Wastewater Treatment by Moving Bed Sequencing Batch Reactor (MBSBR): A Review

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Abstract - *Moving bed sequencing batch reactor (MBSBR) incorporates benefits provided by both Moving bed biofilm reactor (MBBR) and Sequencing batch reactor (SBR). MBSBR is modification of MBBR process which is operated in sequencing batch mode. It is an advanced wastewater treatment technology which involves high treatment efficiency with low capital, operational, maintenance and replacement cost. MBSBR proved to be efficient in removing more than 90% of COD and BOD and other nutrients (N and P) from both domestic as well as industrial wastewater, under appropriate conditions with sufficient retention time. It is a cost effective way of upgrading existing wastewater treatment system as it is efficient, compact and easy to operate. MBSBR can be provided for designing new wastewater treatment plants and also for retrofitting existing wastewater treatment plants where higher removal efficiency is required with low cost. The performance of MBSBR depends on the carrier fill percent, specific surface area of carriers and organic loading. Kinetic models used for optimization of MBSBR are also discussed in this paper.*

Key Words: **MBSBR, Advanced Wastewater Treatment, Biofilm, Attached Growth, Nitrification, Denitrification.**

1. INTRODUCTION

Around 85 % of the world population lives in the driest half of the planet. There are about 783 million people who don't have access to clean water and nearly about 2.5 billion do not have access to adequate sanitation (UN Water World Water Day 2013). It is expected that 60 % of the world population will live with water scarcity if water consumptions remain at the same current level, by the year 2025 (Judd, 2006). It is expected that the need for fresh water will keep increasing with further development of human society. In the next 15 years, more than 90 % of available fresh water resources will be consumed (Kraume and Drews, 2010). Therefore, water reclamation and its reuse are inevitable in the years to come. Wastewater treatment technologies like trickling filters (TFs), rotating biological contactors (RBCs), activated sludge processes (ASPs) which have been in use for wastewater treatment processes for over a century requires advancement and/or replacement with new and more advanced treatment technology that can provide high quality treated water, which can be used for domestic, industrial and agricultural purposes and also for future sustainable practices.

Suspended growth and attached growth biofilm systems such as different activated sludge and bio-filter configurations have a number of inherent limitations even if they are widely used as successful biological treatment schemes for domestic and industrial wastewater. The operational difficulties experienced with these traditional systems stimulated considerable research effort for the development of novel biological processes. In the past few years, studies focusing on hybrid systems combining the advantages of suspended growth and attached growth biofilm systems have increased.

Under these circumstances, moving bed biofilm reactors (MBBR) have been developed as one of the most attractive hybrid systems (Odegaard *et al.,* 1994). Since the last decade, significant research has been conducted on pilot and full-scale MBBR systems for the removal of organic matter and nutrients from domestic as well as industrial wastewater (Rusten *et al.,* 1992; Pastorelli *et al.,* 1997). MBBR is encouraged mainly as more biomass in the reactor can be sustained in the reactor and thus, more stable treatment efficiency can be achieved, through the use of the carrier elements of various nature and type (Odegaard *et al.,* 2000).

In the last two decades, Sequencing Batch Reactor (SBR) is another highly successful biological treatment alternative widely studied and used for domestic as well as industrial wastewater treatment (Wilderer *et al.,* 1997; Artan *et al.,* 2001). SBR offers number of significant advantages, such as, smaller footprint since various processes can take place in a single reactor, ease in adjusting operational conditions, and flexibility of operation.

Recently, it was suggested that MBBRs could be operated in a sequencing batch mode, in order to get benefit from the advantages of both processes. Helness and Odegaard (1999), carried out research on biological phosphorus removal in a moving bed sequencing batch biofilm reactor (MBSBBR). Where a phosphorus removal efficiency of 98% was reported operating a biological treatment system with MBSBBR. After that, Moving Bed Sequencing Batch Reactor (MBSBR) has attracted a great deal of attention due to its ability to take advantages of both a biofilm reactor and a Sequencing Batch Reactor (SBR). Specifically, MBSBR show improved biomass concentration in reactors with corresponding higher specific removal efficiencies, greater volumetric loads, and increased process stability towards shock loading. As suspended active sludge with a short generation time can afford space to nitrifiers, meanwhile the biofilms developed on carriers can support Phosphorus Accumulating Organisms (PAOs) (Odegaard., 2006). MBSBR can remove nitrogent and phosphorus from wastewater. It is one of the advanced aerobic wastewater treatment process, which is based on the plastic carriers on which biomass attaches and grows (Odegaard *et al.,* 2000). It is continuously operating, non-cloggable biofilm process with no need for backwashing, low head-loss and a high specific biofilm surface area (Rusten *et al.,* 1998a).

