APPLICATIONS OF ROTATING BIOLOGICAL CONTACTORSIN WASTEWATER TREATMENT

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ABSTRACT

Rotating biological contactors are generally used as secondary treatment of domestic, hospital and industrial wastewater, operating asan aerobic and anaerobic fixed film biological treatment. Rotating biological contactors areeffective in the removal of biodegradable matter,pathogenic bacteria,nitrogen, recalcitrant compounds, heavy metals,emerging contaminants, and dyes from wastewater. In this paper, we present the design and operating principles of rotating biological contactors, and we review some of the most important results related to the applications of rotating biological contactors for the treatment of wastewater originating from different activities.

INTRODUCTION

Wastewater pollution is a serious concern, causing toxic effects tothe human health and other living organisms heath, and the environment.Many pollutants are so toxic that they can cause health problems in humans at trace levels.

In wastewater treatment, the biological processes are the most attractive in terms of economic costs and environmental concerns.

The biological treatment is typically based on suspended growth batch reactors as activated sludge processes, tricking filters and rotating biological contactors [33, 34].

Because many organic substances in the wastewater are toxic or resistant to biological degradation, the biological processes do not always provide satisfactory results [21].

Rotating biological systems with fixed carriers were originally developed and extensively used for wastewater treatment, but they are also used in treating waste gas and gas-liquid mixtures.

The concept of rotating biological contactors was first developed in the early 1900s for the biological treatment of domestic wastewater and consisted of a cylinder with wooden slats [32]. In the 1960s, the commercial development, research, and installation occurred in Germany and the United States. During this time, the development of media with high specific surface area increased removal rates and reduced the treatment costs. The popularity of RBCs grew and they are currently operated across the globe.

Currently, the mechanical evolution of the RBC is focused on media panel design, media support structures and auxiliary support systems including bearings, power units and transmission systems [17].

Rotating biological contactors (RBCs) are generally used as secondary treatment, operating as an aerobic and anaerobic fixed film biological treatment of domestic and industrial wastewater [24]. The RBC is primarily used for sewage treatment in small communities, though it is currently being used for larger treatment operations.

The RBC uses captive biological slimes to remove substances from the liquid wastewater by physical and biological means [20].

The term RBC generally defines a class of fixed biofilm filters where the media (circular discs) is attached to a central horizontal shaft that rotates slowly [3], and the media is partially or totally immersed in the wastewater [26].RBC shafts can be positioned parallel or perpendicular to the wastewater flow.

The depth to which the biomass can grow is controlled by the shearing action on the biomass as it passes through the wastewater [17]. The microorganisms that constitute the biofilm have a better chance of adaptation and survival (especially during periods of stress) as they are protected within the matrix [27].

The RBC biofilm is highly absorptive and the biological population, growing on each stage of the RBC rotor media surfaces, reflects the environmental and loading conditions in the wastewater flow. Since the biofilm plays an important role in the efficient treatment of effluent in biological reactors, knowledge of the adhesion, development and dynamics of biofilms is important.

RBCs are a superior alternative for the removal of organic biodegradable matter,removal of pathogenic bacteria from domestic sewage, and also for nitrification, denitrification and phosphorus removal from domestic, municipal, hospital and industrial wastewater.

Biological nitrogen removal involves aerobic and anoxic conditions. Denitrification is accomplished through the addition of an anoxic step following or preceding the aerobic step (post or predenitrification). Postdenitrification involves the addition of an external carbon source (such as methanol). Predenitrificaton does not require the addition of external carbon, but depends on the recycle of effluent to the anoxic unit [15].

There are many applications of RBCs in wastewater treatment. RBC consortia offer specific biological remediation for certain aromatics molecules including hydrocarbons, heavy metals, xenobiotics, pharmaceuticals and personal care products [13].

RBCs are very promising for the biological treatment of wastewaters containing recalcitrant organopollutants such as phenol, chlorophenols, fluorophenols and trichloroethylene, due to the high biomass retention [1].

Microbial decolourization of dye wastewater reduces the complex colour components in the wastewater into simple compounds like carbon dioxide, ammonia and water. As the RBCs disks offer a growth media for the microbes and good contact between the microbial species and pollutants in the system, they are often used in treating dye wastewater.

