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A REVIEW ON SEWAGE TREATMENT AND POLISHING USING MOVING BED BIOREACTOR (MBBR)

JAMAL ALI KAWAN*, HASSIMI ABU HASAN, FATIHAH SUJA, OTHMAN BIN JAAFAR, RAKMI ABD-RAHMAN

Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
43600 Bangi, Selangor, Malaysia
*Corresponding Author: jamal_kawan@yahoo.ie, hassimi@ukm.edu.my

Abstract

Effluent treatment and polishing using moving bed bioreactors (MBBRs) are advanced technique in biological treatment operations become increasing widely and popular use all over the world to treat various types of effluents with very different operating status. It is a combination of two separate processes suspended and attached growth systems for the treatment in order to minimize the concentrations of the contaminated parameters at the required level for reuse or final destination. The MBBR has been proved to be effective in great removing biochemical oxygen demand (BOD) and chemical oxygen demand (COD) with nutrients (N and P) from the effluent stream simultaneously. It provides additional capacity of wastewater treatment technology with high treatment efficiency; low capital, operational, maintenance and replacement cost; single reliable and robust operation procedure. This process can be used for new sewage treatment works or for modifying (upgrading) existing wastewater treatment plants as it is efficient, compact and easy to operate. The efficiency of MBBR depends on the filling percent of biofilm carriers to be provided inside the tank, surface area of the biocarrier, diffused aeration supply and the organic loading. The aim of this paper is reviewing the sewage treatment and polishing using moving bed bioreactor MBB technology as an alternative and successful method. It presents the advantages of the MBBR compared to conventional waste water treatment. The review also includes many relevant researches carried out at the laboratory and pilot scales plants that could improve these systems by enhancing performance and reducing costs.

Keywords: Moving bed biofilm reactor (MBBR), Biofilm carriers, Plastic media, Effluent Polishing, Wastewater treatment.

1. Introduction

In general, biofilm process is rising well favoured over activated sludge systems (AS) for nutrient and organic carbon removal. The advantages of biofilm systems over AS systems are more compact, thus the treatment capital costs are reduced. The generation of biomass that needs to be separated is significantly lower and therefore, alternative solids separation systems which have lower footprints and higher efficiency such as floatation and filtration can be considered. The attached biomass in biofilm-based process results in the ability to operate at high concentrations of active biomass, which increases the biological removal rate and makes them more resistant to overloading and toxic compounds [1]. In biofilm-based processes, the biomass can be specialized for specific treatment purposes [2]. For example, nitrification and de-nitrification can successfully be achieved in biofilm-based processes since nitrifiers, which are slower growing micro-organisms, are retained by the biofilm [3, 4].

While biofilm systems have been developed to take advantage of these characteristics, they do have their challenges as well. For example, trickling filters require high volumes, rotating biological contactors are subject to mechanical failures, fixed media submerged biofilters have difficulty maintaining even flow distribution on the media surface and granular biofilters require back washing and hence cannot be operated continuously.

Moving bed biofilm reactors (MBBR) have been developed to overcome these drawbacks and still benefit from their advantages [2]. Advantages of MBBRs over the other biofilm reactors include the lack of a requirement for backwashing, they are not prone to clogging, they can be operated continuously, they provide high surface area for microbial growth, and they have a low head loss [5].

The objective of this paper intends to provide the advantages of the MBBR compared to conventional waste water treatment. The review includes many relevant researches carried out at the laboratory and pilot scales plants.

2. Description of MBBR

The exploitations of a ceaselessly moving little suspended carrier parts in moving bed bioreactor (MBBR) is a new approach in biological sewage treatment technology for the preservations of water and is gaining momentum worldwide. However, in this method (MBBR) carrier parts are fashioned to be somewhat heavier, but most times lighter density of the containing liquid or water, but often made with an oversized extent that allows it free movement with the water or liquid section of the reactor. According to Loukidou and Zouboulis [6], this system of free circulatory movement of suspended carrier parts in the water allows the biomass to be fully grown on those carriers. The system of operations of the MBBR is likewise identical with the Integrated Fixed-film Activated Sludge (IFAS) method [7], although the IFAs presents a slight different approach in that the arrangement of the IFAS systems comprise of a return activated sludge stream which is essential to the IFAS process. In the MBBR method, Schmidt and Schaechter [8] admit that more than 90% of biomass are likely trapped and cultivated in the media instead of being suspended in the liquid. This can be associated with the facts that (i) the carriers are made to remain in suspensions within the reactors due to perforations or screen arrangement at the discharge [9, 10]; (ii) the carrier is deliberately designed with a small polyethylene cylinder- like materials with potentials to have a high specific surface area to accommodate biofilm growth. This therefore further eliminates the requirement for the reactor to have a sludge recirculation to achieve the specified optimum biomass concentrations while allowing only the surplus biomass to be separated with ease from the effluent and (iii), the additional advantage of the MBBR over the typical activated sludge system is seen in the high Solids Retention Time (SRT) that can be realized thence usually quantity of sludge production be below this typical activated sludge process and implying a lower cost of sludge disposal in MBBR relative to the typical activated sludge systems. However, the movement of the carrier inside the reactor, as noted by Borkar et al. [11], could be a performance of the aeration within the aerobic reactors as shown in Fig. 1(a), whereas in the anaerobic or lack of oxygen reactors it is generated by a mechanical stirrer as shown in Fig. 1(b).

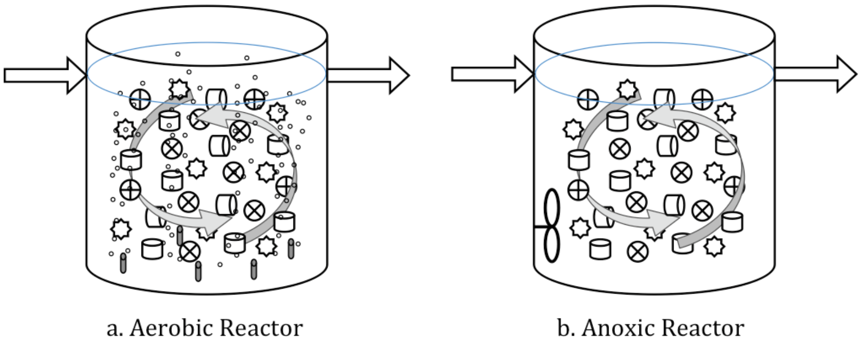


Fig. 1. The mechanisms of the moving bed bioreactor.

