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Applicaion of Moving Bed Biofilm Reactor (MBBR) for Treatment of Industrial Wastewater: A mini Review

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Abstract: This research aims at presenting Moving Bed Biofilm Reactor (MBBR) technology as one of the alternatives and efficient methods for treating industrial wastewaters at a variety of conditions. In the last decade, this technology became more popular and widely utilized worldwide, due to the fact that the need for clean water keeps to rapidly increase with the increase in the population of the world grows year by year, which is why a high number of the waste-water treatment facilities are necessary expand, for the purpose of providing additional capacity with the minimal costs. The present study aimed at covering the most significant MBBR processes, like the fundamental process of the treatment, biofilm kinetics, and MBBR operation principles. This review includes as well a large number of the relevant researches that have been performed at the lab and pilot scales, in addition to cover the important procedures on the basic process of the treatment, which affects the influent types as well as the carrier type. None-the-less, this review concluded yet has been compiled herein and reported to be acquiring more sufficient insights and outlook upon the theme with a view to meet the new method. For that purpose, the most feasible technology may be the advanced biological process (i.e., the bio-reactor systems), which include the MBBR system

Key Words: biofilm, industrial wastewater, Moving bed biofilm reactor (MBBR), dyeing wastewaters, nitrification and denitrification.



1. Introduction

Today, due to the increase in the flow and the organic loading, numerous plants of the wastewater treatment have been expanded for the purpose of providing more capacity. The secondary waste-water treatment plant (WWTP) treatment is often carried out through the use of biological processes, which may be categorized as either being attached or suspended growth [1]. The most widely utilized and conventional system of the suspended growth has been represented by the popular Activated Sludge (AS) process. However, this procedure may pose a few drawbacks in the case of being when exposed to an increase in the organic and hydraulic loads. For increasing the performance levels of the existing Activated Sludge system, there would be a necessity to increase the biomass amount within the aerobic reactor [2]. One of those processes is the AS with the suspended fixed-film packing, like (MBBR).

2. Moving bed biofilm reactor

MBBR has been considered as a growing bio-film technology that was gaining attention in the sector of the waste-water treatments for the past two decades [3]. The MBBR has been first established in Norway at the Norwegian University of Sciences and Technology in cooperation with a Norwegian company called Kaldnes Miljøteknologi (presently AnoxKaldnes AS).

MBBR technology has been installed in the late 1980s and early 1990s. Though it's rather an innovative technology to the U.S. (it was first introduced in 1995), there have now been more than 400 installations all over the world in the industrial as well as the municipal sectors, with more than 36 in North America [4].

MBBR process has been developed on the basis of a combination of the traditional AS process and biofilter process. It involves specially designed plastic carriers called biofilm carriers for biofilm attachment. The carriers are held in suspension throughout the reactor through the aeration, liquid circulation, or mechanical mixing and are kept in the reactor with the use of a grill or a sieve, which allows the simple separation of treated waters from biomass that contains the carriers [5] and those media have a density which is quite similar with the water density [6].

3. Basic characteristics of the MBBR [5]

1. The continuous process of the flow-through-which eliminates the necessity for the backwash and minimizing the head loss and operational complexity;
2. Highly compact reactor – as a result of the large surface area of the bio-film as well as the highly active specialized bio-mass;
3. Multiple objectives of the treatment – like the removal of the BOD, denitrification, and nitrification in a flow-through series arrangement, which provides quite flexible and simple system;
4. No sludge separation and extra space requirement due to the fact that the majority of active biomass is retained along with the biofilm carriers. This gives an advantage over the activated sludge process.
5. Versatility as MBBR is suitable to retrofit into the existing tanks during up-gradation of a treatment plant.

4. Process of MBBR

1. The separate process of the biological treatment for the removal of the BOD, nitrification, and/or de-nitrification
2. Pre-treatment system ahead of the existing system of the AS for increased removal of organic matters.

5. Kinetics of biofilm

The kinetics of the removal of the substrates in the applications of the biofilm highly depends upon the substrate's concentration in the treated wastewater, which has been depicted in Figure 1, showing the progression of kinetic description from a 1st order bank of aerators. Odegaard *et al.* (2000) [8] proved that the expression at the low levels of the concentration to 0th order expression at quite high concentration levels. The transition from the low to the very high concentration of the substrate has been described by a 1/2nd order expression.