The efficiencyof pollutants removal is strictly related to the aeration /oxygenation capacity during RBC treatment [16].Oxygen transfer is achieved 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 [29].

Organic removal expressed as biochemical oxygen demand BOD or chemical oxygen demand COD is used to express the performance of the RBC process. BOD is one of the most widely used parameter to determine the pollution degree of polluted wastewater [2].

There are many parameters affecting RBCs performance: organic loading rate, hydraulic loading rate, biomass, rotational speed, wastewater temperature, staging, RBC media, dissolved oxygen levels and medium submergence [24], hydraulic retention time (HRT), wastewater and biofilm characteristics, effluent and solids recirculation, and step-feeding [4].

RBCs have the unique advantage of continual biomass removal and have the potential to operate over a long period of time without interruption [8]. Other advantages of RBCs arehigh treatment efficiency, high biomass concentration per reactor volume, feasibility, resistance to toxic loads, design simplicity, easy operation, low sludge volume index values in the second clarifier, no requirement of sludge recirculation, low land area requirement, low energy consumption, low operating and maintenance costs [4].

MATERIAL AND METHOD

RBCs are constructed of plastic or polymer materials (polystyrene, polyvinyl chloride, polyethylene and acrylic plastic) media circular discs or molded sections that are closely spaced to ensure a relatively large total surface area within a relatively small space, but far enough apart to avoid filter clogging from biological growth and bridging.

The disc packs (supporting media) are contained in a tank and rotate by 2-5 rpm. Rotation helps to eliminate excess solids. The discs have 2-4 m diameter and thickness of up to 10 mm. The rotating discs are partially submerged (40-45% of disc diameter) in wastewater flowing into the reactor (Fig. 1).

The rotation of discs ensures mixing and aeration of the liquid and supplementation of oxygen and nutrients to support the growth of different functional microorganisms immobilized as biofilm on discs surface [26]. The rotation also leads to bulk fluid mixing, convection through media/biofilm pores, compound diffusion to the film and subsequent product exchange with the reactor and surroundings [25].

As the shaft rotates, the surface of rotating discs alternately comes in contact with the microorganisms and organic content of wastewater and atmosphere. During shaft rotation, the microorganisms get attached to the discs, and oxygen needed to maintain aerobic conditions in the system is transferred into wastewater from the atmosphere. The microorganisms adhered to discs grow andforma biological film on the surfaces by oxidizing the organic matterin wastewater on the disc surface. As the biofilm thickens, aerobic condition occurs closer to the disc surface and the thickened biofilm (slime layer) is sheared off by incoming wastewater flow, being removed in the secondary clarifier before the final disposal of treated effluent [20].

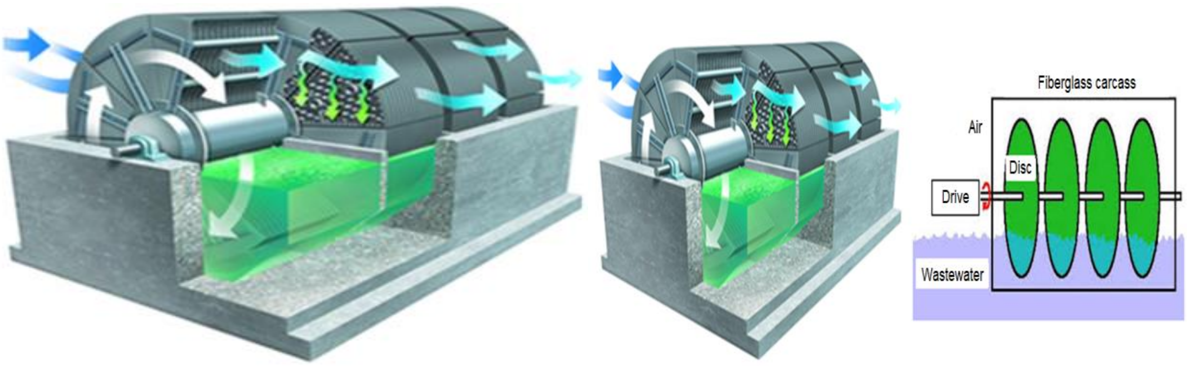

Fig. 1. Rotating biological contactor [38]

In RBCs, the aerobic zone was observed in the upper 50-100 µm of the biofilm and the anaerobic zone was detected close to the disc [9]. Studies on the spatial structure of functional bacteria in the biofilm showed that the aerobic nitrifiers (*Nitrosomonas* and *Nitrospira*) were found at the top of biofilm while the anammox bacteria were exclusively found in the lower half of biofilm [10].

