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REVIEW ARTICLE

Wastewater treatment using attached growth microbial biofilms on coconut fiber: A short review

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ABSTRACT

Treatment of wastewater is one of the major challenges in developing countries. Improper management of wastewater may cause serious health and environmental problems. There are many wastewater treatment methods in the world and these techniques need expertise knowledge, infrastructure facilities and high maintenance cost. In the context of developing countries, having low cost and environmental friendly wastewater treatment methods may be useful for the day today uses. Therefore, studying on the plausibility of wastewater treatment using attached growth microbial biofilms on coconut fiber may evidence for the fact that coconut fiber biofilm treatment systems could be used in the above need, as a reliable method.

Keywords*: Attached growth, biofilms, coconut fiber, developing countries, wastewater treatment*

INTRODUCTION

There are many wastewater treatment methods in the world such as activated sludge, bio-filtration, extended aeration, trickling filter, oxidation ditch, anaerobic rock filter and anaerobic sludge stabilisation (Dhote *et al.*, 2012). However, these techniques need expertise knowledge, the infrastructure facilities and high maintenance cost. Therefore, the people who live in developing countries mainly focus on a novel, low cost, environmental friendly biofilm attached treatment systems (Pell and Wörman, 2011). Among them, biofilm attached coconut fiber treatment system is a more popular and reliable method given its durability and availability of coconut fibers especially in South Asian countries (Dharmarathne *et al.*, 2013).

Biofilm is a three dimensional structure of microorganisms colonies on a surface and degrades the surface material rapidly (Wiesmann *et al.*, 2006). After the maturation stage, biofilm is finally ended by detachment and bacteria may then colonise in new areas (Pell and Wörman, 2011). The biofilms in wastewater treatment consist of heterotrophic bacteria that degrade the materials in the bulk fluid and purify the wastewater up to a certain level.

As there are very few studies on the assessment of water purification in relation to the attached growth microbial biofilms on coconut fiber this review helps fill up lacuna by aiming to discover current biological wastewater purification processes, biofilm attached systems and advantages and limitations of coconut fiber biofilm treatment system.

Biological wastewater treatment

Biological wastewater treatment can be categorised based on their purpose and functional properties (Figure 1).

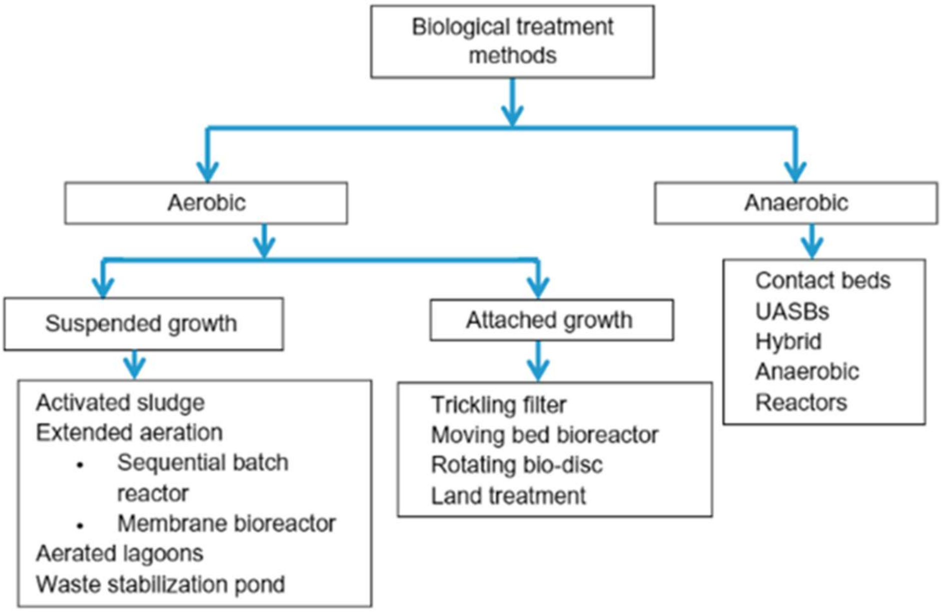

Figure 1: Different biological treatment processes as adapted from Ranade and Bhandari (2014).

The systems are categorised by the existence of air in the process environment and the characteristic of microbial environment. In the aerobic systems, oxygen drives the biological system and acts as the electron acceptor of the respiration process. But, in the anaerobic system, the electron acceptor is organic or inorganic molecule (Banat *et al.*, 1997). New cells are produced by using energy derived from aerobic respiration process. While in the anaerobic biological system, methane, ammonia, carbon dioxide and new microbial cells are produced at the end of the digestive process (Arslan *et al.*, 2016).

