Wastewater Treatment in Baghdad City Using Moving Bed Biofilm Reactor (MBBR) Technology

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ABSTRACT
In this study, a laboratory scale system of Moving Bed Biofilm Reactor (MBBR) was used to treat municipal wastewater from a domestic community in Baghdad City to get the water free from BOD for reuse in the irrigation or discharge to the river. The aim of the described experimentation was the comparison of a low cost MBBR and an activated sludge system (AS); the other aim from this research is to derive successful MBBR wastewater reuse projects in Iraq. Laboratory experiments were conducted in two parts, firstly at BOD_5 load of about (150-200) mg/l, filling ratio of plastic elements in the MBBR reactor was 40%. Aerobic reactor consumed most of the biodegradable organic matter. The BOD_5 removal efficiencies were 78 and 90% for MBBR & AS respectively. Second part when BOD_5 load about (900-1300) mg/l used (synthetic wastewater)، filling ratio is 67%. The removal efficiencies of BOD reached 73 % for AS and about 88% for MBBR.

Keywords: Bioreactor, biofilm carriers, moving Bed Biofilm Reactor, BOD removal, municipal wastewater in Iraq.

معالجة مياه الصرف الصحي في مدينة بغداد باستخدام تقنية مفاعل الطبقة البيولوجية المتحركة

الخلاصة
في هذه الدراسة تم تهيئة منظومة مختبريه قياسية لغرض معالجة مياه الصرف الصحي مصدرها أحد المجمعات السكنية في مدينة بغداد باستخدام مفاعل الطبقة الحيوية المتحركة بهدف استرجاع جزء كبير من الماء الخالي مـــن الاحتياج الحيوي للأوكسجين (BOD) والذي يمكن استخدامه فيما بعد لأغراض السقي أو أعادته إلى النهر. الهدف من التجارب المبينة في هذه

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الدراسة هوأجراء مقارنة مابين تقنيتي مفاعل الطبقة الحيوية المتحركة التي تمتاز بكلفة قليلة والطريقة التقليدية (االحمأه المُنشطة)، والهدف الأخر هو تطوير خبرة عملية عراقية في مشاريع أعادة أستخدام مياه الصرف الصحي التي تستخدم هذه الطريقة.
التجارب المختبرية أجريت في جزئين، الجزء الأول عندما يكون الحمل للأوكسجين الحيوى الممتص بحدود (150-200) ملغم / لتر وحجم الحشوات البلاستيكية في منظومة حوض الطبقة البيولوجية المتحركة بحدود 40% من حجم حوض التهوية. المفاعل الهوائي أستهلك أغلب المواد العضوية القابلة للتحلل حيث كانت كفائة الأزالة للأوكسجين الحيوي الممتص بحدود 78 و90% لكل من تقنيتي الحمأة المنشطة وحوض الطبقة البيولوجية المتحركة على التوالي. في الجزء الثاني للتجارب عند الحمل العالي للأوكسجين الحيوى الممتص بحدود (900-1300) ملغم / لتر باستخدام (مياه صناعية) وحجم الحشوات البلاستيكية بحدود 67% من حجم حوض التهوية. بلغت كفائة الأزالة للأوكسجين الحيوي الممتص بحدود 73% لتقنية الحمأة المنشطة و88% لتقنية حوض الطبقة البيولوجية المتحركة.

NTRODUCTION

Biological treatment processes commonly relies on suspended biomass for the removal of organic carbon and nutrients in municipal wastewater plants. The conventional activated sludge (CAS) process is regarded as one of the most effective and economical processes for the removal of organic pollutants using suspended biomass [1]. The performance of the CAS process is dependent on two sub-processes; conversion of colloidal and dissolved organic matters into suspended biomass and physical separation of resulting biomass from liquid by sedimentation.