There are two main types of RBCs - integral and modular (Fig. 2). Integral systems have a single unit combining primary settlement, RBC biozone and a contained or separate final clarifier; treatment capacity is ≤ 250 population equivalents. Modular systems are mounted in parallel or in series, with separate operations for primary, secondary and solids treatment, and the treatment capacity is >1000 population equivalents [13].

Several modules can be arranged in parallel and / or in series to meet the flow and purification requirements.

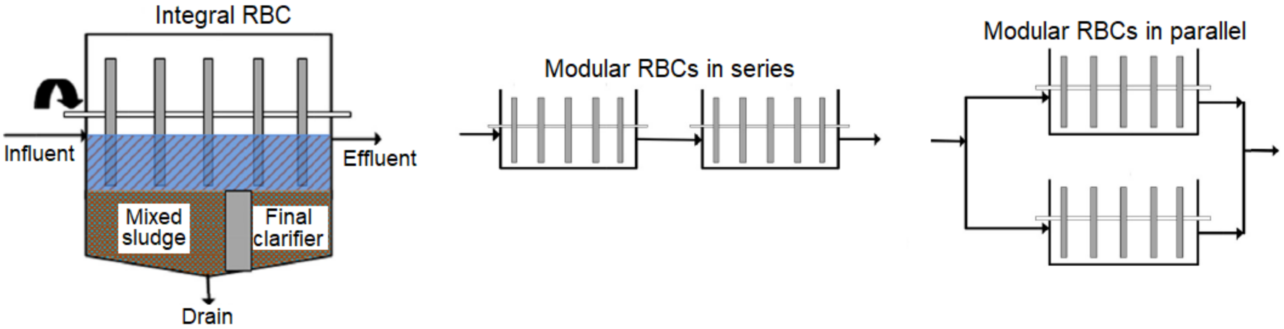

Fig. 2. Types of rotating biological contactors [13]

The carbon-based substrate is removed at the initial stage of RBC treatment. Carbon conversion can be completed in the first stage of a series of modules, and the nitrification is completed after the 5th step. Most RBC systems will include at least 4 or 5 modules in series to obtain wastewater nitrification.

Concerns over the mechanical failure of RBCs due to media deterioration and shaft breaks under the weight of the accumulating bacterial biomass (biofilm) have prevented the wide application of this equipment in the treatment of domestic wastewater. To reduce significantly such failures, improved plastics, stronger shafts and improved bearings were developed [3].

Fig. 3. Bacterial biomass accumulation in RBCs [28, 37]

Nevertheless, the RBC still has some operating problems: difficulty in maintenance of appropriate biofilm thickness under limitation of O_2 supply and biofilm detachment from the bio-drum due to the effect of toxic substances [14].

The RBC process should be designed to remove at least 85% of the biochemical oxygen demand (BOD) from wastewater [18].Higher organic removal rates are observed for increased rotation speeds [19]**,** but high speeds lead to a higher power consumption and detachment of the biofilm resulting in lower degradation rates and lower effluent quality [4].

The RBC process can also be designed to remove the ammonia nitrogen (NH_3-N) from the wastewater [18].

RESULTSAND DISCUSSIONS

Hiras et al. (2004) operated a two stage RBC (anoxic and aerobic)to treat settled municipal sewage. A decrease in COD removal with increasing organic loading rate was found from 50% to 35% at organic loading rate of 90 and 360 g/m^2·day,due to biofilm oxygen transfer rate limiting the efficiency of substrate utilization. The organic removal rate increased from 45 to 125 g/m^2·dayso there was more capacity for bulk COD removal in the system [15].