As can be observed in the Figure, the rate of the substrate removal is limited by the concentration of the substrate only at the low concentration levels in which a small concentration variation can give a proportionate variation in degradation [8]. At the high concentration levels of the substrates, this rate has been limited by the substrate's diffusion to bio-film. Which is why, with the increase in the level of concentration, kinetics start shifting from being dependent upon the concentration to being dependent upon the diffusion and ultimately, the kinetics become in-dependent of the concentration of the substrate, which has been described by the 1/2nd order kinetics. At quite high concentration levels of the substrate, enzymatic efficiency restrains the rate of the removal - 0th order dependence [8].

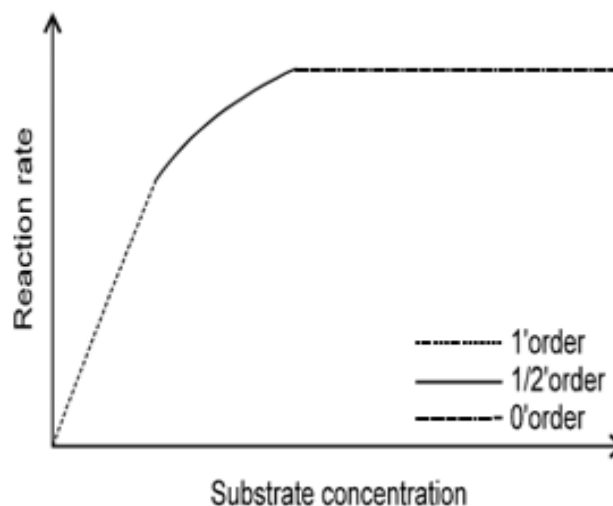


Figure 1. The description of the kinetics with the rate of the reaction as a substrate concentration function [7].

Even though the bio-film process kinetics are usually represented as above, it has to be emphasized that the substrate composition in waste-water determines its kinetic properties [8]. Diffusion has been believed as the most significant phenomenon of mass transfer, and therefore, it is usually taken under consideration in the descriptions of the kinetics. Other mechanisms of transportation, like the advective transport, however, are often not taken under consideration [10].

6. MBBR Operation Principle

The MBBR process development has been based upon the main gathering concept in one system, the optimal AS properties and processes of the bio-film, and the elimination of the unwanted properties of every one of the processes [11].

Unlike the majority of the bio-film reactors, the MBBR utilizes all effective reactor volume for microbial growth, which offers a number of the benefits compared to its competitors. The loss of the

head is decreased considerably, and that has been considered as one of the most important advantages concerning the systems of the fixed-bed, exhibiting a rather high head loss. In addition to that, the medium of the filter of the latter may get clogged or blocked. In contrast to the AS systems, the MBBR require sludge recirculation from a secondary clarifier due to the fact the growth of the bio-mass takes place on the carriers that freely move within the reactor tank. With biomass being fixed upon support media, improved solid retention in biological reactors may be achieved compared to the traditional suspended bio-mass systems, where the loss of the cell happens ultimately as a result of the poor capability for sludge settling. As a result, the biofilm-based processes can exhibit a higher capacity for the volumetric treatment; in other words, they have the ability to treat the same waste-water amount in a smaller volume. In addition to that, the secondary tank's size is highly reduced, and there isn't any need for the periodic media cleaning, as it is needed in the fixed-bed reactors.

Moreover, the existing reactors may be adapted and equipped to the configuration of the MBBR with rather small alterations [11]. The technology of the MBBR may be implemented in the aerobic and anoxic/anaerobic systems. Figure 2 depicts the potential configuration types. In the aerobic systems (Figure 2-a), the aeration is responsible for the carriers' movement. This is why the aerators carry out a dual function, which means that they are responsible for micro-organisms' oxygenation and for maintaining carriers in movements in the medium of the reaction. As a result, a greater air input is needed, contributing to the increase the operation costs, in particular the ones that are related to energy.