There are many factors affecting the efficiency of (CAS) process such as sludge retention time and organic loading [2, 3], and the aeration which facilitates the production of biomass separated from liquid in clarifier [4]. But there are some problems of sludge stability and the need of large reactors and settling tanks and biomass recycling. At present, there has been growing interests in use of attached growth systems (biofilm processes) which are related to biomass growth on support media [5, 6]. The advantages of the attached growth systems over the (CAS) are better oxygen transfer, higher nitrification rate, higher biomass concentrations, more effective organic removal and relatively shorter hydraulic retention time (HRT) [7,8]. Attached growth (biofilm) processes, however, have demonstrated greater efficiency and sustainability than suspended growth processes, in the presence of inhibitory compounds and at high or variable loadings [9]. For these reasons, the moving bed biofilm reactor (MBBR) process was developed in Norway in the late 1980s and early 1990s [10]. The Moving Bed Biofilm Reactor is a highly effective biological treatment process that was developed on the basis of conventional activated sludge process and biofilter process. Moving bed type reactors are biofilm processes utilizing small plastic biomass carriers that mix in the water. The Kaldnes patent's [10] polyethylene carrier elements are shaped like small cylinders with a cross inside and longitudinal fins on the outside. The bulk carrier volume relative to reactor volume is 40–70%. The carriers have a potential growth area for a biofilm of about 500 m^2m^{-3} at 70% filling, while the efficient

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growth area is calculated to be about $350m^2m^{-3}$ [11]. The use of biomass carriers is becoming common world-wide, for many applications, some of which are: compact low operation units, industrial wastewater roughing filters, retrofit and upgrade of municipal wastewater.

Nitrification in Kaldnes MBBRs has been thoroughly studied using both synthetic wastewater [12] and municipal wastewater [13]. As for all biofilm reactors, nitrification rates are influenced by the organic load, the dissolved oxygen (DO) concentration in the reactor, the total ammonium nitrogen (TAN) concentration, the temperature, the pH and alkalinity. Item et al., [12] showed for a situation with 15 ºC and excess TAN concentration at an organic load of $1gBOD_5/m^2$ biofilm surface area/d, a TAN removal rate of 1 g NH_4–N/ (m^2.d) was achieved at a DO concentration of about 5 mg/L. MBBR was studied as biological treatment processes for degradation of phenol. Laboratory experiments are done on adsorption of phenol on carbonaceous adsorbents as an effective advanced process to treatment phenolic wastewater [14]. The moving bed biofilm reactor (MBBR) is an alternative process design which utilizes the advantages of a biofilm reactor and which at the same time can handle high loads of particles, phosphorus and nitrogen removal, consumed most of the biodegradable organic matter and does not incorporate return sludge [15].

The aim of this study was to investigate and compare the BOD_5 removal efficiency in (MBBR) and an activated sludge system (AS). This work also aims to verify the reliability of Moving Bed Biofilm Reactor to treat municipal wastewater in Iraq.

BIOFILM CARRIER

The core principal of the (MBBR) treatment process is the treatment of the incoming wastewater by microorganisms growing in a biofilm on biocarriers suspended in the liquor in the MBBR reactor. The biocarriers "carry" the microorganism's through-out the reactors [6]. Most of the microorganisms in the biofilm are heterotrophic (they use organic carbon to create new biomass), with facultative bacteria predominating. Facultative bacteria can use the dissolved oxygen in the mixed liquor. As the microorganisms populations grow and multiply, the biomass on the biocarriers is thickened. Biomass thickening affects the ability of dissolved oxygen and substrate in the reactor to "reach" all of the biofilm microorganisms. Microorganisms in the outer layers of the biofilm have "first access" to the dissolved oxygen and substrate diffusing through the biofilm [16]. As the dissolved oxygen and substrate diffuses through each subsequent layer in the biofilm, more and more is consumed by the microorganisms in the preceding biofilm layers. Part of the design of each (MBBR) reactor is an aeration system the decrease of available dissolved oxygen through the biofilm produces aerobic, anoxic and anaerobic layers in the biofilm [17].

