Biological Phosphorus and Nitrogen Removal from Wastewater Using Moving Bed Biofilm Reactor (MBBR)

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ABSTRACT

In this research, an experimental study to evaluate nutrient removal from Al-Rustamiyah wastewater by a moving bed biofilm process was investigated. The moving bed biofilm reactor MBBR consisted of five reactors in series with one anoxic reactor MBBR-1, two aerobic reactor MBBR-2 and MBBR-3, outlet chamber and the flocculation part with dosing unit, that were operated continuously at different loading rates of phosphorus and nitrogen. The MBBR tanks were filled with suspended plastic carriers (AnoxKaldnes K_5), with a 50% filling ratio. Under optimum conditions, almost complete nitrification with average ammonium removal efficiency of 82% was achieved. The average phosphorus and total nitrogen removal efficiencies were 76.79% and 70%, respectively.

Keywords: Moving bed biofilm reactor, Al-Rustamiyah wastewater treatment plant WWTP, Efficiency

الازالة البيولوجية للفسفور والنتروجين من مياه الصرف الصحي باستخدام مفاعل الطبقة البيولوجية المتحركه

الخلاصة

تم في هذه البحث, دراسة تجريبية لتقييم ازالة المغذيات من مياه الصرف الصحي (الرستمية) من خلال الطبقة البيولوجية المتحركة . تتألف منظومة الطبقة البيولوجية المتحركة (MBBR) من خمس مفاعلات متسلسلة تعمل على مختلف معدلات الحمل من الفوسفور والنيتروجين. وهي حوض غياب الأوكسجين، حوض التحلل الهوائي عدد 2، حوض التصاريف الخارجة و حوض التلبيد. حيث تم ملئ الاحواض الثلاث الاولى بالحوامل البلاستيكية Carriers وبنسبة ملء قدرها 50%. تحت الظروف المثلى، وقد تحقق النترجة تقريبا كاملة مع معدل كفاءة إزالة الأمونيوم 82٪. وكان معدل كفاءة ازالة الفوسفور والنتروجين الكلي 76.79٪ و 70٪ على التوالي.

INTRODUCTION

Limited water resources and increasing urbanization require a more advanced technology to preserve water quality. One of the important factors affecting water quality is the enrichment of nutrients in water bodies [1]. Wastewater with high levels of organic matter (BOD_5), Phosphorus (P), and Nitrogen (N) cause several problems, such as eutrophication, oxygen consumption and toxicity, when discharged to the environment [2]. Therefore, it is necessary to remove these substances from wastewaters for reducing their harm to environment [3]. These factors have often led to the necessity of upgrading of existing Wastewater Treatment Plant (WWTP). The secondary treatment of the WWTP is usually accomplished by biological processes that can be classified as being either suspended or attached growth process. The conventional and mostly used suspended growth system is represented by the classical and well known activated sludge process (AS). However, this process can present some shortcomings when exposed to increased hydraulic and organic loads. To increase the performances of an existing AS system it would be necessary to increase the amount of biomass inside the aerobic reactor. In the last years, the idea to combine the two different processes (attached and suspended biomass) by adding biofilm carriers, usually plastic carriers, into the aeration tank for biofilm attachment and growth has been proposed. This kind of system is usually referred as IFAS (Integrated Fixed-film Activated Sludge) process [4, 5, and 6]. In these systems the biomass grows both as suspended flocs and as attached biofilm. In this way, it is possible to obtain a higher biomass concentration in the aerobic reactor, but without any significant load increase to the final clarifier. Therefore, the up-grading of overloaded existing plants, no longer able to meet the effluent limits, can be easily obtainable without the construction of new tanks. Furthermore, the increase of the overall sludge age in the system leads to a favourable environment for the growth of nitrifying bacteria [4].