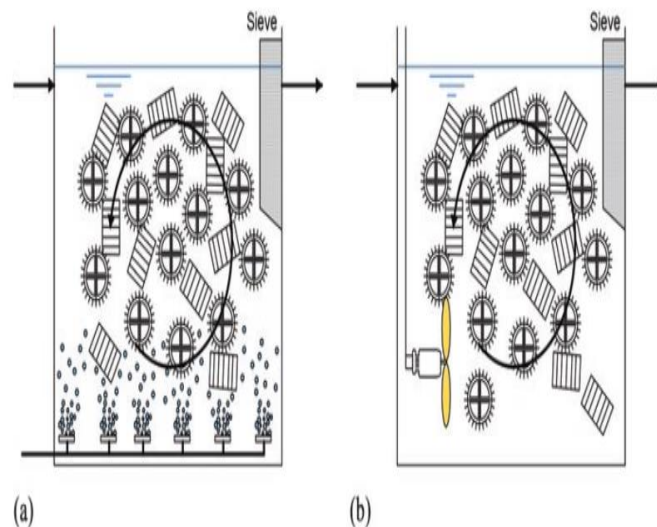


Figure 2: Functioning of the MBBR process variants [10]. (a) Aerobic (i.e., aerated) reactor. (b) Anaerobic-anoxic reactor.

In addition to that, the necessity for the devices providing sufficient aerations and movements of moving supports resulted in the enhancement of the process cost. In the anaerobic/anoxic systems (Figure 2-b), a mechanical device of mixing is needed. In the case of the aerobic systems, the suitable aerators' design is crucially important for the improvement of the MBBR process efficiency [10, 12]. A device, which is usually known as the sieve, is installed at the outlet of the reactor for the purpose of retaining media inside this tank.

Shin et al 2006: A combined process that included chemical coagulation and an MBBR has been researched for treating the textile waste-water. The pilot-scale MBBR system includes 3 MBBR systems (which are: anaerobic, aerobic-1, and aerobic-2 in series), every one of the reactors has been filled by 20% (v/v) of the polyurethane-activated carbon (PUAC) carrier for the biological treatment followed by the chemical coagulation with the FeCl₂. In the process of the MBBR, 85% of COD and 70% of color (i.e., influent COD $\frac{1}{4}$ 807.5mg/L and color $\frac{1}{4}$ 3,400Pt Co unit) have been eliminated with the use of rather low concentration of the MLSS as well as a short time of the hydraulic retention (HRT $\frac{1}{4}$ 44hr).

Biologically treated dyeing waste-water has undergone chemical coagulation. Following the coagulation by the FeCl₂, 95% of the COD and 97% of the color have been generally eliminated. The combined MBBR and chemical coagulation processes have promising potentials for the treatments of dyeing waste-water. Figure 3 illustrates the color reduction and COD in the existence of the PUAC media throughout the biological treatments on the batch-scale. 3820Pt Co of color and 805mg/L of the COD have been eliminated to 2800Pt Co and 531mg/L in the AS system (the MLSS $\frac{1}{4}$ 400 mg/L) and to 1850 Pt Co and 313 mg/L in MBBR (PU-AC carrier $\frac{1}{4}$ 30%, v/v), respectively. The rate of the removal has been 34.10 % for the COD and 26.80 % for the color in AS and 61.20 % for the COD, and 51.60 % for the color in MBBR, respectively. It has been evident that the MBBR system has higher rates of color and COD removal as a result of the higher active bio-mass that has been attached to PU-AC carrier in addition to less HRT.

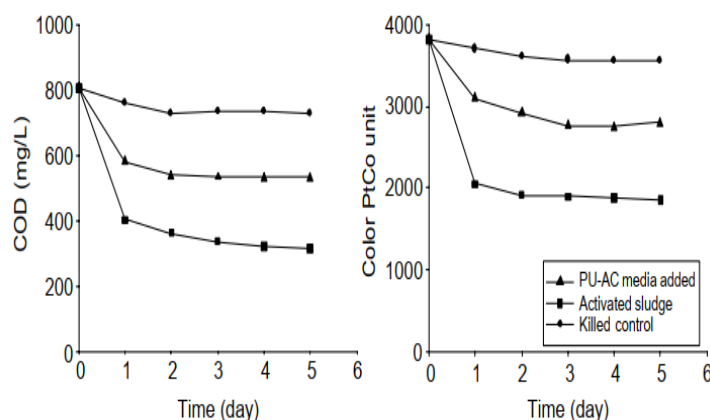


Figure 3: Color and COD removal in the aerobic batch reactor. (i) Killed control (HgCl₂ $\frac{1}{4}$ 300mg/L), (ii) AS (MLSS $\frac{1}{4}$ 4000mg/L) (iii) PU-AC carrier added (30%, v/v) [13].

