Review on Biofilm Processes for Wastewater Treatment

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Abstract: This review paper discusses the application of biofilm as an alternative technology for the treatment of wastewater under various loading and operation conditions. In the past few years the biofilm technology has become more common and widely used in the world to meet the requirement for clean water sources of the world's growing population. Besides, the conventional wastewater treatment plants like activated sludge process present some shortcomings such as not very flexible method (if there is sudden change in the character of sewage and the effluent of bad quality is obtained), so better system is urgently needed to provide additional capacity with the least possible cost and to meet the standard effluent by the local authorities. The increased incoming flow of wastewater to the treatment plants and organic loading always demand for additional treatment capacity. Fundamental research into biofilm is presented in this paper in sections that discuss the use of biofilm whereby a comparison between suspended and fixed film, old and new biofilm are made. Besides, bed types namely moving bed, fixed bed and floating bed, un-submerged fixed film systems of trickling filters and rotating biological contactors are explained. Nutrients removal of nitrogen and phosphorus and nano technology application in biofilm are also explained. Results from investigations of different applications carried out at the laboratory and pilot scales are also discussed.
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1. Introduction

Sewage refers to the category of wastewater eliminated from domestic users which include households, food establishments, industries, agro-economy etc. It consists of various pollutants such as faecal wastes, food debris, grease, detergents and other chemical substances. In general, sewage is channeled through an extended piping system underground to the sewage treatment facility where numerous steps and water purification systems are used to remove the pollutants in wastewater. A direct discharge to open water sources such as rivers and the sea will result in water pollution.

Numerous types of biofilm is employed in biological wastewater treatment system such as trickling filtration system, rotating biological contactors, fluidized bed reactors, fixed media submerged biofiltration, etc. There are certain benefits and drawbacks in these systems and biofilm applications. For instance, the use of biofilm systems is appealing in smaller applications due to simpler procedures, lower maintenance cost and more reliable. However, the most common drawback associated with biofilm is high organic loading that often results in clogged films due to the proliferation of slime bacteria. The proliferation of bacteria also results in other problems such as malodour issues in the trickling filtration system and the restriction of oxygen for biofilm microorganisms (Odegaard, 1999). All sewage treatment facilities are required to conform to the predetermined standards of water quality such as BOD_5 levels, contents of suspended solids and the presence of other waste substances. The current application of wastewater treatment systems which uses activated sludge system, oxidation ponds, trickling filtration and aerated lagoon are regarded as inefficient by researchers (Shahot and Khmaj, 2012).

The issue of compact wastewater treatment system is gaining an elevated concern internationally particularly in densely populated regions where there is a higher strain on the environment which results in high demand on waste abatement. Both the cost and availability of land combined with implementation of secondary treatment standards sets demands for wastewater treatment plants that have a small footprint, produce an effluent of high standard and also comply with waste minimization (Leiknes and Ødegaard, 2001) Biofilm reactors in particular offer alternatives for compact treatment plant designs and more effective than conventional wastewater treatment systems.

2.1 Biofilm System in Wastewater

There are several benefits of using biofilm in wastewater treatment system in comparison with suspended growth systems, such as flexible procedures, smaller space demand, lower hydraulic retention time, increased resiliency, higher biomass retaining period, increased of active biomass clusters, improvement of recalcitrant substance degradation as well as decreased rate in microbial proliferation. Apart from that, the application of biofilm systems also increases the ability in controlling the frequency of reaction and population mechanisms (Borkar *et al*., 2013). The application of fixed and moving bed processes is distinguished by the quality of the support components on which biofilm is configured on static platforms such as rocks, plastic profiles, sponges, granular carriers or membranes. The development and formation of biofilm grown in a five-stage process (Cogen and Keener, 2004). As shown in Figure 1, the early level consists of bacterial attachment to medium. Bacterial proliferation then leads to colonisation of the enclosing space and forms bioflim after dispersion.

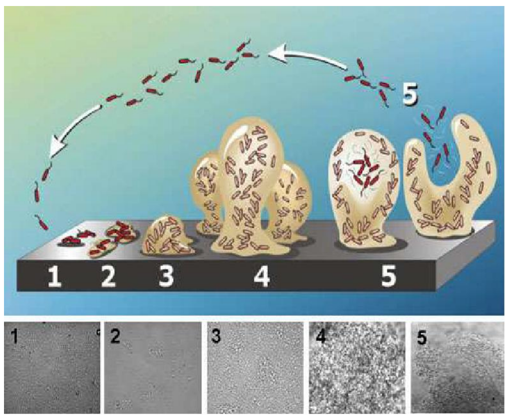


Fig 1: The stages of biofilm formation (Cogen and Keener, 2004)

2.2 Comparison between Suspended and Fixed Film

Despite applying the similar biological metabolism in the removal of carbon and other substances in attached growth and suspended growth systems, there are some distinctness that results in benefits and drawbacks of applying the biofilm system. The basic differenceis the procedure in assembling the biomass, substrate and oxygen. For suspended growth system, effluent from settling tank and activated sludge are combined in the reactor container using aeration. This process enables contact between substrate and microorganisms as well as the introduction of oxygen. The liquid then flows to a settling tank where the microorganisms are removed and the effluent continues to discharge. Figure 2 shows the procedure of activated sludge system. The theory of suspended growth is widely applied in biological wastewater treatment systems, including parameters such as hydraulic retention time and food/mass ratio (F/M) to regulate the formation of sludge.