Moving bed biofilm reactor (MBBR)

Moving Bed Biofilm Reactor (MBBR) process was developed in Norway University of Science and Technology cooperation with Norwegian company Kaldnes Miljøteknologi (now AnoxKaldnes AS) during the late 1980 and early 1990. Ødegaard, et al., (2007) concluded that the MBBR represented a different spectrum in advanced wastewater treatment. MBBR were operated similarly to the activated sludge process with the addition of freely moving carrier media [7]. The idea behind the development of moving bed biofilm process was to adopt the best from both the activated sludge process and biofilm process without including the worst. Contrary to most biofilm reactors, the moving bed biofilm reactor utilizes the whole tank volume for biomass growth as does the activated sludge reactor. This system does not need any sludge recycle as is also the case in other biofilm reactor [8].

The MBBR is a completely mixed and continuously operated biofilm reactor, where the biomass is grown on small carrier elements that have a little lighter density than water and are kept in movement along with the water stream inside the reactor. The movement inside the reactor can be caused by aeration in an aerobic condition and by a mechanical stirrer in anaerobic or anoxic condition (Figure 1). The carriers are kept from flowing out with the effluent by a sieve arrangement at the reactor outlet [9].

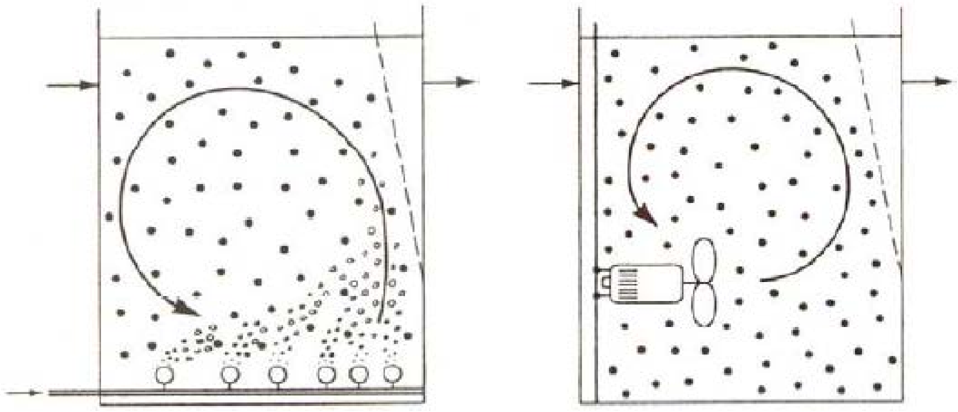

Figure (1): The principle of MBBR process with aerobic reactors (left), anoxic and anaerobic reactor (right) [8]

The moving bed biofilm process is based on the carriers on which biomass attaches and grows. The study conducted by Ødegaard, et al., (2000) analysed the influence of the size and shape of carrier materials on the performance, especially related to highly loaded plants working on municipal wastewater. The results demonstrated that the design of moving bed biofilm reactors should be designed based on surface area loading rate, filling ratio and that shape and size of the carrier do not seem to be significant as long as the effective surface area is the same [10]. The biofilm carrier elements are made of polyethylene (density 0.92–0.96 g/cm^3) and shaped like small cylinders with a cross inside the cylinder and longitudinal fins on the outside to increase the total biofilm surface [11].

Types of moving bed technology

1- Pure MBBR process: the biomass is growing chiefly on carriers that move freely in the reactor.
2- Hybas (Hybrid Biofilm Activated Sludge) processes: The biomass is growing on carriers that move freely in the reactor and act as suspended activated sludge [9].

The object of this study was to evaluate phosphorus and nitrogen removal by applying a lab-scale MBBR system with continuous operation filled with low cost biofilm carriers of AnoxKaldnes K_5 (Veolia water systems company).

Materials and methods

Case Study

Al-Rustamiyah WWTP located on the banks of Diyala River south of Baghdad city, is one of the oldest sewage treatment plant projects in Iraq. It was designed to serve one third the population in Baghdad and distracts sewage into Diyala River after treatment. The type of pilot plant is Hybas (Hybrid Bio-film Activated Sludge).