According to Banat *et al.* (1997), biological wastewater treatment process is odorless and an efficient method. Among all methods, attached method is applied for many wastewater treatment strategies practiced in Asian countries. The main governing factor of attached system is biofilm which consists of aggregated colony of microorganisms on solid surface.

Biofilm technology

Biofilm is defined as communities or clusters of microorganisms that are attached to a surface (Davey and O'toole, 2000). A biofilm can be formed by a single species or different species of microorganisms that have ability to form and interact with biotic and abiotic surfaces (Mohan *et al.*, 2006). In general, there are few steps that are important for the development of biofilm; starting with the initial attachment, establishment to the biotic and abiotic surfaces, maturation of biofilm and finally the detachment of cells from surface (Watnick and Kolter, 2000). The process of biofilm formation is shown in Figure 2.

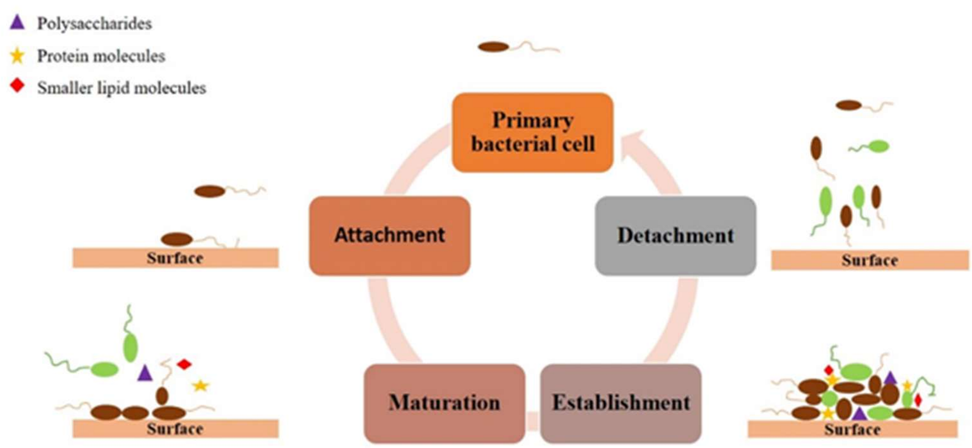

Figure 2: Stages of biofilm formation as adapted from O'toole *et al.* (2000).

According to Watnick and Kolter (2000), the biofilm is made up of same or different microbial communities. As the first step, transient attachment is formed with the surface and other microorganisms which are formerly attached to the surface (Kokare *et al.*, 2009). This transient attachment allows bacteria to search a place before adapting it. After the bacteria are settled it forms a suitable attachment and then associates into a micro-colony to live. Finally, the expansion of biofilm is set up and associated bacteria detach from biofilm surface. The usage of biological treatment process has become popular compared to physical and chemical methods when considering efficiency, economy and environmental concerns (Paul *et al.*, 2005).

Biofilm is one of the biological methods that has been studied to overcome the bioremediation problems (Decho, 2000). The main reason for formation of biofilm is to adapt and survive in the rapidly changing environment and microorganisms are protected by the matrices. As well as, microbial consortium which forms biofilm has the ability to metabolise and decolorise dye since there are intrinsic cellular mechanisms which degrade or absorb of dyestuffs (Watnick and Kolter, 2000).

Biofilm deals harmless and is a proficient option of bioremediation to planktonic microorganisms. Cells in a biofilm have a high adaptability and survival, especially in unfavorable conditions. This situation is due to the matrix which actually acts as a barrier and protects the cells within it from environmental stresses (Decho, 2000). Extracellular polymeric substances (EPS) play a significant role towards the biofilm growth and also it appears as a part of defensive mechanisms for biofilm community. The EPS's can minimise the impact of changing environment with regard to pH, concentration of toxic substances and temperature (Wingender *et al.*, 1999).

When developing a biofilm, for a lengthened biomass residence time the treatment requires either slow growing organisms – which have very poor biomass yield – or a low concentration of wastewater to sustain growth of activated sludge flocks (Abdullah *et al.*, 2011). Therefore, plenty of studies have performed in order to achieve and gain knowledge towards the utilisation of biofilms and to remediate the polluted water bodies and environment. There are number of biofilm reactors used throughout the world but aerobic fluidised bed reactor, aerobic membrane bioreactor and rotating biological contactors are popular according to their working mechanisms (Pulido, 2016). Application of biofilm treatment systems such as coconut fiber biofilm treatment system is now popular in middle income countries, such as South and South-East Asian countries, because of the easy accessibility, durability, efficiency, low cost and environmental friendliness (Sato *et al.*, 2017).

