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A Review of Rotating Biological Contactors System

Prashant A. Kadu*, Dr. Y. R. M. Rao**

*(Associate Professor, Department of civil Engineering, Prof. Ram Meghe Institute of Technology & Research, Badnera, Dist:Amravati 444701 (M.S.) INDIA,)

**(Principal, Dr. Paul's Engineering College, Paul's Nagar, Vannur, Villupuram Dist.,Tamil Nadu State, INDIA)

ABSTRACT

The rotating biological contactor process offers the specific advantages of a biofilm system in treatment of wastewater for removal of soluble organic substances and nitrogen compounds. It is a unique adaptation of the moving-medium biofilm system which facilitates easy and effective oxygen transfer. Media in the form of several large flat or corrugated discs with biofilm attached to the surface is mounted on a common shaft partially submerged in the wastewater and rotated through contoured tanks in which wastewater flows on a continuous basis. The compactness of the system and its economical operation makes it a viable option specially suited for decentralized wastewater treatment technologies. The process optimisation and adaptability under different environmental conditions and influent characteristics remain challenging tasks for the efficient use of this technology.

Key words: Biofilm, denitrification, nitrification, organic substrate, RBC.

1. INTRODUCTION

The implementation of suitable methods for the disposal of wastewater dates back to the times of Roman civilization. However, it was only in the later part of the 19th century that a spurt of activity in the realm of wastewater treatment took place. The growth of the human population, urbanization and industrialization necessitated the treatment of wastewater. It became evident that the untreated wastewater which was discharged directly into water bodies caused pollution and posed health hazards. A lot of research followed in the late 19th century and led to the development of the biological treatment process using aerated suspended biomass, known as activated sludge process (ASP). This was adapted for large-scale treatment applications and involved separate aeration and recirculation mechanisms. In 1923, Los Angeles became one of the first big cities to use an activated sludge process in its wastewater treatment plant.

However, the advent of fixed biofilm systems as a secondary wastewater treatment process seems to precede the use of ASP process. The instance came with first full-scale operation of trickling filters in early 1880s in Wales [1]. But the application of biofilm systems was limited till the middle of 20th century. It increased after new biofilm media material and reactor configurations were developed [2]. The attached growth biofilm systems rendered several advantages over the suspended growth biomass systems. The specific advantages vary with the type of biofilm system and reactor configuration. In general, a biofilm system offers the following advantages [3]:

- High biomass packing density and reactor compactness due to a large specific surface area.
- Short contact periods and cohabitation of aerobic and anoxic micro-organisms within the same ecosystem.
- Reduced sludge bulking and better sludge thickening qualities.
- Lower sensitivity and better recovery from shock loadings.
- Low energy requirements and more economy in operation and maintenance.
- Low sludge production and superior process control.
- Simple in operation and maintenance.

The rotating biological contactor (RBC) is a unique adaptation of the moving-medium attached growth biofilm system which offers an alternative technology to the conventional ASP treatment process. Media in the form of several large flat or corrugated discs with biofilm attached to the surface are mounted on a common shaft partially submerged in the wastewater and rotated through contoured tanks in which the wastewater flows on a continuous basis. RBC systems offer a typical specific surface area of the order of 150-250 m2/m3 of liquid. The principal advantage of the RBC system stems from its high oxygen transfer efficiency which provides greater economy in the long run compared to other processes employing surface aerators or diffusers. It is operationally very economical and efficient at low power consumption values. Though RBC systems are inclined to be sensitive to temperature, and involve capital costs initially, they have proved to be very efficient systems with excellent sludge quality and low sludge volume index values in the secondary clarifier [4]. Properly designed RBCs provide other specific advantages such as high capacity to withstand fluctuations arising in the wastewater characteristics and substrate concentrations and to dampen shock loadings [3].

Estimations reveal that RBCs require about 40-50% of the energy requirements of an activated sludge system [5] and 70-80% of a Trickling filter system [2].