MBSBR is modification of MBBR process which is operated in batch mode. Attached biofilm grows on small carrier elements suspended in constant motion throughout the entire volume of the reactor (Kermani *et al.,* 2008; Qiqi *et al.,* 2012). Contrary to the ASP, it does not need any sludge recycle, as is the case in other biofilm reactors. Since no sludge recirculation takes place, only the surplus biomass has to be separated, which is a considerable advantage over ASP (Odegaard, 1999b). Moreover, nitrification and de-nitrification can also be successfully achieved in biofilm based processes since nitrifiers, which are slow growing micro-organisms, are retained by the biofilm (Wang *et al.,* 2006; Aygun *et al.,* 2008).
MBSBR has some advantages in which the treatment facilities can be improved to produce the economic benefits by reducing the solid load of existing secondary clarifier (Kim *et al.,* 2011). The basic purpose of this review is to study various factors affecting performance of MBSBR, its applications and performance.

- **Advantages of MBSBR:**

MBSBR is an integration of MBBR and SBR processes which has combined advantages of both attached as well as suspended growth systems, as follows:

1. Simple in operation and flexible.
2. Reactor volume reduction, as all the phases are carried out in a single reactor.
3. Increased treatment capacity as it has advantage of both attached as well as suspended growth processes.
4. Reduction in sludge production.
5. Improvement in sludge settling characteristics.
6. Sludge return not required.

2. Factors affecting the performance of MBSBR:

a. Carrier fill percent

The performance of moving bed biofilm processes (viz. MBBR and MBSBR) depends on the carrier fill percent in the reactor and the organic loading. The carriers fill percent (percentage of reactor volume occupied with carriers in empty tank) normally varies from 60% to 70% (Odegaard 1999a, b; Leiknes and Odegaard 2001) or even lesser fill percent than this could be used, to allow the free carrier suspension in the reactor. It has been observed that mixing efficiency decreases at higher carrier fill percentages (Weiss *et al*. 2005). The constant collision of carriers and shear in the process due to movement prevents substantial biofilm growth on the outside of the carrier media, making the inner effective specific surface an important design factor. The varieties of size and shape of carriers provide various amounts of effective specific surface area per volume of carrier.

Different carrier fill percents were investigated by Shaha *et al.,* (2019) for MBSBR. The effect of carrier fill percent over COD removal efficiency was analyzed. And it was interpreted that 60% and 70% carrier fill percent showed less COD removal than other carrier fill percents (50, 40 and 30%). This might be due to inadequate movement of carriers inside the reactor causing poor contact between substrate and biofilm on carriers which had reduced substrate consumption thereby resulting into less COD removal efficiency. Higher COD removal was observed for 30% carrier fill than 70 and 60%. Rapid and uniform movement of carriers was observed for all carrier fill percents other than 60 and 70%. Weiss *et al.,* (2005) and Trapani *et al.,* (2008), also reported limited movement of carriers for higher carrier fill percents for MBBR and MBSBR, respectively. Increase in COD removal efficiency was observed up to 30% carrier fill percent and further decrease in efficiency was observed with decrease in carrier fill percent beyond 30%. This has allocated to lack of adequate surface area available below 30% carrier fill. As per Trapani *et al.,* (2008), higher carrier fill percents resulted into better nitrification efficiency due to presence of high concentration of slow growing nitrifies retained in the reactor. These results conclude that the carrier fill percent is important parameter in MBSBR design and performance.

Aygun *et al.,* 2013 studied the performance of SBR and SBBR in treating sewage and also the effect of power failure on treatment was investigated. Four reactors with 2L volume of SBR and SBBR were used. Three out of four reactors were operated as SBBR 1, 2 and 3. In SBBR Kaldness biomedia K1 was used at various filling ratios of 40, 50 and 60% of volume of empty reactor. The reactors were operated for 4 cycles per day consisting one cycle of 6 hr. (30min-f, 4h-r, 1h-s, and 30min-d). HRT was maintained as 7.5 hr. The average COD removal rates of SBR, SBBR1, SBBR2 and SBBR3 are 86, 88.5, 90.6 and 94.2% respectively. It was observed that the SBBR system was superior to SBR system due to its short recovery period to power failure and better performance for COD and TSS removal and sludge settling properties.