A three-stage RBC was used for the treatment of dairy wastewater. COD removal efficiencies of 80 and 83% were achieved at HRT of 16 and 24 hours. While the HRT was increased to 36 h, the COD removal efficiency was increased to 92 %. 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. COD removal efficiency of 96% was achieved, while the discs surface was increased by 10% [11].

Cvetkovic et al. (2014) investigated the performance of a single-stage RBC with supplemental aeration in terms of removal efficiency of organic and nitrogen content. The wastewater was low strength with maximal measured concentration of 362 mg COD/L, 100 mg NH_4/L and 324 mg TSS/L. The maximal measured removal efficiency of COD was 71% and TSS (total suspend solids) removal efficiency was 56%. The high rate of nitrogen removal was achieved using supplemental aeration. The removal efficiencies of NH_4, NO_2 and NO_3 were 83%, 60% and 52% [7].

Biological denitrification using a pure culture of *Alcaligenes denitrificans*was investigated in a closed RBC, which operated with HRT of 2 h, a C/N ratio of 2:1, with dissolved O_2 concentration below 6 mg/L and under three different phosphate concentrations. *Alcaligenesdenitrificans*was not repressed by O_2 limitation and the removal of nitrate was about 30% more efficient at the intermediate phosphate concentration (20 mg/L) [31].

A RBC was fed with raw domestic wastewater or anaerobic effluents and tested at increasing operational temperatures (11, 20 and 30°C) to evaluate the potential increase in removal efficiencies for different COD fractions (COD_{total}, $COD_{suspended}$, $COD_{colloidal}$ and $COD_{soluble}$), in *E. coli* and in the nitrification rate. The RBC at HRT of 2.5 h and OLR of 47 g COD/m^2·day provided very high residual $COD_{total}$of 228 mg/L when treating domestic wastewater. In RBC operated at the same HRT but at lower OLR’s of 27, 20 and 14.5 g COD/m^2·day with a UASB effluent at operational temperatures of 11, 20 and 30°C, the residual COD_{total} values amounted to 100, 85 and 72 mg/L in the final effluents. A high removal of ammonia and low residual values of *E. coli* was found for the RBC treating the UASB effluent at 30°C as compared to the treatment of domestic wastewater and UASB effluent at lower temperatures of 11 and 20°C. An efficient pre-treatment of sewage implies a substantial decrease of OLR applied to the RBC and improves the residual of COD_{total}, ammonia and *E. coli* in the final effluent [30].

Yeh et al. (1997) investigated the performance of anaerobic RBC in treating high-strength synthetic wastewater at different flow rates and influent organic strengths. The removal efficiency of BOD increased asHRT increased or influent organic strength decreased. The overall BOD removal efficiency ranged from 74-82% at HRT of 32 h, and from 44-53% at HRT of 8 h. The organic loading in influent was very strength and ranged from 3248-12150 mg COD/L [36].

Cortez et al. (2009) studied the effect of two C/N molar ratios (1.5 and 3.0) on denitrification, using acetate as a carbon source, in an anoxic bench-scale RBC treating synthetic wastewater. The effect of different HRT, nitrogen and carbon influent concentrations on reactor performance, at constant C/N, were analysed. The average removal efficiency in terms of nitrogen-nitrate was about 90.4% at C/N = 1.5, lowering to 73.7% at C/N=3.0. Considering carbon-acetate removal, overall efficiencies of 82% and 63.6% were attained at C/N ratios of 1.5 and 3. The increase in nitrogen-nitrate (from 50 to 100 mg $N\text{-}NO_3^-/L$) and carbon-acetate influent concentrations and the decrease in HRT, at constant C/N had a slight negative effect on substrate removal. The C/N=1.5 was advantageous to denitrification. The anoxic RBC was significantly effective at reducing nitrate concentrations [5].