In addition to providing the required oxygen, the aeration system ensures the biocarriers are evenly distributed throughout the reactor. Extremely high turbulence detaches biomass from the carrier and therefore is not recommended. In addition, collision and attrition of media in the reactor causes biofilm detachment from the outer surface of the media. Because of this, the (MBBR) carrier media is provided

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with fins on the outside to protect biofilm loss and promote growth of biofilm. The surface area of the fins does not contribute to the specific area reported [18].

The effective area of the (MBBR) carrier medium was reported to be 70% of the total surface area due to less attachment of biofilm on the outer perimeter of the media.

MATERIALS AND METHODS

The laboratory scale biological system, a moving bed biofilm reactor (MBBR) and activated sludge (AS) was constructed; a schematic diagram of the system is given in Fig. (1) & Fig. (2), the system was operated for 6 months. Municipal Wastewater from Al-Z'afarania domestic community in Baghdad was used for this study; Table (1), with sludge obtained from AL-RUSTUMYIA wastewater treatment plant as seed. The wastewater was pumped daily into the system from a two 30-liter storage tanks (Batch process).

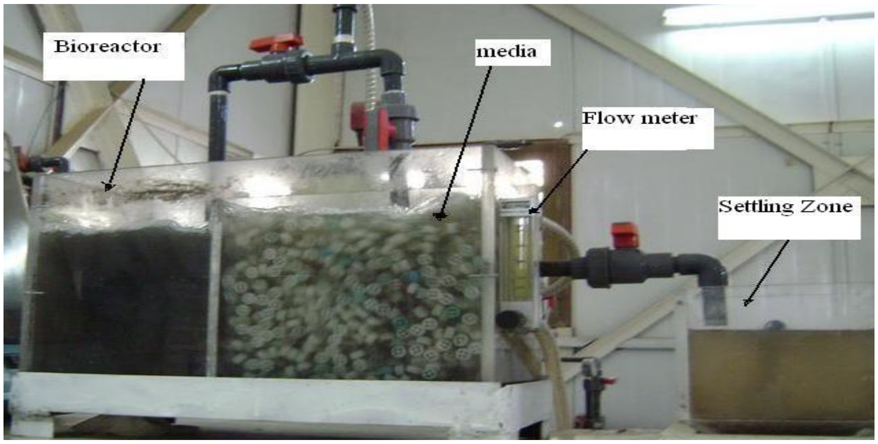

Figure (1) Moving bed biofilm reactor (MBBR) and activated sludge (AS)

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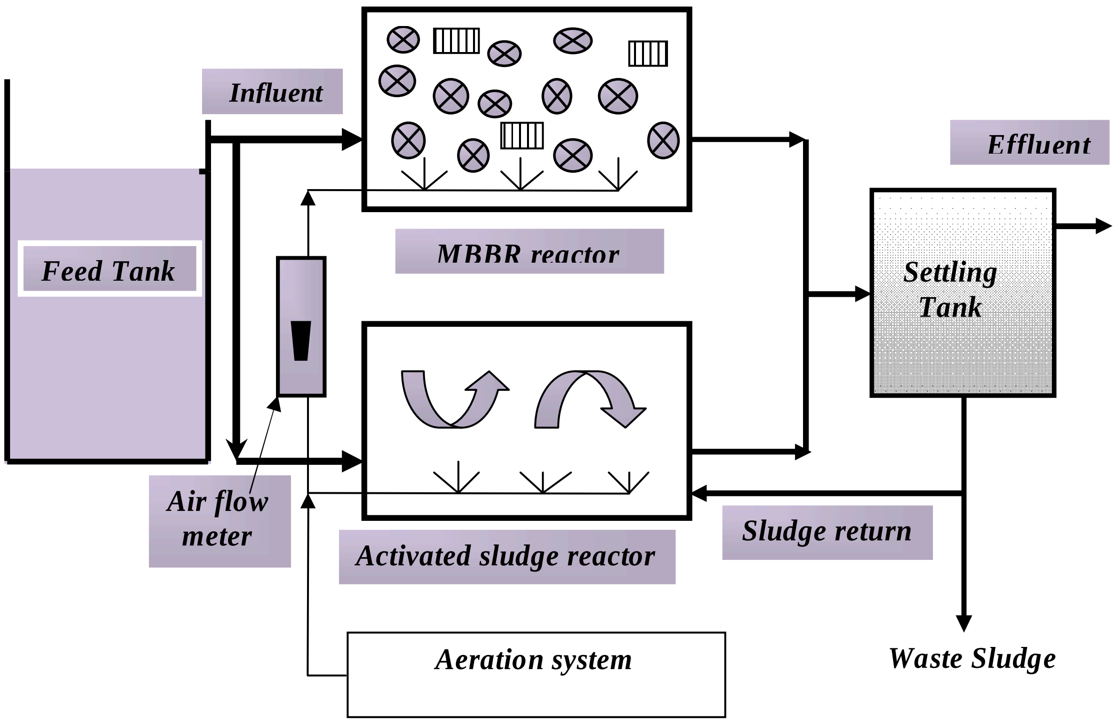