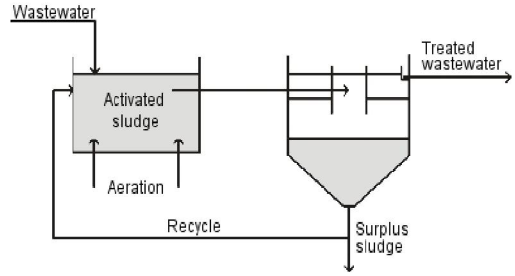


Fig 2: Schematic of Activated Sludge Process (Koumboulis *et al*., 2008)

In biofilm or fixed film (attached growth) processes, the microbial growth occurs on the surface of stone or plastic media. The increase of biofilm surface area enables wastewater to pass over the media and increases the volume of substrate that can be adsorbed from the influent. As the film builds up, diverse habitats are provided for the mineralization and transformation of wastewater constituents such as carbon and nitrogen components. This increases the efficiency of the removal of organic substances from wastewater influent. Aerobic, anoxic and anaerobic mechanisms may occur in individual bioflim and the limiting substrate will alter by the thickness of biofilm. This also shows the complexity in modelling fixed-film processes (APHA, 2005). There are several benefits from the application of fixed-film system such as lower operation cost, lower energy demand, lower reactor capacity, lower requirement for settling volume and lower sludge formation (Chan *et al*., 2009).

2.3 Old and New Biofilm

Today, there are old and new fixed-film systems which are widely applied in distributed wastewater purification facilities. The trickling filter (TF), rotating biological contactor (RBC), fluidized bed reactor, moving-bed biofilm reactor (MBBR) process, and membrane bioreactor (MBR) will be evaluated for to identify the distinctness in mechanisms between systems.

2.3.1 Trickling Filter (TF)

The trickling filter is consisted of a medium with high porosity. In this system, biodegradable substances are broken down through aerobic mechanisms (WSP, 2008; UNEP, 2004)**.**Waste effluent is channelled across the top of the medium by a rotator as shown in Figure 3(a). To elevate the purification volume, plastic packing is used to replace the conventional trickling filters. Figure 3b shows the types of media used in trickling filter. The construction of filtration system is equipped with an under drain system to collect treated wastewater and organic constituents removed. The under drain system provides an important function as collector and aerator. Effluent collected is channelled to a settling chamber to allow the separation of solids from treated effluent (Metcalf & Eddy, 2003). The trickling filtration system aids the microbial absorbability of biodegradable constituents. Microorganisms present in wastewater are retained on biofilm's surface when influent touches the medium. This then enables the attached microorganism to biodegrade organic substances from the effluent (Daigger and Boltz, 2001).

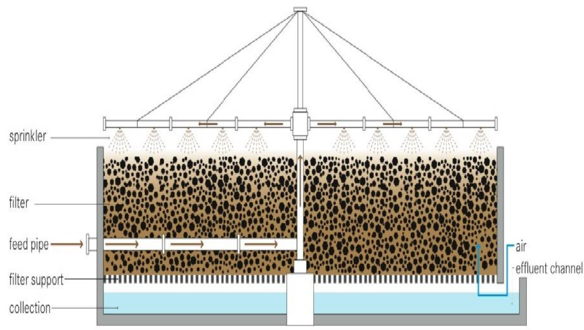
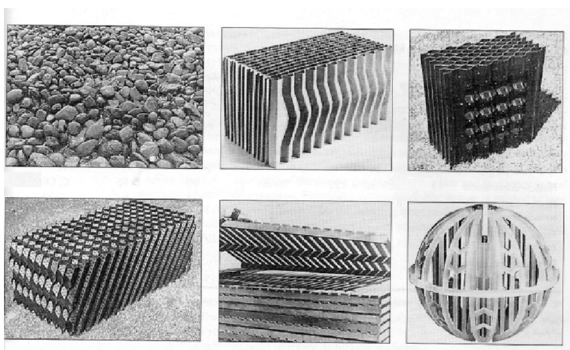


Fig 3: (a) Trickling Filter (Tilley *et al*., 2008)



(b) Types of Trickling Filter Media (Metcalf and Eddy, 2003)

WSP (2008) reported that biological oxygen demand (BOD)removal up to between 60 and 85% can be attained using the loading rate of 1 kg BOD/m^3/day. The level of total suspended solids (TSS) reduction is presumed to be minimal prior to down flow condition. In addition, the level of nitrogen can be reduced through the alternation of organic loading rate. The reduction of total nitrogen (TN) up to 35% and between 10 and 15% of phosphorus removal can be attained (UNEP, 2004; WSP, 2008). Nevertheless, the volume of substrates that can be removed using trickling filter dependent on the treatment procedures. Some researchers have presumed high reduction in ammonia content (USEPA, 2000) while others have indicated no reduction at all (UNEP, 2004).The layer of bacteria has to be removed every once in 5 or 7 years (WSP, 2008) to avoid dead cells from blocking the system (Sasse, 1998). The flushing of bacteria can be conducted through elevated hydraulic loading rates (Sasse, 1998). The regulation of moisture content of filtration system is also crucial, as high humidity results in the breeding of pests such as housefly and mosquitoes (USEPA, 2000).The regulation of effluent recirculation is also important in preventing low flows and flows that are too strong which results in microbial flushing (WSP, 2008). Malodour problem occur in anaerobic condition caused by too much build up and insufficient oxygen. Rehman *et al*. (2012) carried out a study on plastic media trickling filter system and sand filter to treat domestic wastewater of sources with the temperature of 5 to 15ºC. The hydraulic flow rate was fixed at 80±2 ml/min at the duration of 12, 24, 36 and 48 hrs. The results show that the efficiency of BOD_5, COD, TSS, PO4, turbidity and faecal coliforms as 93, 93, 86, 57, 99 and 86 % respectively after treatment of 12, 24, 36 and 48 hrs. After 48 hrs, sand filter is used as the final filter for purified effluent and an approximately efficiency of 95, 95, 100, 73, 100 and 91.5% were achieved in BOD_5, COD, TSS, PO_4, turbidity and faecal coliforms. Harrison and Daigger, (1987) carried out a pilot study to examine the efficiency of trickling filter media. His findings indicated that the quality of the treated wastewater was between 70 and 90 g BOD_S/m^3 with the loading rates of between 3.45 and 3.60 kg BOD_S/m^3.