b. Specific Surface area of carriers

The effective specific surface area of carriers is important in MBSBR. The performance of MBSBR depends upon biofilm area and the effective carrier specific area. Higher specific surface area of carrier media allows very high biofilm concentrations in a small reactor volume which controls the performance of the system. It was reported that, typical biofilm concentration ranges from 3000 to 4000 g-TSS/m^3 which is similar to values obtained in ASP with high sludge ages. Because of this biofilm concentration the volumetric removal rate in MBBR is several times higher than that in ASP (Odegaard *et al.,* 1994). According to Odegaard *et al.,* (1994) the maximum effective specific growth area of carrier is around 70 % of total surface area due to less biofilm growth on the outer perimeter of carrier.

Bolton *et al.,* (2006) conducted study to quantify the biofilm activity on carriers used in wastewater treatment. Fourteen different types of biofilm carriers were evaluated ranging from commercially available products to novel carriers designed. Result of their study showed that the biofilm accumulation depends most strongly on carrier surface properties, such as surface roughness and specific surface area.

c. Biofilm Development

Biofilm development can be defined as the difference between biofilm growth and attachment and detachment processes of biofilm. It is influenced by various processes, including biofilm growth, thickness of biofilm, adsorption and desorption of microorganisms to the solid surface, biofilm adhesion and detachment to and from the solid surface or media (Characklis 1990). The solid-liquid interface between a carrier surface and water medium provides an ideal environment for growth and attachment of microorganisms (biofilm and biomass). Also physicochemical characteristics of water medium such as pH, nutrient levels, ionic strength, and temperature play an important role in rate of microbial attachment to solid surface (Rodney 2002).

According to Characklis 1990, the biofilm detachment, the inter-phase transport of biomass from attached microbial film to bulk liquid phase involves four different processes; including grazing (the consuming of bacteria from the outer surface of the biofilm by protozoa), sloughing (the periodic loss of large patches of biofilm), erosion (the continuous removal of small particles from the surface of the biofilm, primarily caused by liquid shear stress), and abrasion (analogous to erosion, but caused by collisions of particles). From the literature survey, it is concluded that biofilm detachment is one of the least studied and understood factor, among the various factors affecting the biofilm reactor performance. The rate of biofilm detachment is a complicated function of many variables, including hydrodynamics of the aqueous medium, flow velocity, biofilm morphology, and support characteristics.

According to Maslon and Tomaszek (2015), wastewater treatment efficiency depends on the biochemical processes taking place via activated sludge and biofilm microorganisms developing on the surface of carriers. Results have shown that, variation in nitrification efficiency depends on change in total amount of biomass involved in reactor (MBSBBR). Also, it was interpreted that biofilm growing on carriers has potential to improve the efficiency of MBSBBR.

d. Flow and mixing conditions

Efficient system performance requires adequate mixing. The potential factors reported that have an effect on performances are diffuse and mix conditions within the reactor. The nature of carriers used requires development of a very thin, smooth and evenly distributed biofilm to enable transport of substrate and oxygen to the biofilm surface. Considering this, thick and fluffy biofilms are not desired for this system. However, an even distribution of substrates over the biofilm is desired. According to Odegaard (2006), the substrate needs to diffuse into the biofilm and therefore the penetration could be limited. Adequate turbulence helps in sloughing off excess biomass and maintaining adequate thickness of biofilm. Biofilm thickness less than 100 μm for full substrate penetration is usually preferred. Adequate turbulence within the reactor enhances the transport of substrates to the biofilm and this prevents the biofilm from getting too thick due to shear forces.

Moreover, Odegaard (2006) indicated that the biofilm thickness is additionally regulated by abrasion, erosion, sloughing, and predator grazing. Movement of carriers plays a key role, as collision and attrition of carrier within the reactor induces biofilm detachment from the outer surface of the carrier. Due to this reason, the carrier is supplied with fins on the outside surface to guard biofilm loss and promote biofilm growth (Leiknes and Odegaard 2001).

e. Presence of Dissolved Oxygen (DO)

It is recommended that DO in the reactor should be maintained higher than 2 mg/L for efficient COD removal (Wang *et al.,* 2006). Wang *et al.,* (2006), studied that by decreasing DO from 2 to 1 mg/L the COD removal efficiency decreases by 13 %. This indicated that DO is limiting factor in the system. On the other hand, increase in DO from 2 to 6 mg/L resulted in slight increase in COD removal efficiency by 5.8 %. Also they have concluded that, with HRT of 6 hr. simultaneous nitrification and de-nitrification could also be achieved due to limitation of oxygen diffusion into the biofilm. Also the highest N-removal efficiency of 89.1 % (on average) was obtained when the DO was maintained at 2 mg/L. Anoxic conditions occurred and ammonia conversion to NO_2 or NO_3 was restricted at low DO concentrations. Later Schubert et al. (2013) also examined that due to higher bacterial activity with growing biofilm, concentration of DO decreases rapidly (from 10 to 2 mg/L).