Coconut fiber biofilm treatment system

Coconut fiber biofilm treatment system (COTS) consists of three tanks such as receiving tank, sedimentation tank and treatment tanks. Receiving tank is used to collect the wastewater initially; then, it is discharged to the sedimentation tank to settle down the heavy particles in the bottom of the sedimentation tank. Thereafter, settled supernatant flows into the treatment tank where the strings of coconut fibers present (Sato *et al.*, 2017). Also, the biofilm is formed, degradation process is started and treated water is discharged as effluent from the treatment tank. The outline of the COTS of Balangoda urban council is shown in Figure 3 (Sato, 2013).

This treatment system is mostly practiced in South and South-East Asian countries like India, Sri Lanka and Malaysia (Manoj and Vasudevan, 2012). However, coconut fibers have been used in the treatment process to eliminate hydrogen sulfide (Filho *et al.*, 2010). Figure 4 shows the countries that use coconut fiber as biofilm for treatment of wastewater.

COTS is mainly practiced in Asian countries such as Sri Lanka, India, Bangladesh, Vietnam and Malaysia. Coconut fibers are used as absorbent and biofilm surface to treat wastewater methodically (Gonzalez *et al.*, 2008).

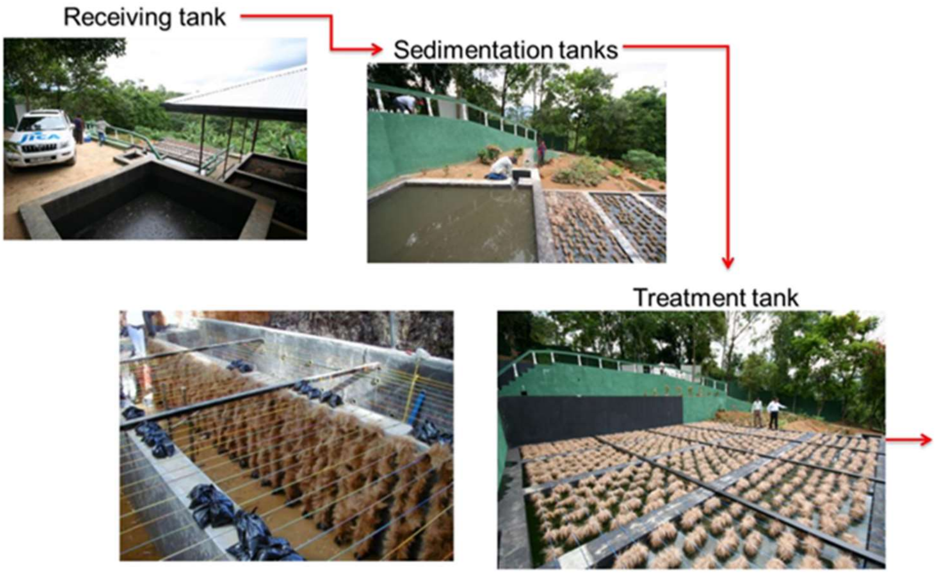

Figure 3: The outline of coconut fiber biofilm treatment system (COTS) in Balangoda urban council, Sri Lanka (Sato, 2013).

Figure 4: The countries that use coconut fibers as biofilm surface to treat wastewater as synthesised based on Gonzalez *et al*. (2008); Filho *et al*. (2010); Dharmaratne *et al*. (2013).

According to the findings from India by Manoj and Vasudevan (2012), denitrification of aquaculture wastewater can be practiced using low cost durable coconut fibers. However, they have studied the coconut fiber biofilm in anoxic bioreactor which is mostly used for the removal of nitrate nitrogen. The removal of nitrate nitrogen has been analysed by using the correlation with total nitrate, dissolved orthophosphates and chemical oxygen demand (COD). The removal of COD was 81% and nitrate removal was 97% where the coconut fiber has been used as the supporting material for the biofilm formation.