2.3.2 Rotating Biological Contactor (RBC)

The rotating biological contactor (RBC) is a fixed film biological secondary treatment device (Metcalf & Eddy, 2003; Lee, 2000).The fundamental mechanism is identical with the process of trickling filtration system. There was an increase use of RBC in the 1960s and 1970s but was soon decreased by various incurring problems such as the failure to meet expected performance, over substrate build ups, damage in shaft, lopsided disks due to instable biomass burden and proliferation of unwanted microorganisms. However, several of these issues have been overcome and the system is again widely applied (Ghawi and Kriš, 2009). As shown in Figure 4, the process consists of a set of disks normally made from plastic stacked beside each other on the same shaft is circulated across the flow of effluent. About 40% of the disks are submerged in the tank. The shaft circulates at the rate of 1 to 2 rpm and soon microbial growth and thickens on the moist surface area of the disks. The layer of microorganisms filters out organic constituents from influent to be assimilated in aerobic metabolism. The rotation proceeds and leaves the wastewater towards the air, transferring oxygen to the layer of microbial build up. As the later re-submerges into the wastewater, excessive waste substances are removed as sloughing by transporting it with the flow of effluent. A single contactor is usually insufficient to attain the standard of treated effluent as required, and this problem is overcome using a series of contactors. RBC energy consumption is approximately 25% of the activated sludge requirement (Kadu, *et al*., 20013).

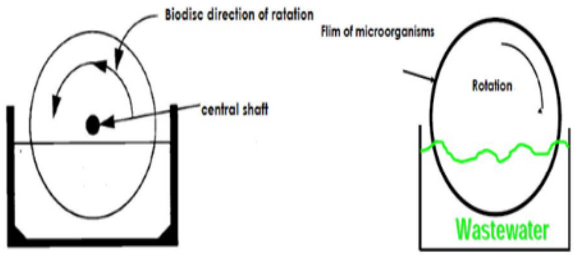


Fig 4: (a) rotating biological contactor: (b) biofilm formation (Kadu, *et al*., 20013).

The degradation of substrates at a higher rate is normally achievable through the elevation of rotation speed that results in higher concentration of dissolved oxygen (Israni *et al.,* 2002; El Monayeri *et al*., 2013). However, the increase of rotation speed also results in higher energy demand and cost, which is not cost-feasible for many wastewater treatment systems (Ramsay *et al.*, 2006). Additionally, excessive rotation speed will also result in the removal of microbial layer and lowers the overall efficiency of treatment process.

The condition of film's surface area is used to classify the categories of biofilms. In overall, films are categorized as having a low, standard, medium or high density. For standard density, films cover about 115 m^2/m^3 of reactor's surface area. Higher gap between media are typically applied in the lead stages of a RBC process train. For medium and high-density films, approximately 135–200 $m^2/m^3$of surface is required and is normally installed in the mid and last section of a RBC system with thinnest microbial layer (Patwardhan, 2003). Cabije *et al.*, (2009) conducted a study to determine the reduction carbon-nitrogen-phosphorus substrates by studying biological contactor-packed media technology (RBC-PMT) which is invented by light polyethylene component as disk. The disks are attached with a set of equalization tanks as a combined wastewater treatment system. RBC-PMT applies a total aerated operation, while the equalization tanks use the approach of anaerobic process. The results indicated a good removal percentage of nitrate-nitrogen; where removal at 79.2% was achieved using high organic loading rate (OLR) and 83.4% at low OLR. For the removal efficiency for phosphate-phosphorus, a total of 91.6 % was achieved using high OLR and 94.4% at low OLR. The results suggest that the removal of C-N-P can be increased through a reduction of OLR. Moreover, they measured the average thickness biofilm growth to be 7.71 μm at high OLR and 2.81 μm at low OLR.

Kinner *et al.* (1982) conducted a study on the microbiology of rotating biological contactor film and they indicated that fluid velocity past the biofilm between 0.18 and 0.45 m/s results in the highest growth of *Sphaerotilus*. Nowak (2000) carried out a study to investigate nitrification and phosphorous removal of a full- scale wastewater treatment system with rotating biological contactors. He proposed that an ammonia concentration less than 5 mg at temperatures above 13^{o}C can be achieved by using the surface loading rate below 2.5 g BOD_5/m^2d.

2.3.4 Moving Bed Biofilm Reactor (MBBR).

Moving bed biofilm reactor (MBBR) is an invention of the Norwegian company (KMT) towards the end of 1980s. MBBRs are continuously operating biofilm reactor and similar to the activated sludge process with the addition of small carrier elements which move along with the water in the reactor as shown in Figure 5. MBBR exhibits more benefits as compared to conventional activated sludge system such as higher oxygen transfer efficiency, lower hydraulic retention time and increased organic loading rate (Chan *et al.,* 2009). Today there are several hundred plants around the world (Hosseini and Borghei, 2005) that use MBBRs for multiple wastewater treatment processes which include the extraction of organic substrates, nitrification and denitrification in domestic and industrial applications. MBBRs are aerobic or anaerobic-anoxic reactors. In the former case, the biofilm carriers are moved by aeration as shown in Figure 5(a), whereas in the latter case, mechanical mixing is used to agitate the biofilm carriers wastewater as shown in Figure 5(b).. Many studies have reported the success of MBBR.(Kermani *et al.*, 2009)