Cortez et al. (2011) studied the denitrification of wastewater and landfilled leachate in an anoxic RBC reactor. They used poly-methyl methacrylate discs with 3 mm thickness and spacing of 20 mm. Although completely submerged discs needed more time to set up, in terms of denitrification, it’s more efficient. At C/N= 1.5, using acetate as carbon source, the nitrate removal efficiency was above 90% and nitrite build-up was at its lowest. Increasing nitrate load causeda decrease in nitrate removal efficiency until biofilm acclimated and removal efficiency recovered. HRT < 10 h was adequate, but decreasing HRT resulted in slight nitrite accumulation [6].

The treatment of a non-biodegradable agrochemical wastewater has been studied by coupling of heterogeneous catalytic wet hydrogen peroxide oxidation (CWHPO) and RBCs. The influence of the hydrogen peroxide dosage and the organic content of the wastewater (dilution degree) were studied. The CWHPO of the raw wastewater at 80ºC and using a moderate amount of oxidant (0.23 g H_2O_2/gTOC) reduced significantly its total organic carbon content and increased its biodegradability. Iron leaching of the heterogeneous catalyst (Fe_2O_3/SBA-15) was less than 2 mg/L in the treated effluent. Under best operating conditions, the resultant CWHPO effluent was successfully co-treated by RBCs using a simulated municipal wastewater with different percentages of the CWHPO effluent (2.5, 5 and 10% v/v). The RBCs showed high stability for the treatment of the highest percentage of the CWHPO effluent, achieving 78% total organic carbon (TOC) and 50% total nitrogen (TN) reductions [23].

An industrial-scale RBC in a recirculating tilapia aquaculture system at 28ºC achieved an average removal rate of total ammonia nitrogen TAN of 0.42 g/m^2·day. Increases in ammonia concentrations improved the removal efficiency up to 3.5 mg/Lammonia concentration, beyond which the removal efficiency remained 40%. Dissolved organic carbon reduction was < 10% per pass and ammonia oxidation was negatively impacted by increasing C/TAN ratio. TAN removal efficiency decreased by 50% at 4.5 C/TAN ratio. Sufficient oxygenation for nitrification was kept as the culture water traveled through the treatment tank. The RBC reduced CO_2 concentrations by 39% as the water flowed through the tank[3].

A laboratory-scale rotating drum biological contactor (RDBC) with immobilized white rot fungus *Irpexlacteus*was used to decolorize synthetic wastewaters containing the azo dye Reactive Orange 16 (RO16) and the anthraquinone dye Remazol Brilliant Blue R (RBBR). Two particulate drum packings were used to immobilize the fungus: the ALSchwimmbett Medium 100L that was not suitable due to low adhesion of the fungal mycelium to the particles, and the oak wood cylinders that supported formation of a thin layer of the fungal biofilm on the surface of the particles resulting to faster degradation of the dyes in comparison with the AL-Schwimmbett Medium 100L particles. In batch decolorization experiments at the initial dyes concentration of 100 mg/dm^3 it took from 4 to 5 hours for the RBBR and 21 hours for RO16 to get 85% decolorization. In the continuous decolorization test at high inlet mass flow rate (0.5 mg/min) of the RBBR dye, the decoloringreached 20% [26].

Continuous biological treatment of coloured wastewater from textile dyeing industry was investigated using the white rot fungus *Phanerochaete chrysosporium* in a RBC reactor. The raw wastewater was diluted with an equal volume of distilled water or media containing glucose at varying concentrations to test its effect on the decolourization. Results showed that the wastewater could be decoloured to > 64% when diluted with media containing glucose; a maximum decolouring efficiency of 83% was obtained with 10 g/L glucose concentration. COD removal efficiencies were consistent with the decolouring efficiencies of wastewaters [22].

Ge et al. (2004) studied the biological decolouring of textile dyestuff Basic Blue 22 by the white-rot fungus *Phanerochaetesordida*ATCC90872 in a RBC. Three different disc types were used: plastic discs, plastic discs covered with metal mesh and metal mesh discs. The plastic disc was the most suitable. The highest decolouring efficiency was obtained with a rotation speed of 40 rpm. Minimum glucose concentration for 78% decolouring efficiency was 5 g/L. Total organic carbon (TOC) removal efficiency was 80% for 50-200 mg/L for initial dyestuff concentrations and decreased to 52% for 400 mg$_{dyestuff}$/L [12].