The first instance of the use of RBC as a biofilm remediation technology is documented in 1928 [6]. The availability of polystyrene marked the beginning of commercial application of RBCs with the first full-scale RBC being installed in Germany in 1958. There are several different designs available today world-wide depending upon specific requirement criteria. More than 16% of all wastewater treatment plants in Switzerland and nearly 31% of the small treatment units with a capacity of the equivalent of a population of 5000 are RBCs [7]. Today, the increasing complexity and inadequate efficiency in operation and maintenance of large and sometimes mammoth sized wastewater treatment plants based on ASP process has paved the way towards the concept of small wastewater treatment plants (decentralized wastewater technologies). The increasing Introduction 25 demand for such small and medium sized plants for urban or sub-urban habitations created the need for alternative processes which are required to be equally effective and more economical. The RBC concept fits in ideally in such cases. Trickling filters have also proven to be an effective biofilm treatment system but the disadvantage is their complexity in operation and requirement of proper recirculation [8]. Apart from the easy and effective oxygen transfer in RBCs, the compact design with separate compartments provides the advantages of a plug-flow system to sustain load surges and provide high efficiency without the requirement of flow recirculation.

2. BIOFILM REACTORS IN WASTE WATER TREATMENT

Different reactors have been developed to take advantage of the biofilm processes in wastewater treatment. The oldest is the traditional biofilter, introduced before the 20th century. It was initially used as screening device but later on it became clear that the mechanism of purification was not purely physical screening, but biological as well [9].This led to the trickling filters where the biofilm grows over stone or plastic carrier material which acts as a media bed and the wastewater trickles down through this media bed. Few years later, at the turn of the century, RBCs were introduced using wood as solid media for the attachment of the biofilm [10]. The original patent of RBC was filed by A.T. Maltby in 1928 [11], The essential difference between the two aerobic systems is that in trickling filters, the media remain fixed in the reactor bed and the water flows over the biofilm exposed in air, while in RBCs, the media rotates through a nearly stagnant bulk water and air. Further development in biofilm technology led to usage of novelty processes like fluidised bed reactors, membrane reactors and moving bed biofilm carriers. However, many of these state-of-the-art biofilm treatment processes come with extra costs which need to be compensated with treatment efficiency. The criterion for selection of a suitable system is often a question of economy, quality of raw influent, desired treatment efficiency and availability of space. In some processes such as membrane filters, the capital costs may be very high, but the operational costs are minimal and it is often economical in the longer run. Each process has its own specific advantage and disadvantage and it remains for the designer and the users to choose a suitable treatment based on specific requirements and economic factors.