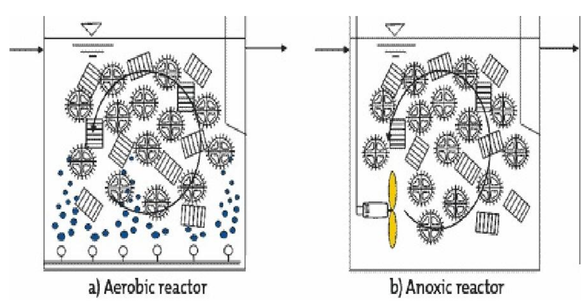
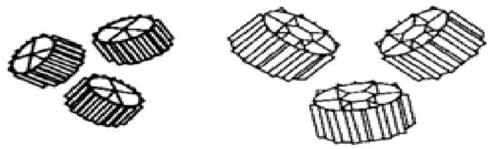


Fig 5: The mechanisms of the moving bed biofilm reactor: (a) Aerobic reactor; (b) Anoxic reactor (Odegaard, 1999)

Odegaard (1999) carried out a study on moving bed biofilm reactor to investigate the efficiency of two shapes of moving bed biofilm. The first shape is the biofilm carrier (K1) which is produced using high density polyethylene (0.95 g/cm^3). It is moulded into a 7 mm long and 10 mm wide cylinder with an internal cross and outer fins as shown in Figure 6(b). Lately one has introduced also a large carrier K2 of similar shape as shown in Figure 6(b). The length and diameter about 15 mm is manufactured for plants equipped with coarse inlet sieves. To cope with the higher biomass on the internal surface, the surface area for K1 carrier is manufactured at 335 m^2/m^3 and 235 m^2/m^3 for the larger K2 carrier with at 67% filling. The filling should be conducted at below 70% for the ease of changing the location of the carrier suspension. The results demonstrate that there are insignificant distinctiveness on the rates of removal in the smaller K1 carrier (with 410 mm^2/piece) comparing with the newer and larger K2 carrier (with 810 mm^2/piece). A small reactor volume is required when using K1 carrier with the same carrier filling. Given this, the larger carrier will only be used when one is afraid of sieve clogging.



(a) KMT (K1) (b) KMT (K2)

Fig 6: Biofilm carriers (a) KMT (K1); (b) KMT (K2) (Qiqi *et al*., 2012)

An investigation using the moving bed biofilm reactor technology was carried out at a total-installation for the wastewater treatment from the pharmaceutical industry (Brinkley, 2008). The pharmaceutical company had a plan to extend the manufacture of their plasma in a location with an aerobic lagoon. A different biological remediation system required for this extension. Due to the plan limitations, the company looked into various treatment alternatives for treating high-impact wastewater with small footprint and potential extension in the future. Due to its ability in remediating high-impact effluent from the pharmaceutical, the MBBR system was selected as the treatment system. The influent BOD_5 was 3197 mg/L and the achieved effluent BOD_5 was 75 mg/L. Rodgers (1999) studied the extraction of organic carbon through the application of new biofilm reactor. The experimental biofilm system as shown in Figure 7 was employed in the study. The bulk fluid reactor was build using polypropylene sheets with 0.4 m width and 0.6 m long internal squares. A 0.3 m side cube which consists cross flow corrugated polyvinyl chloride (PVC) sheets was moved vertically in and out of the water intermittent intervals in the reactor. In the initial stage, a 4.05 m^2 cube was employed, followed by a higher surface area at 6.48 m^2. The system was fed with feed 1 total chemical oxygen demand (COD_T), soluble oxygen demand (CODs) and biochemical oxygen demand (BOD_{s5}) of 2934, 1875 and 1178 g/m^3 respectively and feed 2 were twice those in feed1. Results show that the new biofilm system was easy to be constructed and operated and was efficient in the oxidation process of biological carbonaceous from the fabricated effluent. From the process of carbonaceous oxidation, a total of 43 g $CODS/m^2$ d or 3.8 kg $CODS/m^3$ d were extracted and this result is comparative with the efficiency of other biofilm technologies.

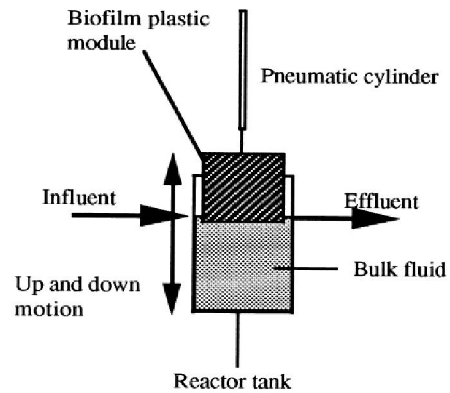


Figure 7: Carbonaceous oxidation model arrangement (Rodgers, 1999)

A pilot study was conducted with vertically moving biofilm (VMBS) system to remediate municipal effluents (Rodgers *et al.,* 2003). The biofilm module was repeatedly directed in a circular vertical motion up into the air and down into the wastewater. A high specific surface area (240 m^2/m^3) plastic with dimensions of 1200 x 600 mm in plane and 600 mm deep was used as the medium. The results show a COD and BOD removal rate of 35 g COD/(m^2. day) and 25 g BOD/(m^2.day) using COD loading of 40 g COD/(m^2. day) and BOD loading at 35 g/(m^2 .day). From a study conducted by Rusten and Westrum (1994), high specific area of the carrier media was proven in allowing a higher biofilm concentration in a small reactor capacity and allows for the control of system efficiency. They indicated that conventional biofilm concentration used is between 3000 and 4000 g TSS/m^3, which is identical to the range used in activated sludge process (ASP). The finding shows that biomass in ASP system is more feasible due to the higher removal rate in the MBBR system.