3. Growth and Detachment of Biofilm 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 [11]. 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 are grown in a five stage process [12]. As shown in Fig. 2, the early level consists of bacterial attachment to medium. Bacterial proliferation then leads to colonisation of the enclosing space and forms biofilm after dispersion.

Bacterial growth in a batch reactor can be characterized by four distinct phases and represented by the Monod growth curve [13]. Batch growth is a process in which a culture is grown in a vessel of fixed volume and the contents are removed after a measured amount of time. The growth conditions within the vessel are constantly changing. Batch growth undergoes four distinct stages: lag phase, exponential growth phase, stationary phase, and death phase. These stages are described in Table 1 and Fig. 3.

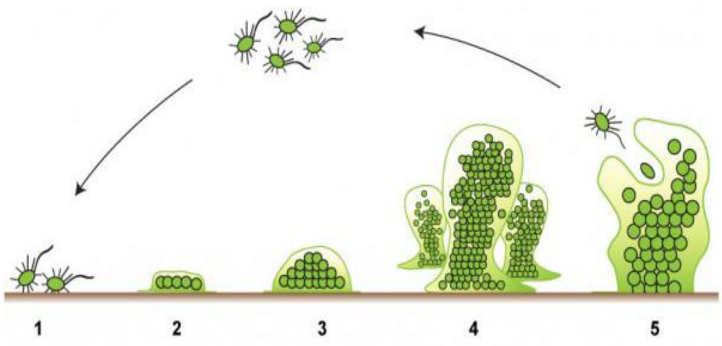


Fig. 2. The stages of biofilm formation [12].

Table 1. Description of the four phases of bacterial growth in a MBBR.

Phase	Description
Lag	Acclimatization stage where cells adapt to their new environment; could be very long depending on inoculum age
Exponential	Nutrients and substrates are in excess; cells have adapted to their environment and grow rapidly; no inhibitions
Stationary	Net biomass growth is zero; nutrients and substrates become limited; growth rate is offset by death rate; cell lysing may be occurring; inhibition may be occurring
Death	No or little growth is occurring; biomass concentration declines at a first order rate

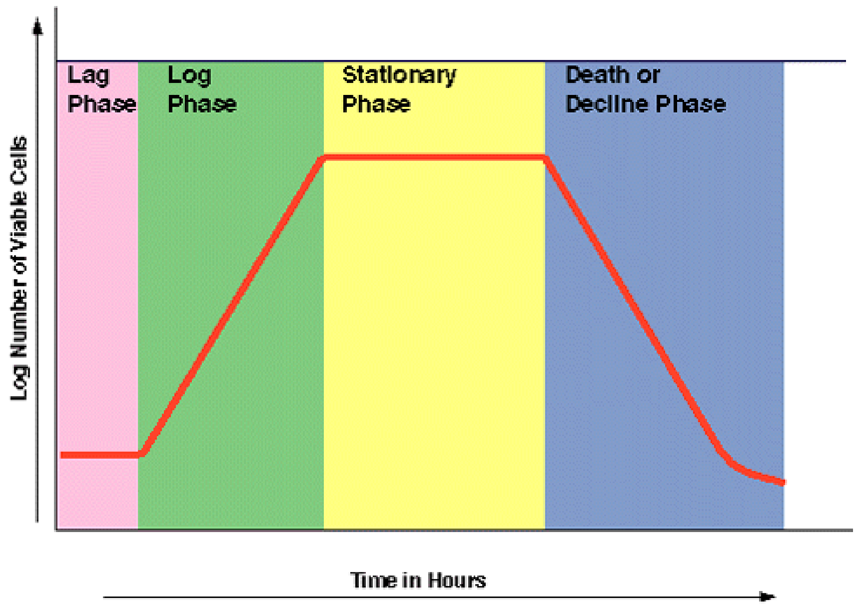


Fig. 3. Monod growth curve characterized by four phases.

4. MBBR Development

The MBBR has its origin in Norway and emerged from the University Science and Technology of Norway within corporation known as Kaldnes Miljǿteknologi or Anox Kaldnes. During 1989 it was the earliest MBBR, though comparatively new technology, but has been introduced in the US as far back as 1995. Currently, there are over four hundred wastewater treatment plants around the world in each of municipalities and industries sections with more than thirty six (36) in North America [11]. However, the idea for the development of the MBBR method was to optimize reliability and the most efficient features of the activated-sludge method in combinations with biofilter method which offers the opportunity and advantages that could be gained from efficient sewage treatment technology [9]. Moreover, owing to the characteristic ability of this organism to stick on surface to make a fixed layers from polymer to be guard itself from sloughing [14] the MBBR method takes this advantage and apply it to the microorganisms growth in the biofilms above the media carrier that move free inside the sewage [10].

In the recent, Moving Bed Biofilm Reactor (MBBR) have been applied in the relevant fields of research of wastewater treatment and is further gaining rising study interested, its applications to remove biodegradable organic materials. The method at the same time has undergone numerous degrees of modification and development in various applications. However, the first application of the moving bed biofilm reactor (MBBR) was for municipal waste material in terms of gas removal [15]. Afterwards, different applications emerged, including enhanced MBBR for chassis removal, phosphorus removal, nitrification and denitrification for municipal and industrial waste material treatment [16]. An important aspect about the MBBR technique to note is the choice of the carrier; this play the most vital and critical part in the systems achievement. Therefore, selecting efficiency carriers is vital for optimal results in the MBBR method. Hence, scientists worldwide are into more research testing for a carrier that is economical with the combined advantages of having surfaces that can enhance microbial growth and hence the improvement of MBBR performance.