The biological treatment contribution by the MBBR system to the entire system in the efficiency of COD removal and the efficiency of the color removal has been up to 85% & 70%, respectively. In the following step of the chemical coagulation, 27.90% of color and 9.20% of COD have been eliminated. In general, 97.40% of the color and 94.90% of the COD have been eliminated by this combined process. The combined procedure of the MBBR and the chemical coagulation has been of high efficiency in the treatment of the textile dyeing waste-water and has the ability to satisfy the national guide-line of the qualities of effluent in Korea. The results of this research indicated that a combined biological pretreatment process, which includes the anaerobic-aerobic MBBR with the use of the PUAC foam as carrier and chemical coagulation, is one of the sufficient techniques for the treatment of the dyeing waste-water [13].

Park et al. 2010: A 3-stage pilot-scale MBBR systems, anaerobic-anaerobic-aerobic in series has been researched for treating the textile dyeing waste-water. Every one of the reactors has been filled by 20% (v/v) of the PU-AC carrier for the biological treatments. For the purpose of determining the optimal MBBR operating conditions, the PU-AC carrier effect, its percentage of packing (v/v %), and pH control on the removal of the COD have been analyzed through the use of the batch experimentations. MBBR has been inoculated with the AS that has been obtained from one of the local plants of the dyeing waste-water treatment. The process of the MBBR has been capable of removing 50% of the color and 86% of the COD (color=553Pt Co unit and influent COD=608mg/L) with the use of a rather low concentration level of the MLSS (average 3000mg/L in the bio-mass that is attached to the PUAC carrier) and the time of the hydraulic retention (HRT=44hr). The process of the MBBR has shown very good potential for treating the dyeing waste-waters. The pilot-scale MBBR in the series (anaerobic-anaerobic-aerobic, A2O) has been operated for the treatment of the real dyeing waste-waters (Figure 4). The first 2 anaerobic MBBR systems were capable of removing 50% of the color and 78% of COD. The majority of the COD has been eliminated in anaerobic MBBRs, and the rest of the COD has been additionally eliminated through the use of the successive aerobic MBBRs. None-the-less, the efficiencies of the color removal at the anaerobic A, anaerobic-B, and aerobic MBBR systems have been 37%, 13%, and 1%, respectively, which has indicated the fact that the color removal had happened in only anaerobic MBBR systems, not in aerobic MBBR, due to the fact that the transformation of the dye-stuff into the aromatic amines had happened under the anaerobic conditions only. After the effluent has been passed through the final aerobic MBBR, COD removal efficiency has been increased to 86% (COD in the effluent = 42 mg/L-150mg/L) [14].

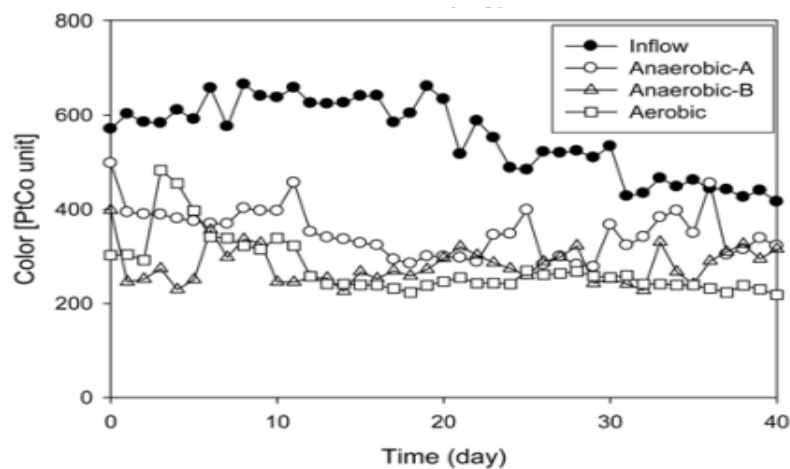


Figure 4. Colour and COD removal from dyeing wastewater in pilot-scale MBBR process.