The impact of high organic loading rates on COD removal and sludge generation in moving bed biofilm reactor was evaluated by (Aygun *et al.,* 2008).The experiment was conducted using a pilot-scale reactor with 2 L of working volume filled with wastewater at a continuous rate. Biofilm carrier (K1) at 50% of the reactor's volume was installed using various organic loading rates at 6, 12, 24, 48 and 96 g COD/m^2.d. The study shows that an increase in organic loading rate from (6 to 96 g COD/m^2.d) followed by a decrease in organic removal capacity (ranged at 95.1%, 94.9%, 89.3%, 68.7% and 45.2% in respective with the loading rate). Furthermore, the use of highest organic loading rate in the MBRR reactor resulted in the biofilm concentration of 3.28 kg TSS/m^3. By applying the MBBR technology, the upgrade of small overloaded activated sludge plant was studied by (Andreottola *et al.,* 2003). They have indicated that COD removal in MBBR system is influenced by hydraulic retention time (HRT) and recommended a HRT above 5 hrs for higher efficiency. Odegaard (2006) conducted a study on moving bed bioreactor in wastewater treatment, he reported that the filling fraction below 70% for cylindrical plastic carrier to allow for smooth unimpeded suspension of moving bed media. The higher loading rates achievable with the MBBR system, smaller size bioreactors are often feasible, but the settleability of biosolids remains the largest challenge in MBBR design (Odegaard *et al.,* 2000). Beside that he reported BOD removal in the range of 95% to 85% for loading rates of 15 g BOD/m^2d to 60 g BOD/m^2d which equivalent to a volumetric loading rate of 5 kg BOD/m^3d to 20 kg BOD/m^3d.

2.3.5 Fluidised Bed (FB).

FB consists of a bed of solid media that is heavier than water or which is small in diameter (Reyes and Malone, 1996; Beecher *et al.*, 1997).

COD removal performance of fluidised bed bioreactor with support material of precipitation carbonate calcium was studied by (Kazemi *et al.*, 2012). They studied the alterations in COD at 3000, 5000 and 7000 mg/L in 3, 6, 12 hr (HRT). The results as shown in Table 1 where decreasing retention time from 12 to 6 hr has less effect on effectiveness of COD removal. Whereas by decreasing the HRT to 3 hr, COD removal efficiency decreased dramatically. The reactor without media lost its efficiency at short HRT. Tracer study techniques were used to compare floating and sunken media of biological aerated filters in a study by Mann *et al.,* (1995). For high solids wastewater, the floating media is suggested as the feasible system

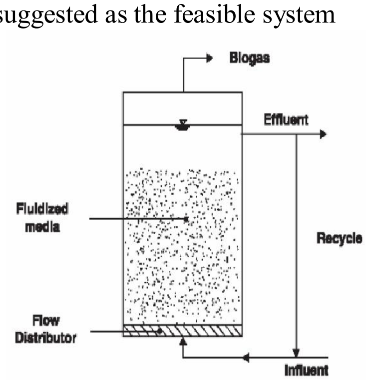


Fig 8: Fluidized bed reactors configuration (Kazemi *et al.*, 2012)

Table 1: Filtered COD reduction efficiency for different wastewater inputs

(HRT) Hour	COD (mg/L)	COD % removal with support media	COD % removal without support media
3	3000	-	-
	5000	20.9	-
	7000	-	-
6	3000	-	-
	5000	73	-
	7000	50.8	-
12	3000	92	74
	5000	90	62
	7000	84	52

2.3.6. Fixed Bed

The carrier component in fixed bed reactors is usually consisted of plastic components steadily set up in and constantly submerged in fluid. Oxygen is required by microorganisms to degrade the organic substances in the wastewater. A highly pressurized aerator installed below the fixed bed provides the required oxygen as well as a good fluid mixture. The air from the aerator also carries dead biomass of microorganisms to be removed in the last remediation stage. Figure 9 shows the fixed bed reactor configuration.

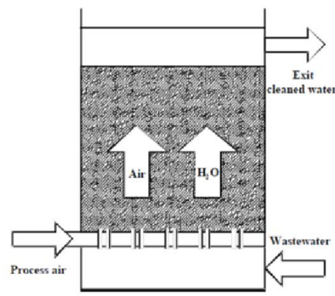


Fig 9: Fixed bed configuration

A combined anaerobic-aerobic system for treatment of textile wastewater using Cosmo ball as the fixed media was studied (Ahmed *et al.,* 2007). Experimental investigation was carried out by Cosmo ball media. The results show that the bacteria developed on the cosmo ball surfaces was in excess of 5000 to 10000 mg/L. This high value of bacteria growth on each of the Cosmo ball will yield a good efficiency in wastewater treatment and it is suitable in the anaerobic and aerobic condition. Ghaniyari-Benis *et al.,* (2009) carried out a study on the remediation of medium-strength wastewater consisted of molasses as carbon compounds through anaerobic process and a multistage biofilm reactor with a volume of 54 L. The wastewater had an up flow mode inside each stage, formed by packed beds using Pall rings as a media to support the forming of biofilm. A surface area of the Pall rings was 206 $m^2/m^3$and filled up to 64%. The results show that the efficiency of the multistage biofilm reactor in remediating wastewater with medium-strength. In the experiment, the wastewater was treated using OLR of 9 kg COD/m^3day resulting in 88.3% COD removal efficiency. In addition to that, decreasing HRT from 24 to 16 hr gave no changes to the rate of COD removal. However, the rate of COD removal was slightly decreased to 84.9% with HRT of 8 hr.