5. The Advantages of MBBR System

In the literature useful information on the advantages of the MBBR method have been clearly outlined. Some of the most noteworthy points include that pointed out by Loukidou and Zouboulis [6]. According to these authors, MBBR method have the advantage of higher biomass concentrations, reduced sensitivity to toxic compounds and the absence of long sludge settling periods.

Schmidt and Schaechter [8], noted that that the method is less disposed to the process disturbances from poorly settling biomass that is not found in other methods. In the view of Fang [17], the method is generally economical (cost effective) over other known methods. Furthermore, Horan et al [18] agree that both organic and ammonia removals are efficient and could be achieved in a single stage in the MBBR method.

In addition, moving bed biofilm filter within its small footprint compared with the activated sludge treatment has an advantage of a small property area requirement which is just one fifth to one third of that needed for activated sludge treatment [19]. According to this same author the MBBR also has the cooperative advantage and a lower temperature effect on the rate of biological nitrification.

Although, operational costs may be higher in the MBBR method than that of activated sludge treatment, but the systems (MBBR) is more efficient for BOD removal and tertiary nitrification and denitrification resulting in suspended or attached growth nitrification [20]. Haandel and Lubbe [21], point to the fact that the MBBR system has become very popular for use in industrial applications and other applications with high variation in the expected load in time owing to the advantages of the MBBR system flexibility of carrier's fill fractions.

More interesting findings and advantages of MBBRs compared to that offered by the fixed-bed biofilm reactors are the MBBRs method use full tank size because the carriers move randomly within wastewater [10] and eliminating the case of cyclic backwash [22]. Therein fixed filter it is painstaking to achieve an excellent distribution of the load on the filter. This drawback doesn't exist in MBBRs since the carriers move freely within the wastewater [23]. More importantly, a biofilm reactor area is particularly useful when desired for slow-growing microorganisms because the carriers could prevent wash out [24]. Other advantages is that already existing overladen activated sludge processes may be easily converted into MBBR processes without the need for building or reconstructions of new tanks [22] and excess sludge only need to be separated [10].

Considering the number of advantages of the MBBR method, some factors have also been noted to have an effect on the performance of MBBR. The high specific area of the carrier media dictates the system performance due to high biofilm concentrations presence in a relatively small reactor volume owing to the lack of the need of sludge recycle [9]. Therefore, it been reported that typical biofilm concentrations vary from 3000 to 4000 g TSS /m^3 which is comparable to the results achieved in activated sludge processes with high sludge ages. Table 2 shows the advantages and disadvantages of MBBR compared with other systems**.**

6. Previous MBBR Study Efforts

The MBBR method as mentioned earlier came into existence in Norway and this was between the late 1980 and early 1990, and the development represents a unique field in advanced waste material treatment [15]. MBBRs were operated much more in the same manner as the activated sludge method with the addition of freely moving carrier media but without sludge circulation. However, there are a number of references on the MBBR methods and series of paper have been published. Most of these documented reports present important findings and development of the MBBR and waste treatment technology. Some of these are highlighted in this review.

Rusten et al. [25], through numerous testing gained knowledge from a number of studies and data were gathered from small scale effluent treatment plants and hence the onset of the Moving Bed Biofilm Reactor systems. In the earlier stage of the discovery the focus was directed to organic matter removal in MBBR systems while at present is used as complete treatment solutions or with alternative treatment processes (hybrid system) together with AS and membrane bioreactors for excessively polluted waste water.

Table 2. Advantages and drawbacks compared with activated and granular sludge and fixed biofilm systems.

System	Advantages	Disadvantages
Activated Sludge	- Conventional and common process - Large surfaces	- Usually low sludge settling ability - Foaming and sludge bulking problems - High surplus biomass production - Vulnerable to shock loads or high concentrations of toxic compounds in the influent
Granular sludge	- No need for a clarifier if SBR is used - Higher biomass retention - No sludge return - Higher settling ability - Co-existence of aerobic and anoxic microorganisms on granules - Highest rate of reaction/m^3	- More complex operation (in case of SBR) - Discontinuous discharge (in case of SBR) - Extensive shear stress may damage granules - Start up period may be long
Fixed film (RBC)	- No need a clarifier - Low energy consumption -Alternation of oxic and anoxic conditions -Co-existence of aerobic and anoxic microorganisms on the disks	- May need maintenance
Fixed film (Trickling filter)	- No need for a clarifier	- Problems of clogging and maintenance
MBBR	- No need for a clarifier or biomass recirculation - Low sludge production - High specific surface area and higher biomass density - High biomass retention (high sludge age) - Small footprint - Possibility to upgrade existing systems - Co-existence of aerobic and anoxic microorga-nisms in biofilms - More robust technology and resilient bacteria population - Possibility to handle high loads or temporary limitations - Easy to operate and simple design - Low maintenance required - No problem of clogging	- Longer start up period may be required

An interesting case is that of Nogueira et al. [26] who studied the influence of factors such as dissolved oxygen concentration on the nitrification dynamics within the circulating bed reactor (CBR). The study was addressed partly at laboratory scale with synthetic water, and partly at pilot scale with secondary effluent as feed water. The most remarkable results of Nogueira et al. [26], is that this authors identified that the nitrification kinetics of the laboratory CBR as a function of the oxygen concentrations can be described according to the half order and zero order rate equations of the diffusion reaction model applied to a porous catalysts. In this regards the authors pointed out that when oxygen was the rate limiting substrate, the nitrification rate reached a half order function of the oxygen concentration. By fitting the diffusion-reaction model to experimental result, the average oxygen diffusion coefficient estimated by these same authors was around 66% of the respective value in water. These authors were therefore able to show in their experimental results that either the ammonia or the oxygen concentration could be limiting factor for the nitrification kinetics.

According to Odegaard [27], the elemental characteristic of the MBBR was the unique design of biofilm carriers, in which the geometric shape, sizing and materials of the construction had been considered thoughtfully to maximize performance. This was a key distinction from the activated sludge method where treatment performance was directly associated to reactor volume. In the MBBR, surface area could be increased by planning carriers to have a high specific surface area or by adding greater quantity of carriers to a reactor volume. This therefore offers the flexibility for future treatment capacity upgrades without requiring the constructions of additional reactors.