3. FEATURES OF A RBC SYSTEM

RBCs offer a low cost solution with high efficiency and inherent advantages. The most stand-alone feature is facilitating easy transfer of oxygen from air while enabling biofilm affected treatment simultaneously. Due to remarkably low energy consumption, efficient aeration of water due to rotation while simultaneously making efficient contact between biofilm and water, they offer an ideal choice as small wastewater treatment units under situations where space is limited [12]. Oxygen remains as one of the most limiting substrates in biofilm treatment, and the deeper and faster the oxygen diffusion is inside the biofilm, the better the aerobic treatment. The advantages of this system are extremely low cost for mixing and high oxygen provision [2]. The system is also less susceptible to fluctuating hydraulic loadings as compared to the trickling filters. In its simplest form, an RBC unit consists of a series of closely placed discs that are mounted on a horizontal shaft and are partially submerged in wastewater. In other words, a part of the discs is immersed in the bulk liquid while the other part remains exposed in air. In some cases, the disc is completely submerged in bulk liquid to initiate anoxic conditions of treatment. The shaft is driven mechanically using an electric motor or pneumatically with compressed air drive so that the discs rotate perpendicular to the flow of wastewater. The rotation helps to maintain oxygen diffusion through the air liquid interface and enables aerobic biofilm growth and resultant nutrient removal. In practice, RBCs are preceded by a primary clarifier and succeeded by a secondary clarifier. As stated, the wastewater previously undergoes primary treatment in settling tanks before entering into the RBC unit. The effluent from the RBC also requires a secondary clarifier to separate out the sludge from the treated wastewater. The repeated rotation of the disc media by the shaft not only supplies oxygen to the micro-organisms in the biofilm but also to the suspended biomass in the bulk liquid. The discs are usually made of plastic (polythylene, polyvinyl chloride or polystyrene) and are contained in a trough so that about 40% of their area is typically immersed in wastewater. They are arranged in groups or packs with baffles in between them to reduce surging or short-circuiting. Normally RBCs are designed and operated in a series of stages, ranging from three to four stages, separated by baffles. The purpose of staging is to make the RBC behave like a plug-flow system and eliminate short circuiting. Typically, the first stage always receives the highest organic loading and provides maximum organic removal efficiency. The latter stages are used for nitrification as well as residual organic carbon removal. After the fourth stage, improvement of organic removal is insignificant [2].When there is recycling of wastewater from the last tank to the first one, denitrification may be achieved in the first tank, where there is high organic loading (due to the influent) and low dissolved oxygen content. In specific set-ups, the rotational speed may be varied in each stage depending upon the oxygen requirement at that stage so as to optimise removal efficiency under given loading conditions and to enable variation of hydraulic shear forces to initiate detachment of biomass. This can help to control biofilm thickness. Normally the rotational speed cannot be made very high and there is disc size restriction. This checks high peripheral velocities, which may cause shearing off of the liquid film and consequently substrate limitations in the biofilm. To protect the biofilm from exposure to temperature extremities and heat loss and to prevent the growth of algae, RBC units are almost always covered. It is also important to protect the plastic discs from direct exposure to UV rays and weather. Discs may also be immersed up to 80-90% submergence, which provides less loading on the shafts due to buoyancy and larger media contact volume. This design is used especially suited for denitrification effects [13]. But for aerobic treatment of wastewater, deeper submergence of discs does not allow adequate aeration and dissolved oxygen levels in the liquid lower down. Consequently, additional aeration units need to be used to provide sufficient aeration and suspension of biomass in the trough. Fully submerged RBCs can be used for anaerobic mode of treatment [14]. Overall performance of RBC systems for nutrient removal from wastewater depends upon several factors:

  Influent wastewater characteristics
 Hydraulic loading rate
 Organic loading rate
 Ammonium loading rate
 pH
  System configuration
 Rotational speed
 Specific surface area of discs
 Disc submergence
 Number of stages
 Recirculation rate
 Drive mechanisms
 Shaft arrangement (common shaft with single rpm or separate shaft for each stage)
  oxygen transfer rate
  ambient and wastewater temperature
  media density

The most important physical factors affecting the overall removal efficiency of the system are oxygen mass transfer rate and temperature. Oxygen transfer rate is again dependent on operating temperature and physical set-up of the system. The thickness of the biofilm is controlled by the availability of nutrients and surface turbulence due to rotational speed.

3.1 PROCESS DESIGN AND NUTRIENT REMOVAL PERFORMANE

3.1.1. ORGANIC SUBSTRATE REMOVAL

The critical hydraulic retention time for removal of carbonaceous substrate in RBCs is about 3-4 hours and studies have revealed that further increase in retention has little effect on improvement in performances. For a given system, as the applied loading rate increases, the removal efficiency decreases. Under normal operating conditions, carbonaceous substrate is mainly removed in initial stages of the RBC.

3.1.2 NITRIFICATION

The oxidation of ammonia is an important feature in assessing the performance of a biological reactor. Heterotrophic bacterias offer strong competition to nitrifiers in the initial stages with high BOD concentrations. So the maximum nitrification rate occurs when the soluble BOD load reduces sufficiently. Studies suggest that full nitrification can only be achieved when the organic loading rate is less than 5gBOD/(m2.day) [15]. The recommended initial BOD5 loading rate as per ATV-DVWK standard is 8-10g/(m2.d). Therefore, nitrification always occurs prominently in the later stages of RBC set-up. The highest nitrification rate depends upon oxygen concentration in the boundary layer and dissolved oxygen concentration in the bulk liquid, which should not be oxygen limited. Also concentration of ammoniacal Nitrogen should not go below 3-5 mg/l in the bulk liquid for best results bulk liquid for best results.