A numerical study of flow across Cosmo balls by using computation fluid dynamic (CFD) was studied with the objective of analysing the flow pattern of wastewater across the Cosmo ball in the wastewater tank (Hussain *et al.,* 2010). The results show that, the lag of flow through the individual Cosmo ball indicates that the hollow region in the ball can induce higher retention time for wastewater treatment. This will greatly improve the efficiency of the wastewater treatment plant as well as to reduce the area needed for the treatment due to sufficient time for the microbial in the wastewater to obtain oxygen for the oxidation process.

Fujie *et al.* (1994) studied the ecological process of aerated biofilter using respiratory quinone. The impact of high temperatures on the efficiency of biological aerated filters (BAFs) in removing carbonaceous components has been studied, and results shown the highest growth of microorganisms at 38°C (mesophiles). Higher temperatures resulted in the reduction of microorganism growth that removes organic constituents in aerated biofilter process (Visvanathan and Nhien, 1995). At above 41°C the the rmophilic microorganisms succeeded the growth rate of mesophiles and resulted in the overall biomass and removal efficiency. A study on the immobilization in fixed film reactor reported that smooth or evenly-surfaced medium prevents the growth of biomass as it prevents microorganisms from attaching to its surface (Harendranath *et al.,* 1996). Reactors that use such media could be unstable under variable air and liquid velocities causing biofilm sloughing. Moreover, rough medium enables microorganisms to steadily adhere to the surface area, resulting in biofilm build ups and higher removal efficiency. Newbigging *et al.,* (1995) carried out a study of up flow or down flow BAFs that shows the most efficiency and they found that higher nitrification is attained by an up flow BAFs than a down flow reactor. Twelve biological aerated filters was evaluated which resulted in below 90 COD_T g/m^3 for a loading of 5.5–6.0 kg COD_T/m^3.d (Canler and Perret, 1994).

2.3.7. Membrane Bioreactor (MBR)

The integration of membrane process like microfiltration (MF) or ultrafiltration (UF) with a suspended growth bioreactor results in a system called membrane bioreactor (MBR). It is possible to operate MBR processes at higher mixed liquor suspended solids (MLSS) concentrations comparing to conventional settlement separation systems, thus reducing the reactor volume to achieve the same loading rate.

This system was introduced by Dorr-Oliver Inc. towards the end of 1960s which integrated the application of activated sludge bioreactor with a cross flow membrane filtration loop. The process uses polymeric flat sheet membranes with between 0.003 and 0.01 µm of porosity (Judd, 2010). The difficulty in justifying the usage of such system due to the cost of membranes hindered the replacement of conventional activated sludge system with MBR. However in 1989, a solution was found by Yamamoto and his colleagues by submerging the membranes in reactors, which is shown in Figure 10. Figure 11 shows the design of MBR system with a separation device placed externally (side stream MBR).

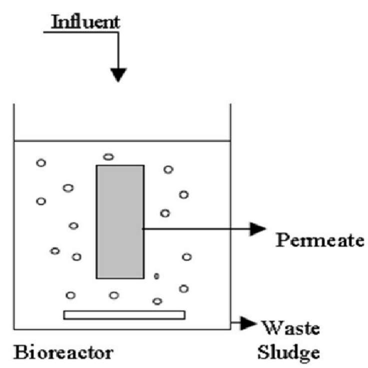


Fig 10: Submerged MBR configuration with membrane unit into the bioreactor (Melin *et al.*, 2006)

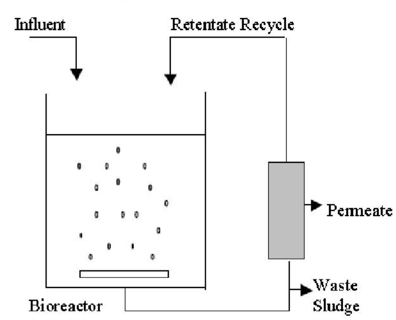


Fig11. Side stream MBR configuration with a separate membrane filtration unit (Melin *et al.*, 2006)

Submerged MBR systems with submerged membrane are normally employed as compared with side stream configuration particularly for the bioremediation of domestic effluents. Coarse bubble aeration is used for mixing and to prevent malodour issues. Nowadays, the submerged system is more commonly applied in the industry due to lower energy demand (Judd, 2010).

Leiknes and Ødegaard (2001) investigated the potentials of a moving-bed-biofilm membrane reactor (MBB-M-R) hybrid process as an alternative system for compact wastewater purification system. The study demonstrated that 85-90% COD removal is achievable at 30-45 kg COD/m^3.d using 30 min as hydraulic retention times and the flux of 60 L/m^2.h. Moreover the treatment efficiencies are comparative with typical operating condition for membrane activated sludge (AS-M) with 1-3 kg COD/m^3.d, HRT between 4 and 10 hours and flux rates at 15-25 L/m^2.h. Therefore, a high-rate MBB-M-R reactor operating with between 10 and 15 higher volumetric loading rates and between 10 and 30 lower HRT combined with flux rates that are 3-4 times greater shows the potential of high-rate MBB-M-R hybrid process.