Sytek-Szmeichel *et al.,* (2016), compared efficiency of SBR and IFAS-MBSBBR systems under same working conditions. Cycle time was 8 hours and DO concentration was maintained about 3 mg/L for both systems. This has helped to achieve the 95.1 % COD removal, 97 % nitrification and 99 % biological phosphorus removal. Total nitrogen (TN) removal of 91.7 % was achieved for IFAS-MBSBBR whereas 86.3 % TN removal for SBR.

3. Applications of MBSBR for COD, BOD and Nutrients removal:

Table 1 summarizes applications and performances of MBSBR in treating domestic as well as industrial wastewater.

Table 1: MBSBR performance for COD, BOD and Nutrients removal

Application	Experiment Scale	Treatment Performance	Reference
Domestic Wastewater (Synthetic) Treatment	Lab scale reactor	94% COD removal 44% total Ortho-phosphorus 50% filtered Ortho-phosphorus removal	Prendergast J. *et al.,* 2005
Poultry Slaughterhouse Wastewater (Synthetic) Treatment	Lab scale reactor	BOD_5, TKN and TP removal efficiency of MB-ASBR were 1-2, 2-3 and 10-12% higher than Conventional SBR >95% removal efficiency for MB-ASBR at all organic loading rates	Sirianuntapiboon S. and Yommee S. 2005
Piggery Wastewater (Synthetic) Treatment	Lab scale reactor	OLR: 0.59 to 2.36 kg.COD/m^3.d SBR- COD removal > 80% 75-87% TKN removal MB-SBR- COD removal > 90% 86-93% TKN removal	Sombatsopop K. *et al.,* 2011
Nitrogen removal (Synthetic wastewater)	Lab scale reactor	Polyurethane (PU) foam cubes were used for biofilm development 84% TN removal at carrier packing volume of 40% was achieved TN removal decreased with increase in size of PU	Lim *et al.,* 2011
Domestic Wastewater (Sewage) Treatment	Lab scale reactor	SBR- average COD removal 86% SBBR-1,2,3 : Average COD removal 88.5, 90.6, 94.2 % at 40, 50 and 60% CFP HRT= 7.5 hrs.	Aygun *et al.,* 2013
Recycled Paper wastewater	Lab scale reactor (GAC-SBBR)	HRT varied as 48, 24, 12 and 8 hours Higher, 92 % COD removal and 99	Osman *et al.,* 2013

		% adsorbable organic halides (AOX) removal at 48 h HRT	
Sugar Industry Wastewater (Synthetic)	Pilot Plant	COD and BOD removal > 80% Stover-Kincannon (error=6.40%) and Grau (error=6.15%) models provided good results for CT optimization	Faridnasra *et al.*, (2016)
Dairy Wastewater Treatment (SBBR)	Lab scale reactor	Organic loading varied as 1,130 to 1,560 g-BOD_5/m^3.d with 30% carrier media in reactor SBR: 63.5 % COD removal and 66 % ammonium removal SBBR: 81.8 % COD removal and 85.8 % ammonium removal	Ozturk A. *et al.*, 2018
Domestic Wastewater Treatment	Pilot Scale Plant	97.8 % COD removal 77.5 % BOD removal 100 % TSS, 21.7% TP and 12.2 % TN removal	Jucherski A. *et al.*, 2019
Domestic Wastewater Treatment	Lab Scale Reactor	Higher COD removal with 30% carrier fill percent and 1.5 to 3.5 hr. aeration time MBSBR Design: SLR- 3 to 7.5 g COD/m^2.d VLR- 0.35 to 0.7 kg COD/m^3.d HRT- 2.25 to 4.5 hrs F/M- 0.1 to 0.18 d^{-1} COD removal efficiency of MBSBR 16% > SBR	Shaha S. *et al.*, 2019