Figure (2) Schematic diagram of the MBBR and activated sludge (AS)systems used in this study

Table (1) Influent synthetic wastewater Specifications

No.	Composition	Concentration
1	TDS	1000 – 4000 mg/L
2	BOD_5	150-1200 mg/L
3	TSS	800 mg/L
4	TKN	50 mg/L
5	NH_4-N	1 mg/L
6	PO_4-P	10 mg/L
7	pH	7 - 8
8	Temperature	20°C
9	Fecal Coliform	4 *10^7

The pilot plant consisted of two 10-liter rectangular basin for each reactor in parallel, constructed from Perspex, one for AS treatment and the other for MBBR. These reactors followed by the 7-liter rectangular basin with a conical bottom (Clarification /Settling Zone). The aeration system consisted of a manifold of 1/2

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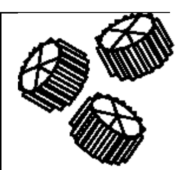
inch (inner diameter) made from (Chlorinated Poly Vinyl Chloride) (CPVC pipe), a vertical pipe connector to the manifold and rising above the liquid level in the reactor to prevent flow of liquid to the compressor when the compressor was turned off. A temperature resistant flexible tube was used to connect the vertical pipe and the compressor. An airflow meter was installed to measure air supply to the reactor. Air supply was maintained between 3.5 and 4 L/min. Valves mounted on the compressor were used to regulate the airflow. The aeration system provided coarse bubbles and kept the media (Kaldnes media) in suspension and circulation. Stainless steel screen is provided at the outfall end of the reactor in order to keep the biofilm carriers in the reactor. The biofilm (or biomass) grows on small carrier elements suspended throughout the liquid in the reactor, biofilm carrier elements (Kaldnes media) were used in this study referred to as biocarriers [8, 10]. Suspended media were made of high density polyethylene (density 0.95 g/cm^3); which has a density slightly less than water. The biocarrier (medium) is shaped in a form of a wheel, Table (2) and has a height of (7mm) and diameter of (10mm), It is reinforced in the inside with a cross members, which increase the available interior surface area for biofilm attachment. The effective specific area of the medium is 500 m^2/m^3 [8, 11].

One important advantage of the moving bed biofilm reactor is that the filling fraction of biofilm carriers in the reactor may be subject to preferences. In order to be able to move the carrier suspension freely, it is recommended that filling fraction should be below 70% (volumetric filling of plastic elements in empty reactor) [10, 19].