2.4. Nutrient Removal using Biofilm Process

Wastewater containing high levels of phosphorus and nitrogen results in numerous environmental impacts such as reduced oxygen concentration, the disturbance of ecological system, and loss of aesthetic value of water system when directly eliminated into the environment (Luostarinen *et al.*, 2006). Therefore, the removal of the components from wastewaters is necessary in order to reduce their harm to the environment (Wang *et al.*, 2006). Biological processes based upon suspended biomass are efficient in removing organic constituents from municipal wastewater treatment system. However, issues such as the settling of sludge and the need for large reactors, settling tanks and biomass recycling are common (Zhao *et al.,* 2006). Biofilm processes have proved to be a good option for the removal of organic constituents and are without some of the problems of activated sludge processes (Odegaard *et al*., 1994). The application of biofilm reactors are especially relevant when slow-growing microorganisms have to be retained in the treatment tank. The processes of nitrification and denitrification have been individually successful in the biofilm reactor (Kermani *et al*., 2009). Both components exist in different configurations. To remove pollutants in the form of minute particles, physical treatment such as sedimentation and filtration are required, while chemical or biological treatment are required to removed dissolvable pollutants.

2.4.1 Nitrogen Removal

Nitrogenous components present in domestic effluents in the form of ammonia, particle organic nitrogen and soluble organic nitrogen. To remove nitrogenous components in wastewater, the processes of nitrification and denitrification are normally applied (Breisha *te al*., 2010). There are two aerobic stages associated with nitrification. In the first stage, oxidization occurs and ammonia is converted nitrite by a group of autotrophics. In the second stage, nitrites ate further oxidized to nitrate by another group of autotrophics (Vymazal, 2007).

Denitrification occurs in the absence of oxygen where nitrates are reduced to nitrites and then to ammonia and nitrogen gas. Denitrification can be attained using heterotrophics in anaerobic conditions, where oxygen molecules in nitrates are taken up by for metabolisms and produces nitrogen gas as metabolic by-products (Gerardi, 2003).

2.4.2 Phosphorus Removal

Total phosphorus presents in the form of soluble and particulate phosphorus. The main components of phosphorus in wastewater exist predominantly as orthophosphate associated with a small amount of organic phosphorus. Wastewater from domestic and the industry commonly contain phosphorus concentration between 3 and 15 mg/L (Grubb *et al*., 2000), while the highest level permitted prior to discharge is 1 mg/L (Tran *et al*., 2012).

Chemical treatment is commonly practiced and is the most feasible option for removing phosphorus by changing the forms of soluble phosphorus to insoluble particles and further removed through settling or filtration (Qasim, 1999). The biological phosphorus removal is a microbial process widely used for removing phosphorus from wastewater to avoid eutrophication of water bodies and is a cost-effective method for wastewater before being discharged into the streams and rivers. Biological treatment in removing pollutants from effluents is seen as a good alternation to conventional methods, such as incinerator or landfills disposal (Krishnaswamy *et al*., 2011).

Biological treatment of phosphorus was reported by Kim *et al*., (2011). They studied intermittent aeration system with changing flow in mobile media biofilm reactor and examined the efficiency of water purification system using synthetic wastewater. The system being conducted in a laboratory scale, they used 5.5 L reactor and removed 97.7%, 73.1% and 9.4% of organic matters, total nitrogen (TN) and total phosphorus (TP), through the operation of 4 hr cycle on system and 10 days SRT and 8 hr HRT. The maintenance of solids loading in the reactor is conducted at MLSS 1200-1400 using 25% volume media packing. An up flow anaerobic-aerobic fixed bed (UA/AFB) combined reactor using a synthetic wastewater was applied by Moosavi *et al.* (2005). The system was controlled at 5 HRTs between the period of 5 and 24 hr; and results showed that the HRT of 7 hr was suitable for simultaneous removal of COD nitrification and denitrification. Removal rates of 95.4, 94 and 94.5% were achieved for COD, nitrification and denitrification respectively. However, the reactor shows good performance in phosphorus removal. Mendoza *et al.* (1997) studied the nitrification in an up flow and down flow BAFs. They found that up flow and down flow BAFs attained similar suspended solid, soluble, and total COD removal even though the rate of nitrification in the down flow were two times higher than the up flow reactor. While (Grasmick *et al.,* 1984) compared the nitrification in up flow and down flow BAFs and it was discovered that the efficiency of down flow reactor is higher than the up flow unit at higher rates of ammonia loading. Figure 12 shows the schematic drawings of up flow and down flow of biological aerated filter (BAF).

Levstek and Plazl (2009) carried out a pilot study on the impacts of using different types of carrier on the process of nitrification. Two distinctive carriers were used in the experiment; a high density cylindrical polyethylene ring shaped carrier (AnoxKaldnes, K1 carrier) and a spherical Polyvinyl Alcohol (PVA) gel bead shaped carrier (Kuraray, PVA-gel carrier). The results show that there are difficulties in comparing the performance of the two different carriers due to difference in filling fractions and reactor capacities. K1 carrier and PVA-gel beads showed identical maximum rate of nitrification, where the rate up to 3.5 gNH_4-N/m^2d was indicated for K1 carrier and 3.1 gNH_4-N/m^2d for PVA-gel beads. Mannina and Viviani (2009) investigate the nutrient removing performance of moving bed bioreactors at 33% and 66% filling ration and noticed little performance variation in terms of wastewater constituent removal.