3.1.3 DENITRIFICATION

The usage of RBC systems for denitrification is not very widespread. Laboratory scale studies indicate that for an influent NO3-N concentration of 50mg/l, the maximum denitrification rate is 15.2gNO3-N/m2.day at a rotational speed of 2rpm [13].In case of liquid temperature going below 13°C, temperature correction factors need to be taken into account.

These can be obtained from pilot studies and literature. In general, when the temperature drops from 13 to 5°C, nearly 2.5 times more media surface area is required for achieving the same performance [2].

3.2 RBC BIOFILM

A layer of biological growth, slimy in nature and about 1-3 mm in thickness is established on the surface of the disc. This biological slime that becomes attached to the disc surface assimilates the dissolved and suspended organic materials from the wastewater. Excess biomass is sheared off into the tank, while the rotating action of the discs maintains the solids in suspension. Eventually, the effluent carries these solids out of the system and into a secondary clarifier, where they are separated. Structurally the composition of the biofilm is highly heterogeneous. It is made up of a matrix of microbial cell clusters and intermediate voids with spatial distribution of autotrophs, heterotrophs, other bacterial cells and protozoa. Microscopic studies reveal that the outer biofilm layer is more heterogeneous and complex. It is composed of filamentous bacteria, protozoa, eukaryotic algae and small metazoans. The inner layers are relatively more uniform and compact [16]. During the initial stages of RBC set-up for BOD removal, heterotrophs compete with autotrophs (nitrifying bacteria) in the outermost biofilm layers for oxygen and space. The bacterial population gets diminished in the inner biofilm layers, because it contains a major fraction of non viable bacteria compared to the outer layers [2].The active metabolic cell fraction reduced from 35 in the outermost biofilm layer to 15 in the innermost biofilm layer [17]. Filamentous mirco-organisms present in the biofilm such as Beggiatoa ssp and Sphaerotilus natans often cause flotation problems and the sheared sludge refuses to settle [18]. Excess growth of Beggiatoa serves as a caution signal to the performance of RBC units because the blooming of these sulphur oxidising bacterias prevents the sloughing of thick biofilm from the discs, which may result in overloading on the media supports [19]. Studies show that there are several means to control the biofilm thickness. These are increasing rotational speed, reversing the rotation-direction periodically to develop shear stresses in opposite direction, supplementary aeration for pre-oxidation of reduced-sulphur so that Beggiatoa growth is sulphur-limited, step feeding the influent and chemically stripping with alkali, chlorine and other chemicals. The most influential parameters controlling biofilm growth and decay are wastewater temperature, oxygen supply, organic and hydraulic loading rates.

3.3 OPERATIONAL PROBLEMS

Mechanical failures often occur in RBC units. The most common are shaft failures, bearing failures and media support structure failures. This may arise due to overloading conditions from high hydraulic loading rate, excess biofilm growth, microbially influenced corrosion, low frequency corrosion fatigue, improper greasing and inadequate locking of nuts and bolts [20]. If the RBC unit is not housed properly, the discs may get exposed to UV radiations and bad weather conditions in tropical climates, which can damage the disc material. Another problem associated with this is excess growth of algae which may clog the shaft and disc movement. So the RBC units need to be adequately covered.

4. CONCLUSIONS:

RBCs enable high DO concentrations in the bulk liquid due to diffusive transfer of oxygen from air into the exposed liquid film surface. Therefore, requirement of external aeration in the reactor compartment can be avoided. The adoption of the new boundary layer concept reveals that average DO levels in the liquid film usually remains higher than in the bulk liquid.

Under variations of nutrient and hydraulic loading rates in influent, RBCs can sustain such fluctuations within a tolerable range and perform efficiently. Although this is valid for most biofilm systems, RBCs may provide an economical advantage.

Temperature increase shows an improvement in the overall removal efficiency.

Denitrification is only partial in RBC systems and occurs predominantly in the initial stages of the RBC where high heterotrophic population and anoxic ambience is readily available.

Flow recirculation reveals little improvement in the overall removal efficiency of the RBC system.

Submergence level of 40-42% is optimum for all stages and shows best results.

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