Table (2) MBBR carrier elements employed in the experiments[10]

Material	**Polypropylene (density = 0.95 g cm^{-3})**	
Shape	Cylindrical	
Dimensions	Height = 7mm Diameter = 10 mm	
Effective specific surface Area	500 m^2/m^3	

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BATCH EXPERIMENTS

Experiments were devoted to a performance comparison of the BOD_5 removal efficiency between MBBR & AS. The effluent from each reactor was individually fed into the clarifier/Settling Zone downstream of the reactors to separate suspended solids in the effluent stream for each reactor. It was decided to carry out a comparison test at various BOD loads using pilot plant consisting of one MBBR reactor and a one AS reactor corresponding settling tank, operated in parallel. In the first part of the experiments (15-26) November, using municipal Wastewater from Al-Z'afarania domestic community in Baghdad, the BOD_5 load about (150-200) mg/l, filling ratio of plastic elements in the MBBR reactor (volume occupied by carriers in empty reactor) is 40%. The second part of the experiments (2-11) December, using synthetic wastewater comprising glucose as the main organic constituent plus balanced macro and micro nutrients and alkalinity, high BOD_5 load about (1000-1200) mg/l, the MBBR reactor was filled about (67-70) % (recommended percentage volumetric filling of plastic elements in empty reactor), [19].

SAMPLING AND ANALYSIS

Samples were collected from influent and sampling port of each reactor daily (different influent each day). Temperature, dissolved oxygen and pH were measured in each reactor every workday, immediately before sampling. Sampling bottles stored in a refrigerator for BOD_5 analysis. The samplers were started at 8:00 AM and turned off at 3:00 PM.

RESULTS AND DISCUSSION

As noted above, the core principal of the MBBR treatment process is the treatment of the incoming wastewater by microorganisms growing in a biofilm on biocarriers suspended in the liquor in the MBBR reactor. The biocarriers “carry” the micro-organisms throughout the reactors. Table (2) shows an AnoxKaldnes biocarrier with biofilm growth. Biofilms are communities of microorganisms growing on surfaces. The microorganisms in the biofilms are essentially the same as those in suspended activated sludge wastewater treatment systems.

Fig. (3) show the soluble BOD removal with time using AS & MBBR technologies. The temperature was 20ºC (filling ratio of plastic elements in the MBBR reactor is 40%). It can be observed that the total BOD (TBOD) removal rates in the MBBR reactor were higher than AS ones (for the same (TBOD load), and this improvement increase with time. This explains the microorganisms grow and multiply in the MBBR reactor; the decrease of available dissolved oxygen through the biofilm layers produces aerobic, anoxic and anaerobic layers in the biofilm. Different biological action occurs in each of those layers as specific microorganisms grow in the different environments within the biofilm. In the upper layers of the biofilm, where dissolved oxygen and substrate concentrations are high, the micro-organism population will be aerobic higher level organisms. Deeper into the biofilm, where the oxygen and substrate concentrations decrease, in those layers "Nitrification" occurs, these results showed in Fig. (3), are consistence with Moving Bed Biofilm Reactors performance reported in the literature [5].

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The main goal of biocarrier design is to provide a high internal surface area that will promote biofilm growth in a protected environment. These carriers suspended in liquid and kept in constant circulation by the aeration system of the reactor this increases the surface area of contact between the organic matter and suspended solids. Hydraulic retention time (HRT) = 7.5h.

BOD removal efficiencies versus operation period are shown in Fig.(4); the average efficiencies for (TBOD) removal were 83 % for MBBR and 70% for AS. Fig.(4) shows that the (TBOD) removal efficiencies was improved with time (especially for MBBR because the growing of Biofilm increases on carriers media). Finally achieve effluent quality with BOD_5 less than 30mg/l according to the normal standard of Biological treatment.