3.1 Nitrification and De-nitrification:

MBSBR's have favorably been used for nitrification and denitrification. It is ideally suited for nitrification applications because the process enables the proliferation of nitrifying bacteria within the protected surface area of the biocarriers used for biofilm development in MBSBR. Nitrifying bacteria have comparatively slower growth rates and are strongly influenced by water temperature. This process is reliable for complete nitrification within compact tank volumes by enabling the biological process to sustain a high density population of nitrifying bacteria without relying on increased solid retention time (SRT) or MLSS. As for all biofilm reactors, nitrification rates are influenced by the organic load, dissolved oxygen concentration in the reactor, total ammonium nitrogen (TAN) concentration, temperature, pH and alkalinity. According to Odegaard (1999a) the organic load is a key factor. And Rusten et al. (2006) explained that at loading over about 4 g BOD_7/m^2.day, high oxygen concentration (6 mg/L) is required for nitrification to take place. It is reviewed that an oxygen level above 2–3 mg/L is required to initiate the nitrification process. Hence, the nitrification rate is linearly dependent upon the oxygen concentration up to more than 10 mg/L (Barwal 2014).

Denitrification is the biological reduction of nitrate to nitrogen gas. This four step process (as $NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$) returns nitrogen gas to the atmosphere. Using an anoxic environment, nitrate is the electron acceptor that can be combined with a wide range of electron donors. Two common processes for denitrification are pre-denitrification, using influent wastewater organic substrate, and post-denitrification, being endogenous and/or externally driven as given by Metcalf and Eddy (2003).

A process with a thick biofilm enables Simultaneous nitrification and denitrification under aerobic conditions in the bulk water phase (Helness and Odegaard, 2001). Oxygen will only penetrate to a certain depth in the biofilm giving an outer aerobic layer, where nitrification occurs. The deeper layers will be anoxic with denitrifying bacteria utilising the nitrate produced by the nitrifyers in the outer layer. Biological phosphorus removal with simultaneous nitrification - denitrification and phosphate uptake in the aerobic phase has been reported in biofilm systems by several authors (Garrison-Zuniga and Gonzalez Martinez, 1996; Helness and Odegaard, 1999 and Pastorelli et al. 1999).

Dulkadiroglu *et al.,* (2005) examined the effect of temperature and sludge age on performance of MBSBBR for COD removal and nitrification. The experiments are conducted in a lab-scale MBSBBR operated at three different temperatures (20º, 15º and 10º C) with a synthetic feed simulating domestic sewage characteristics. Results of the system revealed that efficiency over 90% for organic matter removal at high rates was secured at all operation conditions applied. The nitrification rate was significantly influenced by changes in temperature but complete nitrification occurred at each temperature. Both nitrification and ammonia removal rates were reduced by higher biomass content at the same temperature. In another study carried out by Maslon and Tomaszek (2015), nitrification efficiency of 98.8±0.7% was achieved in operating MBSBBR.

3.2 Phosphorus removal:

Biological phosphorus removal can be achieved in MBSBR. Biological phosphorus removal is performed by bacteria that have the ability to accumulate more phosphate than is required for growth. Phosphorus accumulative organisms (PAOs) play a significant role in phosphorus removal. Generally, biological removal of phosphorus occurs under anaerobic conditions when volatile fatty acids (VFAs) are converted to degradable organic matters (bsCOD) through fermentation and then stored in the cellular inner granulates such as poly-hydroxy-butyrate (PHBs) by PAOs. The energy required to store PHBs under anaerobic conditions is supplied by breaking down stored polyphosphate which leads to degradation of ortho-phosphates and increase PHBs concentration in the liquid. Under aerobic conditions, PAOs consume the stored PHBs, and through this process, they achieve the energy needed to grow and absorb the ortho-phosphate from the liquid (Tchobanoglous et al. 2003). Organic carbon uptake and phosphorus release have been achieved in the anaerobic phase of the cycle, while phosphorus uptake was observed in the aerobic phase (Maslon and Tomaszek, 2015). Biological phosphorus removal depends on exposing the biomass to alternating anaerobic and aerobic conditions. In MBSBR, this must be done by alternating between anaerobic and aerobic conditions in the same reactor.

Helness and Odegaard (1999), studied the biological phosphorus removal in a sequencing batch moving bed biofilm reactor (SBMBBR). It was concluded that, Biological phosphorus removal can be achieved in SBMBBR. In order to achieve good and stable phosphorus removal over time, the length of the anaerobic period should be tuned to achieve near complete removal of easily biodegradable COD in the anaerobic period.