Shore et al. 2012: This study examines the utilization of an MBBR as a step of tertiary treatment for the removal of the ammonia in high temperatures (35°C-45°C) effluents and quantifies a variety of the ammonia and nitrite-oxidizing bacteria phenotypes that have been responsible for nitrifications at the increased temperature degrees. Bench scale reactors that operate at 35°C and 45°C have been capable of the successful removal of more than 90% of influent ammonia (about 19mg/L NH₃-N) in the industrial and synthetic waste-water.

There have not been any bio-treatments noticed at 45°, even though the effective nitrification has recovered rapidly in the case where the temperature has been decreased to 30°C with the use of the q-PCR, *Nitrosomonas oligotropha* has been discovered as the dominant ammonia oxidizing bacterium in

bio-film for 1st reactor operation phases. In the following phases, the *Nitrosomonas nitrosa* has been noticed, and its raised presence could've been responsible for the improvement in the efficiency of the ammonia treatment. The accumulations of the nitrite in some of the instances seemed to be correlating with the temporary low existence of the *Nitrospira* spp. There have been 3 bench scale reactors operated for a 116-day period. Every one of the reactors had a 3.50L operating volume, and a 200 min. time of the hydraulic residence. They have been filled by 300 ± 5 pieces each of BioPortz-TM media, a high surface area (580 m²m³) cylindrical support that has been made of the HDPE (ca 2cm dia. 2cm tall, Entex Tech, NC) corresponding to a 50% fill. Figure 5 illustrates a diagram of the experimental setup. The carrier media with nitrifying bio-film has been obtained from one of the pilot studies at South Durham Waste-water Treatment Facility, which has been described by Kim et al. (2010) and transferred immediately to reactors of the bench scale. The synthetic waste-water (as can be seen in the composition below) has been pumped to every one of the reactors at a 17.5 ml/min rate [15].

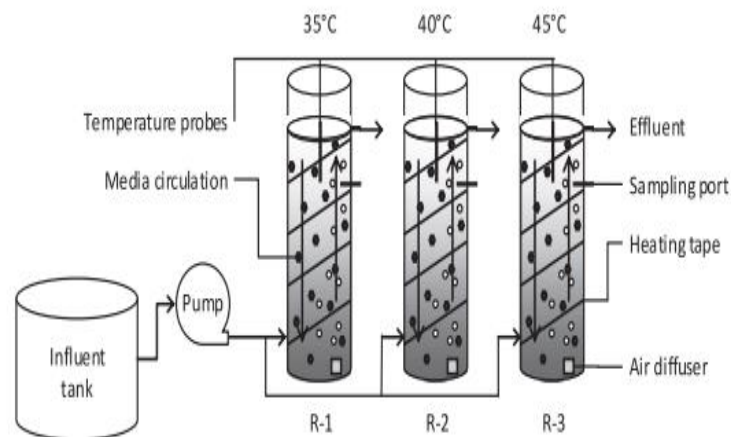


Figure 5. Diagram of bench scale experimental setup

Dvorák et al. 2014: described the operational experience with 1st full-scale application of an MBBR in the Czech Republic. This system has been utilized for the treatment of the industrial waste-water from Lucebni zavody Draslovka as. (Kolin) chemical plant, and in particular, the one from the production of the di-phenylguanidine. Waste-water has been characterized with the high cyanides and aniline contents, quite high salinity, residues of phenylurea and diphenylguanidine, and considerable levels of the fluctuation in the concentration levels and temperature degrees throughout the year. Long-term (5year) MBBRs operation showed that, after the initial stabilization and the implementation of the additional pre-treatment, this system has been able to treat such difficultly bio-degradable industrial waste-waters with a high efficiency of the removal, with average efficiency of the removal of the cyanide, which ranged as 75-99%. The efficiency of the aniline removal has reached as well >85%, whereas the removal of the phenylurea, N,N-diphenylurea and diphenylguanidine has been nearly quantitative. The full-scale MBBR plant operation that has been utilized for the treatments of the industrial waste-water from the production of the DPG has been observed for a 5year period. The system of the MBBR provided the ability of effectively treating the waste-water that has been treated earlier with quite low effectiveness. Presently, the major pollutants' removal efficiencies, such as the aniline and the cyanides, are quite high. The concentration levels of the Cyanide effluent have been consistently less than the maximal permitted limit, and the treatment of the MBBR waste-water system provided Lucebni zavody Draslovka a.s. (Kolin) with the ability to fulfil the requirements of the new Czech Water and Waste Acts as well as the Czech Integrated Pollution Prevention and Control Act. Moreover, each conducted step regarding the new MBBR system has resulted in declining the