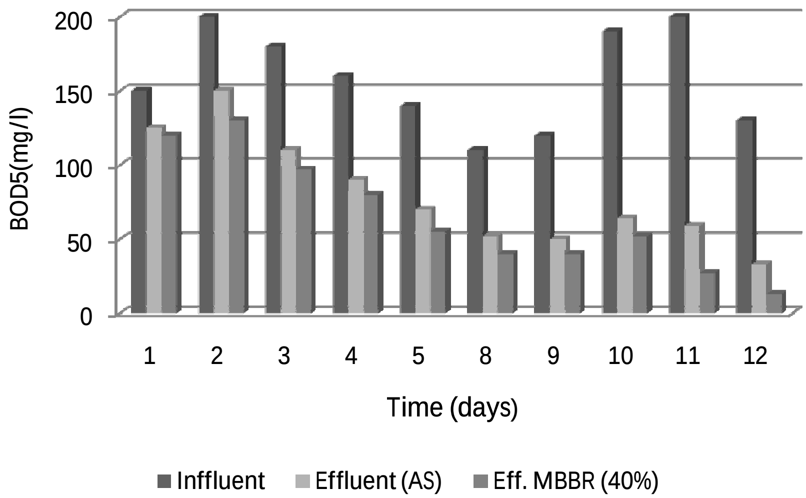

Figure (3) BOD_5 removal with time using AS & MBBR(40%) technologies during the first set of experiments (15 – 26 NOV.)

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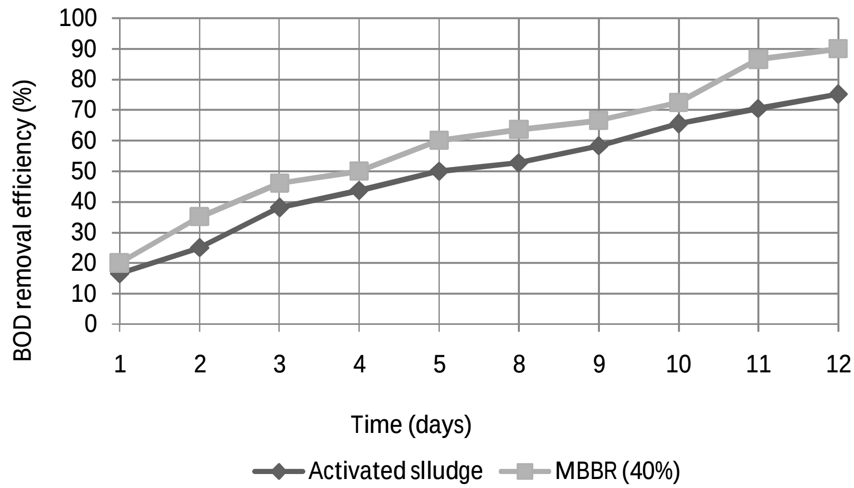

Figure (4) BOD removal efficiencies versus Time using (MBBR (40%) & (AS) during the first set of experiments (15 – 26 NOV.)

In the second part of the experiments, by increasing the number of plastic carrier's medium (Moving Bed Biofilm reactor was filled about (67-70) %), Fig. (5) shows clear preference of the moving bed biofilme reactor technology against activated sludge process especially for high BOD_5 load under 8 h HRT, temperature was 20ºC, pH and dissolved oxygen are (7-8), 7mg/l respectively. The volumetric removal rate in the MBBR is several times higher than that in the activated sludge process.

Fig.(6) shows that at the beginning of the experiment, (TBOD) removal rate was very low but after 4 months of the study, it reached 88% at HRT = 8h. This is due to the fact that microorganisms grow in a biofilm on biocarriers suspended in the liquor in the MBBR reactor. As the biofilm grows a natural "sloughing" of the biofilm off the biocarriers occurs. That sloughing maintains the biofilm at a thickness supported by the incoming organic load. i.e the (TBOD) removal efficiencies from day to day was improve.

The results shown in Fig. (6), are consistence with Moving Bed Biofilm Reactors performance reported in the literature [11].