Karamany [28], had been involved in investigating the performance of combined reactor model. For this purpose simulations comprising of both suspended growth biological reactor and attached growth biological reactor were constructed to envisage the effects. The set-up had comprised of the RBC with fill and draw cups and diffused air. However, the fill and draw cups were intended for simulating the attached growth reactor, while the diffused air simulated the suspended growth reactor. This researcher, Karamany [28], further investigated the rate of oxygen transfer applied to four (4) different configurations; three (3) were tested using tap water and the fourth set of experiment was made using primary treated wastewater.

Notably, Maurer et al. [29], performed a detailed investigation on denitrification in a full-scale installation and another in a pilot plant for moving bed biofilm treatment (MBBT). Two different types of carriers were employed and investigated in conventional activated sludge reactors. These were: foam cubes and plastic tubes (Kaldnes®). The two investigated carriers showed similar behavior with regard to the results obtained for denitrification capacity, temperature dependency and maximum COD and nitrate removal. However, the most important finding was that in contrast to the plastic tubes (Kaldnes®), the sponge cubes stored remarkable amounts of substrate. The maximum denitrification rate with acetate as a substrate was 420 g N/m^3.d at 10 ºC and 730 g N/m^3.d at 20 ºC. An average denitrification rate of 240 g N/m^3.d (10 ºC) was achieved with wastewater. A maximum of about 37% of the COD in the influent was denitrified with a volumetric loading rate in the anoxic zone of 2.2 kg COD/m^3.d.

Some other interesting investigations are to be noted**.** These include the studies of Andreottola et al. [30], who evaluated the feasibility of the application of an MBBR system for the upgrading of overladen municipal wastewater treatment plant (MWWTP). The author presents findings that showed that the MBBR solution was feasible and could be considered to offer several advantages including better potential in the nitrification process, ease of management and the chances to use the existing tank with very few modifications.

Rodgers et al. [31], on the other hand present an excellent review of four (4) types of moving medium biofilm reactors for the treatment of wastewater. This study proved to be of great interest. Their review was however, based on published case studies and covers areas such as: rotating biological contactor (RBC), moving bed biofilm reactor (MBBR), vertically moving biofilm reactor (VMBR) and fluidized-bed reactor (FBR). Their overall conclusions was that among many of this methods the MBBR is an excellent and better process for upgrading existing wastewater treatment system.

One should forget the work of Borghei et al. [32], these authors had a focused studies and employed the Moving Bed Biofilm Reactors in treating completely different domestic and industrial wastewaters. At the moment, there are over four hundred units of full scaled sewer water treatment that have embraced this method.

Others in the likes of Verma et al. [33] conducted a survey on aerobic bio-filtration processes for wastewater treatment. They assess a range of systems (both conventional and advanced bio-filtration), including MBBR systems. This author maintained that MBBR process is reliable for the upgrading of existing wastewater treatment systems. However, in their findings they noted that generally, for fluidized systems (including MBBR systems), capital costs are comparatively low, but operating costs are higher due to pumping/aeration requirements.

Åhl et al. [34] proved further that the aeration system additionally, provided enough oxygen required in such a way that the outer surfaces of bio films were aerobic and so were capable of reaching comparatively fast biodegradation. According to these research findings of Åhl et al. [34], the bio films grew and were partly detached from the carrier while the detached parts were carried by the liquid into the secondary clarifier for separation. The authors concluded that the biologically-produced solid production of this technique was more than ten times than that of the AS systems.

Rusten et al. [23] describing in a study was able to show that the traditional systems such as trickling filters were not volume effective while mechanical failure has been a common problem associated with the RBCs. The authors emphasized also that it difficult for even distribution of the load over the entire carrier surface in fixed media submerged bio filters. However, in the past decades, some renewed interest had increased in biofilm processes for wastewater treatment with new technologies being developed showing improved performance compared to traditional biofilm systems. Odegaard [9], operated MBBRs in much similar way as the activated sludge method but with the addition of freely moving carrier media.

Brinkley et al. [35], in their studies noted several constraints as regards to upgrading of several existing sewer water treatment facilities for improved effluent flows. However, several of these existing facilities present some challenges relating to constraints on area for enlargement. The author therefore concluded that the

MBBR method which is flexible is good for upgrading existing treatment plants especially those that were limited in area such as with small or narrow field.

Brinkley [35] researched on the processes that would treat variable high strength wastewater in a relatively small area but with provisions for future expansion. The author was on the choice of the MBBR process due to the outstanding results and success the process had for treating high strength wastewater which could be applied and comparable to pharmaceutical applications. However, treatment were carried out with 0.5 million gallons per day (mgd) MBBR process consisted of two reactors operated in series of designs to treat effluent BOD_5 of 3,197 mg/L and less than 75 mg/L, respectively.

Delnavaz et al. [36] was of the opinion that that MBBR is appropriate alternative for common activated sludge reactors in treating domestic and industrial wastewaters in large scale. Three moving bed biofilm reactors were tested and used to treat synthetic wastewater of aromatic amine compounds. These reactors were cylindrical shape had an internal diameter and an operating depth of 10 and 60 cm respectively. The reactors were filled with light expanded clay aggregate as carriers and operated in an aerobic batch in ceaseless continuous conditions. Evaluation of reactor's efficiency was done at different retention time of 8, 24, 48, 72 hours with an influent COD from 100 to 3500 mg/L. The filling ratio was 50%. The maximum obtained removal efficiency was 90% (influent COD= 750 mg/L), 87% (influent COD = 1000 mg/L), 75% (influent COD= 750 mg/L).