According to Filho *et al.* (2010), coconut fiber was used to treat wastewater including hydrogen sulphide. As well as, sugarcane bagasse and polyurethane were used as biofiltration matrix for gaseous mixtures containing hydrogen sulphide in University of São Paulo, São Carlos, Brazil. Average elimination capacity of hydrogen sulphide through biofilters with polyurethane, coconut fiber and sugarcane bagasse were in the range of 17.8 – 66.6, 18.9 – 68.8 and 18.7 – 72.9 g m^{-3} h^{-1}. Thus, it can be clinched that the coconut fiber also reduces hydrogen sulphide efficiently as an absorbent and good surface material for biofilm formation (Filho *et al.*, 2010). According to the results obtained from Gonzalez *et al.* (2008), coconut fiber has also used as potent absorbent in Cr (VI) removal.

Low *et al.* (2015) stated that coconut coir is an effective solution to remove organic matter, phosphate and ammonia, as an absorbent. A simple column, model which consisted with coconut coir as absorbent, has been used to treat wastewater of polluted river (Desa Bakti) in Malaysia. The maximum growth rate is observed as 4.7756 g cells d^{-1} in the column because of the nutrient availability in polluted water.

The first COTS was established in 2004 at a site of Nuwara Eliya municipal council to treat the leachate of waste landfills. Then, the COTS was constructed in Balangoda urban council, Kuliyapitiya urban council and Tangalle urban council to treat the sewage water (Sato, 2013).

According to Dharmarathne *et al.* (2013), COTS was analysed by using chemical parameters such as biological oxygen demand (BOD), COD, pH, oxidation reduction potential (ORP) and dissolved oxygen (DO). The BOD values were decreased with the time of treatment process and it can be indicated that the microorganism may degrade the organic and inorganic substances in the wastewater. Other parameters such as total organic carbon (TOC), total carbon (TC) and inorganic carbon (IC) showed constant values throughout the process but BOD/COD ratio has reduced with the time. It can be assumed that the biodegradation of wastewater is decreased at some point. This would be due to the depletion of nutrient and oxygen for the bacterial community in the biofilm.

The results obtained by Sato *et al.* (2017) showed further that the TC, TOC and total phosphate (TP) and total nitrogen (TN) were reduced at the end of the experiment when the coconut fiber density was high. Therefore, the availability of porosity and oxygen enhance the degradation process of wastewater and the removal percentage depends on the supplying conditions, proper control and density of COTS.

Water quality parameters tested in wastewater treatment through microbial biofilms

The monitoring of water quality parameters are essential to detect the efficiency of wastewater treatment process (Bourgeois *et al.*, 2001). Parameters can be classified into three categories such as physical, chemical and biological parameters. Figure 5 shows main categories of parameters that tested to find the efficiency of wastewater treatment system.

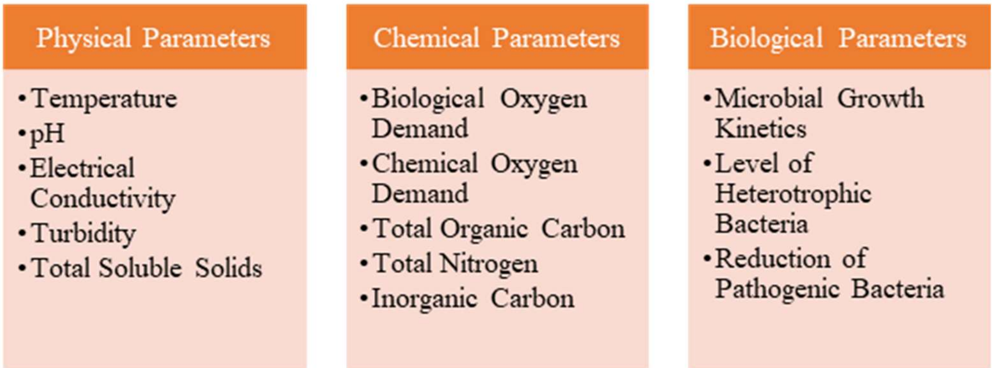

Figure 5: Classification of parameters tested in wastewater treatment system synthesised based on Dharmaratne *et al.* (2013); Sato *et al.* (2017).

The physical parameters such as temperature, pH, electrical conductivity and the total soluble solids were not significantly changed (Dharmarathne *et al.*, 2013) because these parameters depend on the external environmental condition and wastewater load (Sato *et al.*, 2017). However, turbidity can be changed in all the samples of treated water compared to untreated bulk wastewater (Mohan *et al.*, 2008). Therefore, most of the physical parameters would not change significantly throughout the wastewater treatment experiment.