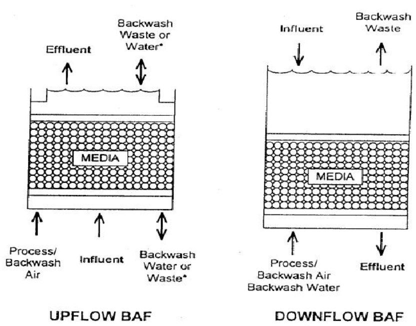


Fig 12: Schematic drawing of up flow and down flow biological aerated filters (Mendoza-Espinosa *et al.*, 1999)

The application of fixed bed biofilm reactor for removing nitrogenous constituents from sewage was studied by Lee *et al.*, (2001). An 11.2 m^3 laboratory-scale fixed bed biofilm reactor consist using anaerobic, anoxic and aerobic condition in series and filled by bar- type media. They tested two hydraulic retention times of 7.6 and 10 hours under various loading rates and temperature conditions. The removal efficiencies of BOD_5 and COD were 87% and 77% under highest organic loading rate of 0.95 kg COD/m^3.d. There was no significant difference by changing of temperature between 10 and 29^{o}C. The results show that at 7.6 hrs of HRT the nitrification efficiency was maintained over 92% until the loading rate reached 0.13 kg N/m^3.d and then gradually decreased. However, at HRT of 10 hrs, the efficiency of nitrification was maintained over 95% up to loading rate of 0.28 kg N/m^3.d. 94.6% of COD removal and 95% of ammonia-N removal was achieved when various structures of fibrous carrier were used in anaerobic conditions (Zhang *et al.,* 2007).

Studies on the integration of biofilm and activated sludge system for removing nitrogen and phosphorus constituents using biological treatments was done by Liu, (1996). The system applies fibrous carriers installed in an anoxic tank to stimulate the growth of denitrifying bacteria, while phosphate was removed by channelling sludge to the anaerobic tank. The initial effluent contains 319 mg/L of COD, 60 mg/L of NH_4-N of and 10 mg/L of total phosphorus. Using a total HRT of 20-30 hours and a temperature of 10–15^{o}C, results showed the final COD of 39.4 mg/L,1.3 mg/L of NH_4-N,13.4 mg/L of NO_3-N, 0.6 mg/L of NO_2-Nand 0.8 mg/L of total phosphorus in the final effluent.

2.5 Nano Technology Applications in Biofilm

Nanomaterials refer to chemical components produced at a scale ranged at 1-100 nm.

Several distinct characteristics are associated to the components such as higher strength, rates and chemical reactivity (Cristina *et al*., 2007).

Kriklavova and Lederer (2010) developed nano fiber carriers to use in biofilm reactor for the treatment of industrial wastewater. They found that too small a layer would not support microbial growth and too large a layer would be too costly to manufacture, the researchers found the optimum amount of nano-layer fibre filling. From the visual evaluation of the temporal development of the growth of biofilm on the carriers, they state that the best combination, from the point of view of the speed of colonization, is the nano-yarn marked (Layer of nanofibres 2) as seen in Figure 13. A comparison study was made between the commercial AnoxKaldnes carriers type of K3 as seen in Figure 14, made with a particular surface area of 500 m^2/m^3 and the nanofibre carrier with specific biofilm surface is more than 1000 m^2/m^3. The results show that the bacterial biofilm captured very slowly on the commercial polyethylene AnoxKaldnes carriers. This slow growth is caused by a lack of adhesion of the microorganisms to the surface of the carrier. On the other hand, in the first few days of colonization the microorganisms settle directly on the layers of the nanofibre. The presence of these layers is essential for rapid colonization. The growth of biofilm on a carrier with nanofibre layers is up to four times better than commercial AnoxKaldnes technology.

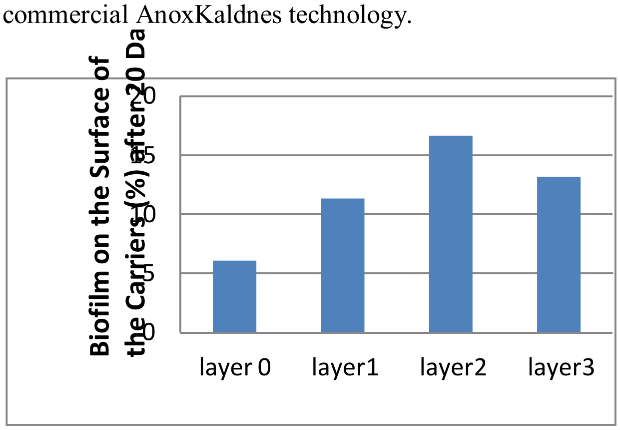


Fig 13: Evolution of biofilm growth on various layers of nano-carriers (adopted from Kriklavova and Lederer, 2010)

The culture's efficiency of biofilm on a fibrous carrier at pilot-scale consisting of four reactors in series using 0.82 day HRT resulted in total COD removal of 92.8% and ammonia-N concentration of less than 1mg/L at 98.1% (Szilagyi *et al.,* 2011). A unique polypropylene fibrous artificial biofilm carrier with different filling ratio at each reactor stage is included to evaluate the system's efficiency at different conditions.


Fig14: Biofilm carriers KMT (K3)

The process was operated in aerobic condition without re-circulation for the removal of organic constituents and nitrification.

Monosov (2008) developed a fibrous structure forming textile from filaments to decrease the generation of sludge in biological reactor. According to the researcher, the biological treatment resulted in 30 mg /L of TSS in wastewater.

Conclusions:

Nowadays the amount of wastewater is rapidly increasing due to increasing world's population. Therefore, better system is urgently needed to meet the standard effluent and in providing the volume needed due to the increase in flow and organic loading. In the recent years, biofilm technology is becoming increasing widely used in different countries for treating wastewater under various loading and operation conditions, effective for both BOD and nitrogen removal. Attached growth results the maintenance of higher biomass content in reactor comparing to suspended growth system such as activated sludge. This can make the reactor less in volume and reduces the dependence on biomass separation where a high separation (up to 10 times) is required. Researchers continue to focus on the development of biofilm technologies, and there is a high potential in extending the system on nutrient control applications.

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