Aygun et al. [4] studied moving bed biofilm reactor (MBBR). Attention was directed to areas where biomass were hooked up to little carrier parts that were moving freely at the side of the water within the reactor. The authors tested this for for organic matter removal at Five (5) completely different organic loading rates. A lab-scale reactor with a volume of 2 L was designed and fed ceaselessly with artificial sewer water (or waste water). The reactor was full of the Kaldnes biomedia K1 that was employed in the patented Kaldnes Moving Bed biofilm method at 50% volume of empty reactor. Hydraulic retention times (HRT) within the reactor and within the settler were operated to be between eight (8) and four (4) hours, respectively. An initial start-up period of four weeks for biofilm growth on the carrier was followed by another ten weeks testing period. By changing the sewer water composition, the operation of the system was adjusted, one at a time to (five) 5 completely different organic loading rates of 6, 12, 24, 48 and 96 COD/m².d. The findings were that organic removal potency declined with increasing organic loading rate, in the range of 95.1%, 94.9%, 89.3%, 68.7% and 45.2% as the organic loading rate was subsequently raised from 6 to 96 g COD/m².d.

In additions to the group of studies that were conducted, notably, Kermani M. et al. [24] assessed the moving bed biofilm method conducted in a laboratory scale for organics, phosphorus and nutrients removal from artificial wastewater. For nutrients removal, moving bed biofilm method had been applied in series with anaerobic, anoxic and aerobic units in four (4) different reactors. Moving bed biofilm reactors were operated ceaselessly at completely different loading rates of nitrogen and Phosphorus.

Nikhitha et al. [37] carried out a study where five (5) liter capability reactor was employed as a moving bed biofilm reactor with rubber foam as carrier material. The study of the carrier material was done and also the experiments were conducted in aerobic batch mode. Laboratory experiments were done at room temperature and synthetic wastewater comprised of phenol as the main organic constituent. In additions balanced nutrients and alkalinity were fed to the reactor and tests were conducted for numerous phenolitic concentrations of 10, 50, 100, and 400, respectively. The results indicated that the removal potency of phenol and COD is influenced by the Hydraulic Retention Time (HRT) and also the initial phenol concentration that was fed into the reactor. The utmost efficiency was achieved at eight days for an initial phenol concentration of 400 mg/L and also the same at two (2) days for a lower phenol concentration of 10 mg/L. For wastewater containing low phenolic concentration, most potency was obtained at lower HRTs than that for higher concentrations.

The works of Zafarzadeh et al. [38] was able to show by experiments in moving bed biofilm reactors (MBBRs) on incomplete (or partial) nitrification process in pilot plant configuration for 300 days. Investigations had been based on the effects of dissolved oxygen (DO) and associated influent ratio of chemical oxygen demand to nitrogen (COD:N) ratio of biological nitrogen removal from artificial wastewater. This same researcher was able to reveal and provided evidences that operational conditions (such as 500 mg COD/l, 35.7 mg NH4-N/l, 7.14 mg PO4-P/l, HRT = 20 h, Qr/Q = 3) fluctuations in the concentration of DO had no negative influence on COD removal rate in R2 and complete soluble organic carbon removal of about 99% efficiency were achieved and occurred in the total MBBRs system.

The study carried out by Di Trapani et al. [39] was more or less a comparative study. This same author conducted a pilot-scale comparison between a traditional AS treatment system and a MBBR treatment system. The aerobic reactor in each system adopted was of similar size. The MBBR system was efficient to treat twice as much amount of wastewater as the AS system and yet maintaining similar performance in organic and nitrogen removal. The same authors, in their conclusions pointed out that that the higher treatment efficiency of the MBBR system demonstrates that it's a better technology for the upgrading of overladen wastewater treatment plants.

Reliable investigations by Kim et al. [40] demonstrated that that intermittent aeration process may be simply applied to the existing activated sludge system and could be extremely reliable against the loading changes. The existing intermittent aeration method with alternating flow being applied on the oxidization ditch was also applied on the continuous flow agitated (disturbed tank) reactor with advantages from both processes. The author pointed out that these could also be extended to the development of the process to considerably reduce the return of sludge in the clarifier and to secure a better quality of treated water by employing the moving media. However, test were conducted in a laboratory scale had been operated in HRT 8 eight hours apart from the ultimate clarifier and this showed the removal efficiency of 97.7%, 73.1% and 9.4% in organic matters, TN and TP, respectively with operational range of four (4) hour cycle system SRT 10 days. After adding the media, the removal potency of phosphorus showed similar level to that before the addition. However, the removal efficiency of nitrogen was better and achieved at 7~10. In addition to this, the solids that were maintained in the MLSS 1200~1400 at 25% of media packing were attached onto the media and no sludge was allowed coming into the clarifier.

Sombatsompop et al. [41] studied assumes a comparative study on the efficiency of pig farm wastewater treatment by the applications of the moving-bed sequencing batch reactor (moving-bed SBR) system withheld medium, and also the typical sequencing batch reactor (SBR) system, by assigning the organic load from 0.59 to 2.36 kg COD/m³.d. The COD treatment potency of the SBR and moving- bed SBR was greater than 60% organic load of 0.59 kg COD/m³.d and higher than 80% at the organic loads of 1.18-2.36 kg COD/m³.d. When the organic load was increased the moving-bed SBR system yielded higher treatment efficiency than that of the SBR system.

Yang et al. [42] verified Moving Bed Biofilm Reactor (MBBR) technology as an alternative and successful method to treat different kinds of effluents under different conditions. Due to the fact for the non-requirement to analyze the bio solids dynamics and how they are influenced by process changes relevant to applied wastewater treatment systems suggested new routes to reactor design and optimization and therefore the biofilm growth, detachment and modeling of MBBR continue to draw important research attention.

Mahmoudkhani et al. [43] conducted a study that was geared toward treatment of waters around Teheran industrial plant contaminated with crude oil compounds. During the study period a laboratory scale with a total liquid by volume of 550 Litre was used. The reactor was filled with 85% of polyurethane elements occupying 3% of the reactor's liquid volume. Pilot conditions were as follows, Temperature= 15 to 25 ° C, pH= 6.7 to 7.5, dissolved oxygen = 4 to 5 mg/L, MLSS= 1400 to 1700 mg/L Hydraulic Retention Time (HRT) = 240 minutes and unlimited Solid Retention Time (SRT). After suspended oil removal was carried out by oil separation system, COD, NO_3-N and PO_4-P removal efficiencies in the case of the MBBR, filtration and activated carbon was 99, 94 and 58%, respectively. The results of the average effluent from each reactor showed that denitrification process preceding the aerobic MBBR, filtration and activated carbon and in pre-denitrification system in filtration, consumed most of the perishable organic matter. While, for the case of formaldehyde, phenol as well as total petroleum hydrocarbon (TPH) parameters, the removed in the pilot was by an amount of up to 96%, 79% and 94%, respectively.