discharge level of the waste-water and a reduction in the waste sludge production; MBBR is an almost waste-free technology [16].

Majid et al. 2019: In this paper, the lab-scale MBBR efficiency has been researched with the use of the K-3 Kaldnes carriers. The contaminant that contains COD of 1000mg/l to 3500mg/l has been utilized for the examination of the efficiency of the system through the measurement of the levels of COD and BOD at a variety of the HRT levels, inlet CODs, and temperature degrees. It has to be noted that the carriers of the K3 Kaldnes have not been utilized in earlier researches. For the purpose of determining the optimum HRT, COD, and BOD of effluent have been observed at a variety of the HRTs of 3h, 5h, 8h, and 12h. The fundamental aims of this research, taking under consideration literature review, may be summarized as:

1. In the earlier studies, the impacts of limited temperature on COD removal amount was discussed. Studied ranges have been between (1°C and 20°C and 30°C to 50°C [20, 25]. This indicates the fact that there isn't a detailed understanding of the impact of the temperature upon the behavior of the MBBR. In this experimental research for the enhancement of current information, the efficiency of the removal of the variety of the COD amounts and the micro-organisms' activity upon lab-scale MBBR in which the temperature in the range between 19°C to 32°C will be researched.
2. the literature review has shown that the maximal researched COD in the stream of the wastewater has been 2,500 mg/l. In this study, assessment of the lab-scale MBBR efficiency is researched with the use of a variety of the input COD values up to 3,500 mg/l.
3. There is no sufficient amount of detailed information on the determination of the optimum HRT in addition to its impacts upon the effectiveness of the BOD removal. This is why, in this research, whereas the determination of the optimum HRT, its impacts upon the COD and BOD removal are discussed.
4. in spite of the earlier researches where the carriers of the K2 and K1 were utilized, in this study, the carriers of K3 will be used in the process of the treatment of the industrial waste-water.

Optimal HRT has been 8 h with the efficiency of the COD removal >80%. In spite of the HRT=12h with maximal efficiency of the COD removal, which has been up to 86%, HRT=8h have been selected as optimum HRT as a result of time-consuming process of the refinement with merely a minor 3% difference in the efficiency of the removal. In addition to that, the impacts of the temperature ranging between 19°C and 32°C have been researched at optimum value of the HRT. Results have indicated the fact that there has been a sharp variation in the slope of the COD removal effectiveness at a value of temperature that ranges from 20°C to 25°C as a result of high microorganism activities, which result in increasing the efficiency of the COD removal from 70% to about 90%. Through the increase in the degree of temperature higher than 25°C, the increase rate in the effectiveness of the COD removal has been decreased by up to 94%. Based on those results, 27°C can be taken under consideration as an optimal degree of the temperature. Researching the impacts of a variety of the inlet COD values up to 3,500 mg/l is reflecting a non-monotonic behaviour in the efficiency of the MBBRs. Generally, for every inlet COD value, the MBBR exhibits over 80% efficiency of the removal [17].

