastewater and so on. The procedure has been followed for the media profiles such as polypropylene. When all the five batches were processed by using polypropylene as bio-media, the polypropylene media was taken out.

3.2. Characterization of synthetic waste water
The synthetic wastewater was prepared by using chemicals such as glucose (C6H12O6), potassium dihydrogen phosphate (KH2PO4), and potassium nitrate (KNO3), starch etc. Stock solutions were prepared according to the Indian standard code and diluted as per requirement. The properties of synthetic wastewater are tabulated on the below in table composition of synthetic wastewater
Table 2. Properties of synthetic wastewater

| Batch name | Organic loading (mg/l) | Phosphate(mg/l) | Nitrate (mg/l) |
|------------|------------------------|----------------|----------------|
| 1          | 100                    | 5              | 15             |
| 2          | 300                    | 10             | 20             |
| 3          | 600                    | 20             | 25             |
| 4          | 900                    | 30             | 30             |
| 5          | 1200                   | 40             | 45             |

4. Nitrate Removal
Nitrate is the nutrient that is required for the growth of microbes. The removal efficiencies for polypropylene bio-medias for different batches are represented below.

![Figure 4. Nitrate removal efficiency for polypropylene bio-media](image)

The results of the graph in Figure 4 interprets that maximum removal efficiency has been achieved at 48 hours and day-5. A maximum nitrate removal of 86.2% has been achieved.

5. Phosphate Removal
The phosphate removal efficiencies of for different batches with polypropylene media profile have been represented below graphically. The results obtained in Figure 5 shows maximum phosphate removal efficiency of 96.3% and have been achieved at 48 hours for most of the batches.

![Figure 5. Phosphate removal efficiency for polypropylene bio-media](image)
6. COD Removal
The COD removal efficiencies for different concentrations media profile have been graphically represented. A maximum COD removal efficiency of 91.2 % has been achieved and 48-hour duration is proved to be appropriate for all the batches.

![Figure 6. COD removal efficiency for polypropylene as bio-media](image)

7. Result and Discussion
This section contains information about all the outcomes that has been derived from the experimental studies. The outcomes and reason behind fluctuation are discussed in this section. The results are for media profiles i.e. polypropylene foam on the basis of various parameters such nitrate and organic content, phosphate.

8. Conclusions
From the analysis of results obtained for the present study it has been concluded that, polypropylene foam as a bio-media has greater efficiency for organic matter removal that is 91.2%. The nitrate removal efficiency for polypropylene 86.2%. The phosphate removal efficiency 96.3% is obtained for polypropylene. The 48 hr detention period gives maximum removal efficiency.

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