Barjenbruch and Exner [44] conducted project which was aimed to fill the information gaps and the lack of performance, including operational reliability and maintainability of the various different types of waste water treatment plant (SWWTP) under real operational conditions. The evaluation was carried out for duration of fourteen (14) months to match twelve (12) different pilot-scale effluent treatment plants.

Javid et al. [45] carried out a feasibility study of the possibility of upgrading and retrofitting municipal effluent treatment plants at laboratory scale employing Moving Bed Biofilm Reactor (MBBR) method. For this purpose, aerobic pilot was operated for nearly one year in several conditions, during which a moving bed carrier with a selected biofilm area of 500 m²/m³ and a filling rate of 60% was utilized. System efficiency in removal of BOD5 and COD was examined at different hydraulic retention times (HRTs) which were at 1, 1.5, 2, 2.5, 3 and 4 h. The results obtained showed indicated that the high ability of the system to tolerate organic loading and to stay stable at a high food to organism (F/M) quantitative relation. The system created effluents with good quality at low HRTs and lead to an average BOD5 removal efficiency of nearly 88% during the operational period. The Organic Loading Rate (OLR) applied to the system had a range of 0.73-3.48 kg BOD5/m³.day and 2.43-11.6 g BOD5/m².day, at which the reactor showed a good performance and stability.

Jafarzadeh et al. [46] conducted a study where simultaneous nitrogen, phosphorous and COD removal in a pilot-scale enhanced Sequencing Batch Reactor (eSBR) was investigated. The reactor consisted of a pre-anoxic zone and internal recycle and was fed with synthetic wastewater. The study was performed by operating the reactor in 6-hour cycles in three different operational modes during a time frame of 279 days. The results under the best operational conditions revealed that the average removal rate of COD, TN, and TP were obtained as 93.52, 88.31, and 97.56%, respectively. A significant denitrifying phosphorus removal (more than 80%) occurred at run1 and 3 which started the cycle under anoxic condition.

Gulhane et al. [47] carried out to analyse the performance of Hybrid Moving Bed Biofilm Reactor consisting of three reactors with the first reactor working on the principle of attached growth technology, second reactor working on the principle of suspended growth technology and third reactor working on the principle of moving bed biofilm technology, The study still under process, enhance hybrid moving bed bioreactor (HMBBR) efficiency by adopting certain modifications such as variation in media type, aeration capacity and proportion of biofilm produced in biofilm carriers during biological wastewater treatment. He is expected that the HMBBR working in combination with Attached and Suspended Growth Reactor will provide the best results as compared to normal Moving Bed Biofilm Reactor.

7. Factors Affecting MBBR System Performance

The performance of the MBBR biologically system is affected by several factors. These factors include, Hydraulic Retention Time (HRT), Surface Area Loading Rate (SALR), Dissolved Oxygen (DO), Carrier size and shape, carrier percent fill, diffuse, mixing and aeration rate. The impact of each will be explained in the detail in the sections below.

7.1. Carrier size and shape

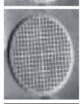
Several styles of carriers with varying shape and sizes have been developed to suit different applications. The emphasis according to Odegaard [2] is that that the filling degree may be chosen depending on the type of applications.

As regards to Odegaard et al. [48] who studied the influence of carrier’s size and shape on the performance of MBBR systems studies being carried out on carriers obtained from different makers. The researchers found the MBBR organic loading rates per carriers area (i.e. g COD/m²•d) to plays a crucial role within the treatment efficiency of MBBR reactors. Higher area was shown to considerably improve the performance of those systems. According to the findings of this same authors, specifically, the influence of the carrier area shows no distinction in removal rates between carriers with different shapes however with the same surface area.

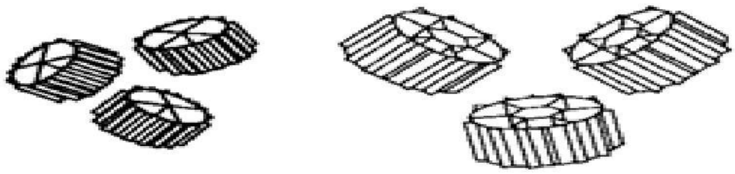
However**,** Robescu et al. [49] emphasized the need for a good design and planning of biofilm carrier which is necessary for a good mass transfer and nutrients to microorganisms and pointing out that the key parameters of the biofilm carriers are its shape and the percentage of the tank filled with it.

Vayenas [50] on the other hand was on the opinion that the attachment of organism to the surface and the resulting growth of the biofilm community rely upon the surface of the biofilm carriers that are rougher, more hydrophobic, and coated with surface-conditioning films. Therefore, the performance of the system was concluded to independent of the shape of carriers but rather related and totally dependent on the surface area of the carriers. Carrier types and properties are shown in Table 3 [51].

Table 3. The physical appearance of the media used in attached growth processes [51].

Manufacturer	Name	Bulk Specific Surface Area[1]	Dimensions (Depth; Diameter)	Carrier Photograph
Veolia Inc.	AnoxKaldnes™ K1 or K1 Heavy	500 m^2/m^3	7 mm; 10 mm	
	AnoxKaldnes™ K3	500 m^2/m^3	12 mm; 25 mm	
	AnoxKaldnes™ Biofilm Chip (M)	1,200 m^2/m^3	2 mm; 48 mm	
	AnoxKaldnes™ Biofilm Chip (P)	900 m^2/m^3	3 mm; 45 mm	
	AnoxKaldnes™ Matrix™ Sol	800 m^2/m^3	4 mm; 25 mm	

Odegaard [52] carried out a study on the 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 the outer fins as shown in Fig. 4(A). Lately one has introduced also a large carrier K2 of similar shape as shown in Fig. 4(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 is an 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. 4. Biofilm carriers (A) KMT (K1); (B) KMT (K2) [42].