Maslon and Tomaszek (2015) carried out research on MBSBBR by using Bioball as media in reactor for biofilm development. It was a very effective process for the complete removal of organics and nutrients, with average soluble COD, total nitrogen and total phosphorus removal efficiencies of 97.7 ± 0.5%, 87.8 ± 2.6% and 94.3 ± 1.3% respectively.

4. Kinetic Modeling:

Kinetic modeling is use of one or more analytical methods for prediction and optimization of reactor performance (Faridnasr *et al.*, 2016). Numbers of kinetic models have been proposed in the literature to depict the overall kinetics of biofilm reactors. It includes Monod kinetic model, first-order substrate removal model, Opaken and Grau second-order models, and modified Stover–Kincannon model (Hassani et al., 2014).

Faridnasr *et al*., (2016), studied all these four models for optimization of MBSBR for sugar industry wastewater. They demonstrated that utilizing kinetic analysis is a useful optimization tool to address the issues related to high strength industrial wastewater treatment. Synthetic sugar industry wastewater was treated at different Cycle Times (CTs) varying from 2 to 4 hours and OLRs (500 to 2500 BOD_5-mg/L) by MBSBR. Four kinetic models were used which was statistically evaluated by Normalized Root Mean Square Error (NRMSE) method. The result showed that modified Stover-Kincanon (6.40% error) and Second–Order (Grau) model (6.15% error) are the most accurate models which are used to predict optimum aeration time.

- **Modified Stover–Kincannon Model:**

Stover and Kincannon developed this model for RBC's with assuming that the substrate utilization rate can be related to the organic loading rate (Kincannon & Stover, 1982). Because of its difficulties in measuring active biomass surface area, this model was modified with substituting the working volume of the reactor instead of surface area of bioreactor. It is one of the best mathematical models used for describing the substrate removal rate of bioreactor. The equation of the model is given as,

$$\frac{ds}{dt} = \frac{Q}{V}(Si - Se) = \frac{Umax.(\frac{Q.Si}{V})}{K_B + (\frac{Q.Si}{V})}$$

Where, ds/dt is the specific substrate removal rate ($g/m^2.d$), Q is flow rate, V is reactor volume (L), Si is influent COD concentration and Se is effluent COD concentration (g/L), Umax.= maximum utilization rate constant (g/L.d), K_B= saturation value constant (g/L.d).

- **Second-order substrate removal (Grau) model:**

The general equation of the model can be expressed as:

$$-\frac{ds}{dt} = k_s . X . \{\frac{Se}{Si}\}^2$$

Where, k_s is second order substrate removal rate constant (d^{-1}), X is a concentration of volatile suspended solid (VSS) in reactor (g/L).

5. CONCLUSIONS

It can be concluded that, MBSBR can be used for secondary wastewater treatment for organic carbon and nutrient removal from domestic as well as industrial wastewater. MBSBR can work efficiently with varying organic and inorganic loading and under various operating conditions. It is concluded that MBSBR is efficient in removing more than 90% of COD and BOD and other nutrients up to certain extent from both domestic as well as industrial wastewater. MBSBR maintains higher biomass in reactor as compared to suspended growth systems such as ASP; this can make the reactor small footprint thus reducing the overall cost. Additionally, nitrification and de-nitrification can also be successfully achieved in this biofilm based process, as slow growing micro-organisms i.e. nitrifies get retained by the biofilm. Also, biological phosphorus removal can be achieved in MBSBR under specific operating conditions. The accumulation of biofilm depends most strongly on carrier surface properties, such as surface roughness and specific surface area. Based on the review, it is concluded that increase in active surface area of the media sustaining bacteria leads to high removal efficiency of the organic load. Furthermore, one can choose any shape for reactor and different operating loads in a given reactor volume, simply by choice of carrier filling. Such results clearly demonstrated the big potential of this technology for different wastewater treatment processes. Also for small scale domestic and industrial wastewater treatment systems, this technology can be proved efficient.

Use of kinetic modeling helps to describe the substrate removal rate. Also, utilization of kinetic analysis is a useful optimization tool for addressing the issues related to wastewater treatment. Thus, it becomes very useful to study and understand the mechanisms controlling the process. The literature survey stated that kinetic modeling for industrial wastewater treatment by MBSBR is least studied and further research is required in this area.

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