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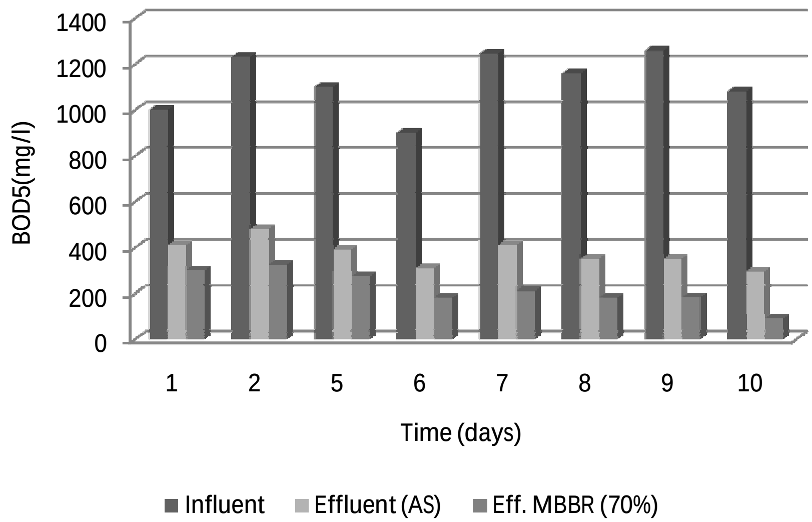

Figure (5) BOD_5 removal with time using AS & MBBR(70%) technologies during the second set of experiments (2 – 11 DEC.)

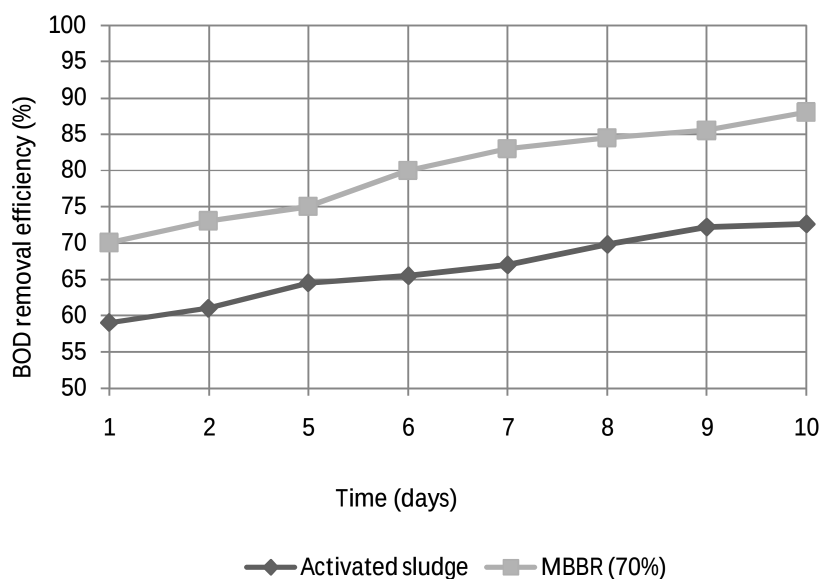

Figure (6) BOD removal efficiencies versus time using (MBBR (70%) & (AS) during the second set of experiments (2 – 11 DEC.)

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CONCLUSIONS

Moving Bed Biofilm Reactors (MBBRs) were tested for biological pretreatment of a municipal Waste-water from Al-Z'afarania domestic community in Baghdad.
In The first part of the experiments, BOD_5 load was about (150-200) mg/l, the wastewater had an easily biodegradable fraction of 60 to 80% of BOD_5 removal (for AS & MBBR) respectively. In The second part of the experiments when BOD_5 load was about (1000-1200) mg/l the removal efficiencies of BOD reached 88% for MBBR and about 70 % for AS.
The MBBR treatment process can offer numerous advantages over a suspended growth activated sludge treatment process. Those advantages include:-

● Denser treatment population per unit volume. That often translates into smaller treatment volumes (i.e. smaller foot print) and greater capacity to successfully treat incoming organic loads.

● High Loading Conditions with very little operator intervention, overall cost of operation and maintenance may be lower than the AS system.

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