7.2. Effect of percent fill

Trapani et al. [53] investigated the effects of different fill-fractions for MBBR process. The authors pointed out that that there was an associated degree of fill-fraction that could be higher by which the reactor removal potency diminished. This is attributed to competition between suspended and attached biomass and the significance of suspended solids within the MBBR. It was found out that with increasing degree of fill-fraction the suspended growth concentration decreases while low suspended biomass decrease the MBBR removal efficiency due to the significant role in enzymic hydrolysis reaction and bio-flocculation within the reactor. It is ascertained that a fill fraction of 35% had a higher COD removal efficiency better than a 66% fill-fraction. On the other hand, a 66% fill fraction rather had slightly better nitrification efficiency that were associated to higher concentrations of slow growing nitrifiers that were retained within the reactor. These results points to the facts an indicate that the fill fraction is a vital parameter in MBBR design which must be taken into considerations based on treatment objectives. The high specific area of the carrier media, which permits very high biofilm concentrations due to a small reactor volume, controls the system performance.

Odegaard et al. [15] was reported that typical biofilm concentrations vary from 3000 to 4000 g TSS /m³ which is similar to the results obtained in activated sludge processes with high sludge ages. Furthermore, it had also been inferred that, since the volumetric removal rate in the MBBR is several times higher than that activated sludge process, biomass in the former are much more viable.

Working on the effects of fill fractions, Wang et al. [54] directed their research to investigate the influence of carrier percent fill on the removal rate of contaminants, biomass and biofilm activity during a suspended carrier biofilm reactor. Percent fill is that volume occupied by the carriers based on the empty bed volume. In their findings it was noted likewise that as the carrier percent fill by volume increased from 10% to 75% the COD removal rate enlarged from 58.4% to 68.4% and 50%, then the removal diminished to 63.3%; thus the optimum carrier concentration ascertained was approximately 50%. It was observed also to be related with some degree to the suspended biomass concentration within the reactor; with increasing the carrier concentration the suspended biomass concentration within the reactors decreased. However, the typical biomass production on the carriers had a peak value at the 50% concentration of carriers [54].

According to Odegaard et al. [48] the percentage of reactor volume comprised of media is restricted to 70%, while 67% is typical. As pointed out by this author waste water characteristics and specific treatment goals are the most decisive factor in determine the percentage of media required in the reactor. The effective area of the MBBR carrier medium is reported to be 70% of the overall area due to less attachment of biofilm on the outer perimeter of the media.

As regards to the works of Lee et al. [1] this author demonstrated the effects of increasing percent fill of carriers. The authors found out that an increase from 5% to 20%, fill of carriers, microbial floc sizes diminished from 73.5 to 49.6 µm. This may be attributed to collisions between carrier particles as well as the suspended particles.

According to a study carried out by Shrestha [55] on MBBR with different filling rate as shown in Table (4), these results showed that the MBBR system achieved higher COD removal efficiency at 20% PE carrier filling rate under the same condition of influent organic loading rate, may due to carriers could move uniformly in 12 L reactor and give favourable surface area for microbial growth.

Table 4. Performance of MBBR in terms of COD removal efficiency [55].

Carrier filling rate (%)	**10**	**20**	**30**	**40**
COD RE (%)	78.02	92.13	87.14	80.39
OLR (kg COD/m³.d)	0.36	0.36	0.36	0.36
HRT (h)	25	25	25	25
Aeration rate (L/min)	4.5	4.5	4.5	4.5

7.3. Effect of diffuse and mixing conditions

Other factors reported to have an effect on performances are diffuse and mix conditions within the reactor, while adequate turbulence is good for efficient system performance. Notably, the biofilm thickness on the carriers poses some constraints in that it affects the size of the fraction of the biofilm with access to substrates. According to Odegaard [9] the substrates needs to diffuse into the biofilm and therefore the penetration could be limited. However, an even distribution of substrates over the biofilm is desired. In this wise the biofilm ought to be relatively thin and evenly distributed over the carrier surface. Turbulence on the other hand within the reactor increases the transport of substrates to the biofilm and this prevents the biofilm from getting too thick due to shear forces. Furthermore, Odegaard [9] pointed out that the thickness of the biofilm is additionally regulated by abrasion, erosion, sloughing, and predator grazing. Carrier movement plays a key role in aerobic MBBR as collision and attrition of media within the reactor induces biofilm detachment from the outer surface of the media. Therefore the MBBR carrier media is supplied with fins on the surface to guard biofilm loss and promote biofilm growth [48].

7.4. Impact of HRT

The efficiency of the MBBR may be improved by increasing the HRT, or through the utilization of multiple MBBR compartments [56]. As pointed out by Andreottola et al. [30] COD removal in MBBR system is influenced by hydraulic retention time (HRT) and suggested a HRT higher than 5 hrs for higher efficiency. However, higher HRT provides enough contact time for the biodegradation of OM and therefore, an extended contact time between support media and effluent enhances the waste material removal efficiency [57]. This might be associated with enough time for attachment of microorganisms on the carrier's surface and therefore, developing an active biomass layer on the carrier's surface. The optimum HRT is completely different due to the distinction in operational condition. For instance, Hajipour et al. [58] found the suitable HRT within the range of 12 to 16.5 hrs and lower performance was achieved when the hormone-replacement therapy decreased to 9 hrs.

If MBBRs are run on a higher organic loading rates, the hydraulic residence time would be quite low for efficient organic carbon removal. In these wise soluble COD is consumed quickly whereas the bulk of particulate COD passes through the reactor unchanged [2]. A challenge related to MBBRs operated at high organic loading rates is that the settleability of the sludge decreases [2]. The lower settleability in extremely loaded MBBRs is also due to the upper fraction of non-flocculated biomass leaving the reactor [5]. MBBRs could doubtless be operated at considerably higher loading rates or low HRTs. The HRT ought to be high enough for soluble organic matter (low weight matter) biodegradation and low enough to hinder the reaction and biodegradation of material within the feed (including mixture solids and high mass matter) [5, 16]. As a result, a compact effluent treatment method which may handle a high loading rate and includes high removal potency may be achieved.