A packed RBC system was applied to treat wastewater containing Cl_2 residue with 20 mg/L concentration. Cl_2had negative effect on RBC efficiency, decreasing biofilm growth. The removal efficiency of the RBC decreased with the increase of Cl_2 concentration or Cl_2 loading. Due to inhibition of biofilm growth by the effects of Cl_2 residue, the effluent suspended solids (SS) was decreased. The biofilm was easily detached from the media under high growth rate conditions resulting in an increase of effluent SS. Removal efficiencies for COD and BOD_5 under highest organic and Cl_2 loadings of 4.07 g $BOD_5/m^2{\cdot}d$ and 203.6 mg $Cl_2/m^2{\cdot}d$, were 58.0 ± 3.2% and 60.7 ± 3.9%, while they were up to 83.3 ± 1.8% and 85.8 ± 2.0%, under the lowest organic and Cl_2 loading of 2.04 g $BOD_5/m^2{\cdot}d$ and 25.5 mg $Cl^2/m^2{\cdot}d$. The effluent SS was < 20 mg/L [28].

A RBC was used to treat shock loadings of 4-fluorocinnamic acid (4-FCA). Intermittent 4-FCA shocks of 35 mg/L were applied (ca. 3 months) with limited mineralization occurring and accumulation of 4-fluorobenzoate (4-FBA) as intermediate. After bioaugmentation with degrading bacteria the RBC was able to deal with 4-FCA intermittent loading of 80 mg/L.A gradual decline in RBC performance led to 4-FBA accumulation. The degrading strain was recovered from the biofilm during 2 months but intermittent feeding may have led to diminishing strain numbers. Distinct bacterial communities in the 1st, 5th and 10th stages of the RBC were revealed by denaturating gradient gel electrophoresis. Several isolates retrieved from the RBC transformed 4-FCA into 4-FBA but only two strains mineralized the compound. Bioaugmentation allowed removal of the fluorinated compound but intermittent feeding may have compromised the bioreactor efficiency [1].

A RBC with biodrum was applied to remove hydrocarbons in industrial wastewater. The biodrum, a cylindrical mesh drum, filled with random packing of polyurethane foam cubes retaining petroleum-degrading achlorophyllous micro-alga *Protothecazopfii* cells, was 40% submerged in the culture. The amount of algal cells, immobilized in the 10 mm cube pieces, was greater than in pieces of smaller pore size. A mixture of n-alkanes (C14, C15 and C16) was used as model oil, and influent hydrocarbons were removed by immobilized cells in the biodrum. The single-stage RBC system was operated at 25 °C and at pH 7.0 in batch mode. The removal rate for n-alkanes in the RBC with biodrum system was significantly increased as compared to those in the RBC system with polycarbonate biodiscs [29].

A RBC was used to treatsynthetic wastewater containing phenols, which are highly toxic and very recalcitrant towards degradation. More than 56% phenol removal was obtained at optimum conditions of 1 g/L glucose and 250 mg/L of phenol concentration at 14 hours retention time, 40% disc submergence and 30 rpm [24].

Filamentous fungus *Fusarium solani*was usedfor removal of colour, COD and total phenols in pulp mill industry effluent, inoculated in RBC of total volume 7.2 L, operated with 40% of useful volume at 37(±2)°C, inflow 3.5 L/day, HRT of 20 h and rotation speed 2 rpm. Maximum removal efficiencies for COD and phenols were 2921 $mg/m^2 \cdot day$ (84%) and 72 $mg/m^2 \cdot day$ (83%), with 60% colour removal. COD inhibition occurred at concentrations>110 mg/L [35].

CONCLUSIONS

The rotating biological contactor (RBC) is one of the most efficient fixed film wastewater treatment technologies.

RBC wastewater treatmentoffers simple, cheap, stable and eco-friendly operations, with high interfacial area generated in the rotating disc to establish good contact between microbial species forming the biofilm and the pollutants.

The RBC is primarily used for sewage treatment in small communities, though it is currently being used for larger treatment operations, due to its efficiency in removing organic matter, pathogenic bacteria from domestic sewage, and also for nitrification, denitrification and phosphorus removal from wastewater.

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