The most standard and widely used parameters are the chemical parameters such as BOD, COD and TOC (Bourgeois *et al.*, 2001). BOD – the potential removal of dissolved oxygen by heterotrophic bacteria in order to digest the organic molecules and for their reproduction (Brookman, 1997) – is highly a measurable parameter in wastewater treatment process. If the treatment process is efficient, the BOD value is reduced (Sato *et al.*, 2017). However, this test lies along with the presence of toxic molecules such as lead (Pb), copper (Cu), mercury (Hg) and chromium (Cr). Therefore, these substances inhibit the growth of microorganisms present in the water sample and it affects the BOD value as well (Brookman, 1997). Moreover, it was the reason to measure COD value before and after the treatment process. The COD means the measure of oxygen which is involved for chemical reactions in wastewater sample. Major advantage of measuring COD is that it can be taken within short period of time; BOD measurement takes 5 d to measure up the available oxygen (Batram *et al.*, 1996). Most of the time, both BOD and COD show linear relationship and a ratio between BOD and COD shows the changes in water quality (Darajeh *et al.*, 2016). If the wastewater treatment process is efficient the ratio (BOD:COD) should be reduced (Sato *et al.*, 2017).

Other than these parameters, total organic carbon (TOC), total nitrogen (TN) and inorganic carbon (IN) can also be measured to identify the chemical composition of wastewater and reduction of the chemical composition in treated samples (Pell and Wörman, 2011). However, these parameters change from time to time, depending on the load of wastewater applied to treatment system.

As biological parameters such as level of heterotrophic bacterial counts, reduction of pathogenic bacteria and microbial growth kinetics should be measured (Wiesmann *et al.*, 2006). However, these parameters are not readily used to measure the efficiency of biological wastewater treatment process (Decho, 2000). Formation of biofilm on surface of biological treatment system can be shown by using scanning electron microscope (SEM) images (Sato, 2013); (Filho *et al.*, 2010). Figure 6 shows a biofilm developed on the surface of coconut fibers in COTS.

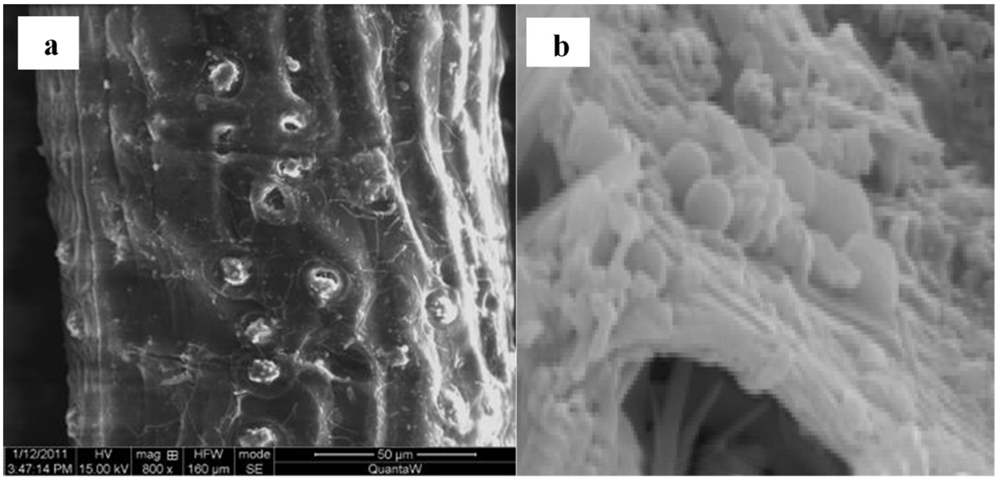

Figure 6: SEM image of coconut fiber x 800 µm (a) before the biofilm formation (Sato *et al.*, 2017); (b) biofilm (Filho *et al.*, 2010).

It is required that biological parameters such as level of heterotrophic bacterial count, pathogenic bacterial reduction and microbial growth kinetics are also measured in COTS. There are no articles available to support the evaluation of biological parameters in COTS. According to Low *et al.* (2015) the growth of microorganisms on coconut fiber surface within an hour has been measured by using weight gain parameters. Other than this finding, there are no readily available data on pathogenic reduction of coconut fiber biofilm treatment system.

CONCLUSION

This review aimed to explore the wastewater treatment through attached growth microbial biofilms on coconut fiber. Findings of the review showed that the biofilm technology is used for wastewater treatment systems. Coconut fiber has been considered as environmental friendly and low cost substrate for wastewater purification. However, the biological parameters should be optimised to clarify the quality of treated water.

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