7.5. Impact of SALR

Optimal removal efficiency was achieved at the threshold loading rate due to the fact that the removal potency of the MBBR is influenced by the biomass concentration in the reactor. In this regards Aygun et al [4] evaluated the impact of higher organic loading amounts on COD removal and sludge generation in moving bed biofilm reactor. The experiment was conducted employing a small scale reactor with an operating volume of Two (2) litres that was full of effluent 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/m².d. The study shows that a rise in organic loading rate from (6 to 96 g COD/m².d) was followed by a decline in organic elimination capability (ranged at 95.1%, 94.9%, 89.3%, 68.7% and 45.2%, respectively with the loading rates).

7.6. Dissolved element of oxygen

As suggested by Wang et al. [54] DO level in the reactor is required to be maintained higher than 2 mg/L for optimal COD removal. The same authors found out that by decreasing the DO from 2 to about 1 mg/L, the COD removal efficiency declined by 13% and therefore pointing to the fact that DO is limiting factor in the system. On the other hand, increasing the DO from a level of 2 to 6 mg/L raised the COD removal efficiency slightly only by 5.8%. Furthermore, their results also showed that concurrently, nitrification and denitrification (SND) may well be achieved during a single MBBR reactor with HRT of six (6) hours due to the limitation of oxygen diffusion into the biofilm. The very best N-removal potency (89.1% on average) was obtained once the DO was maintained at a 2 mg/L. At lower DO concentrations, anoxic conditions occurred and ammonia conversion to NO_2 or NO_3 was restricted and at higher DO concentrations anoxic condition denitrification within the deeper layers of the biofilm did not occur.

8. Interrelationship of The Biofilm Specific Surface Area with Mixing, Substrate Concentration and Predator Worms

It is important to understand the effect of predator worms and snails, mixing and substrate concentrations and their interrelationship on the biofilm specific surface area. While a certain level of predators can be observed both in fixed and moving bed systems, because of differences in mixing, they tend to be a greater nuisance in fixed bed systems. It is important to design methods to control predators to prevent worm blooms that can consume a substantial portion of the biofilm.

Mixing is necessary to maintain the proper biofilm thickness. In the absence of sufficient mixing, the biofilm may become thicker than required and fill in more of the crevices, thereby reducing the biofilm surface area. Also, observations in bench scale studies with a moving bed of sponge media showed that as the biofilm depth increased because of less than normal mixing and shearing, a population of worms began to develop [59]. Conversely, excessive mixing and collision (with walls, other media) can prevent formation of biofilm. As a result, the media may not develop growth on outer surfaces. The growth may only occur in the surface area within an annular ring or within loops of cord that is partially protected.

The amount of media surface that is covered by a biofilm is also affected by the organic carbon concentration in the IFAS or MBBR cell. At higher organic carbon concentrations, the biofilm coverage tends to increase and some biofilm may develop on the outer surface because the biofilm growth rate can compensate for the high sloughing rate. At lower organic carbon concentrations, the biofilm growth rate on the outer surface may be less than the sloughing rate. This results in a sparser biofilm on the outer surface. However, the biofilm on the inner surface is thinner and thus the biofilm surface area of the inner surface is closer to the bare media specific surface area. The sum total of the biofilm surface area between the outer and inner surfaces may not change that significantly for reasonable values of organic carbon and ammonium N in an IFAS or MBBR system in all cells operating with 2.5 mg/L ammonium-N or higher and 5 to 20 mg/L soluble biodegradable COD. The specific surface areas in Table 3 should be applicable. If the ammonium-N and soluble biodegradable COD drop lower, as in the last cell of a multi-cell IFAS or MBBR system, or in summer when a greater fraction of the biological activity takes place in the mixed liquor, the actual biofilm surface area will drop. This does not affect performance because as the temperature drops, the concentrations of substrate in the mixed liquor increases and additional biofilm develops on the media that is present in the cell.

A certain amount of predator worms is part of the normal population of fixed bed IFAS systems. However, under certain conditions, the biofilm may be dominated by predatory worms and snails and this can have a significant impact on the biofilm surface area. Operating techniques have been developed to control the population of predators on fixed bed systems. This includes step feed of some carbon to the media at the downstream end of the basin (maintain higher F/M) and maintaining the requisite mixing. The step feed of carbon prevents situations where the bacteria in a biofilm are starved of carbon for an extended period of time, thereby allowing the population of worms to increase. Another technique is to increase the sloughing rate by supplemental coarse bubble aeration. In some instances, a liquid roll pattern is sufficient.

The Annapolis plant has operated at aerobic Mean Cell Residence Times MCRTs of 4.5 to 6 days for over 10 years without worm blooms affecting nitrification in the plant, SVIs and effluent TSS by designing in the step feed and a liquid roll pattern induced by altering the density of medium bubble membrane diffusers across the width of the tank [60]. A third method is to subject selected modules of the media to low dissolved oxygen for 6 hours every 14 days to interrupt the reproductive cycle or continuously for 48 hours to kill the worms. While this has not been necessary in the past 10 years at Annapolis, it was effective at the plant [61].

9. Conclusions

In the recent years, MBBR technology is becoming increasing widely use in different countries for treating wastewater under various loading and operation conditions, The results of the experiments that have been carried out proven biological phosphorus, nitrogen and organic matter removal could be achieved in a moving bed biofilm reactor (MBBR) operated as a continues flow, with concurrent nitrification/denitrification and phosphorus uptake within the aerobic phase. These processes appear to be more relevant for ammonia removal from sewage lacking in organic matter than the traditional nitrification/denitrification process. MBBR maintains higher biomass content in reactor comparing to suspend growth system such as activated sludge, this can make the reactor small footprint thus reduce overall the cost.

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