Yang et.al 2020: investigated 3 different biological approaches—a conventional activated sludge (CAS) system, membrane bioreactor (MBR), and the MBBR—for the treatment of the textile waste-water from one of the local industries. Results have shown that technically, the MBR has been the most sufficient one of the three technologies, where the removal efficiency of the COD, total suspended solids (TSS), and color have been 91%, 99.40%, and 80%, respectively, with an HRT of 1.30days. However, the MBBR, had a similar efficiency of the COD removal in comparison to the

CAS (82% versus 83%) with half the value of the R.T. (1 versus 2 days) and 73% of the TSS removed, whereas the CAS had 66%. Economically, the MBBR has been a more appealing option for the industrial-scale plant due to the fact that it has resulted in saving 68.40% of capital expenditures (CAPEX) and had equal operational expenditures (OPEX) to the MBR. In addition to that, MBBR had less impact on the environment in comparison to the MBR and CAS in lifecycle assessment (LCA) research due to the fact that it has been capable of reducing the electricity consumption and the de-colorizing agent with respect to the CAS. Based on the economic and LCA analysis results, water that has been treated with the system of the MBBR has been re-used for the purpose of making new dyings due to the fact that the reuse of the water in the textile industry, which is a large consumer of water, would be capable of achieving the economic and environmental advantages. The new dyed fabric quality has been within the permissible textile industry limits.

The colour in influent ranged from 400 mg Pt-co/L to 1,500mg Pt-co/L. The rates of the removal of the colour that has been obtained with the use of the 3 systems of treatment have been illustrated in Figure 6. The average efficiency of the color removal has been 55% in the process of CAS and has been 80% in the system of the MBR, whereas in MBBR system the achieved rate of the color removal has been 61%. The MBR has been considerably more sufficient at the removal of the color compared to the CAS process under identical operating conditions. The MBBR system had a better performance of the color-removal in comparison with the CAS, whereas the value of the HRT (2 days) of the CAS has been twice as the HRT (i.e., 1day) of the MBBR system. For the purpose of meeting the standards of the discharge, de-colorizing agent has been added into effluent from the processes of MBBR and CAS [18].

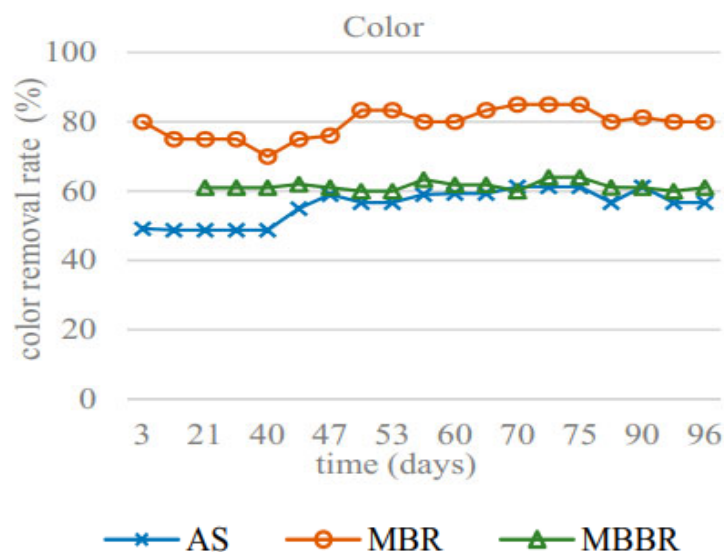


Figure 6. Removal rates of color.

7. Conclusion

1. In the past years, MBB technology becoming a treatment of increasingly common and widely utilized worldwide for the treatment of the variety of the effluent types under a variety of conditions due to the fact that MBBR's concept is combining the 2 different processes (suspended and attached bio-mass), that way, the elements of the carrier allow a higher concentration of the biomass to be kept in reactor in comparison with the process of the

suspended growth, like the AS. Which results in the increase of the capacity of the biological treatment for a certain volume of the reactor.

2. Due to the fact that it is needed to research the way by which bio solid dynamics are affected by the variations to the process relevant to the applied systems of the waste-water treatment and suggest new routes for the design and optimization of the reactor, the growth of the bio-film, modeling and detachment of the MBBR keep drawing significant research attention.
3. The process of the MBBR presents a number of benefits associated with the CAS processes or even to other fixed biofilm-based systems. It needs less space to be implemented, and it's quite suitable for accomplishing the processes of the denitrification and nitrification with no need for the recycle of the sludge between the variety of zones of the redox.
4. For the complete MBBR process overview, additional researches are required for the purpose of better understanding the relations between support material, mixing/aeration device, the configuration of the reactor, and biomass that is immobilized on moving carriers.

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