Location of pilot plant:

The MBBR pilot plant was sited in Al-Rustamiyah WWTP near the grit chamber for stage2, taking the influent wastewater from the channel between the grit chamber and per-aeration tank. The effluent from MBBR goes to a manhole directly connected to Diyala River.

3.2 Experimental set-up

The laboratory scale biological system was design as the moving bed biofilm reactor (MBBR) consists of (show Fig.2).

- Screen (coarse & fine) the bar spacing in the coarse screen 10 mm, the perforation for fine screen ∅ 3mm.
- Tank divided to five parts in series, the first part MBBR-1(Anoxic) with anoxic mixer, the second MBBR-2 (Aerobic), the third part MBBR-3 (Aerobic), the fourth part Outlet chamber and the last Flocculation part with dosing unit and flocculation mixer.
- Final clarifier with dia. 1.5m, high 2m, water volume 3.53m^3 with sludge recycle.
- Drum filter which polyester filter cloth 10µm opening, the separated solids are collected in a separate channel inside the drum and taken out.

Reactors in series can provide greater treatment capacity. The process consists of an anoxic tank followed by the aeration tank where nitrification occurs. Nitrate produced in the aeration tank is recycled back to the anoxic tank. Because the organic substrate in the influent wastewater provides the electron donor for oxidation reduction reactions using nitrate, the process is termed substrate denitrification. The inlet arrangement for influent raw wastewater will be given at the top of tank. To control discharge in and out the pilot plant and dissolved oxygen there is a flowmeter for inflow, outflow and a device for dissolved oxygen control. A sketch of moving bed biofilm reactor is shown in Figure 2 and some key parameters are listed in Table 1. Characteristics of the AnoxKaldnes K_5 plastic media are presented in Table 2.

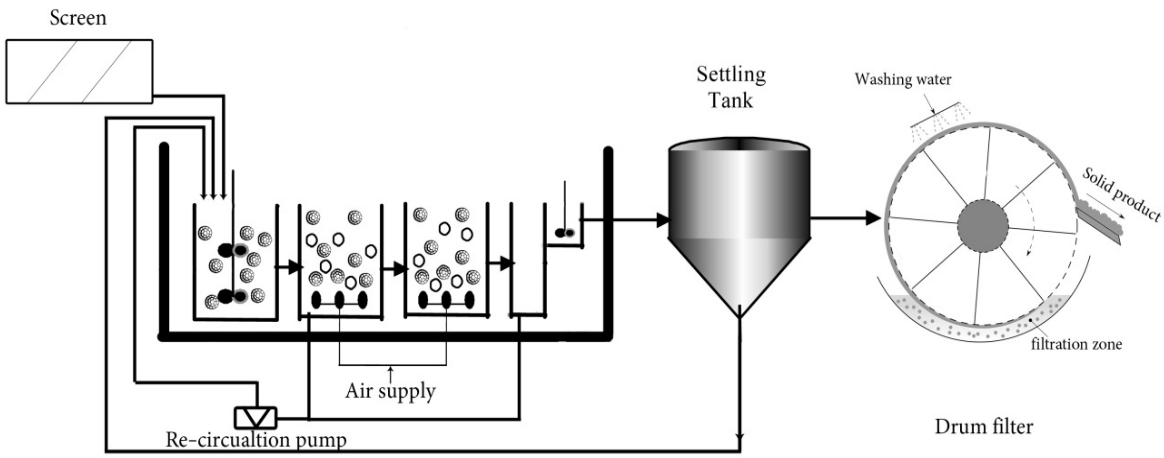

Figure. 2 Schematic diagram of MBBR system

Table 1: Technical data for the moving bed biofilm reactor

Parameter	Anoxic reactor	Aerobic reactor	Aerobic reactor	Outlet chamber	Flocculation
Volume m^3	4.5	2.25	3	1.5	0.18
Water volume m^3	4	2	2.5	1	0.1
Media volume m^3	2	1	1.5	-	-
Filling ratio with carriers%	50	50	50	-	-
Flow rate m^3/hr	1.5	1.5	1.5	1.5	1.5
Flow direction	Up-flow	Up-flow	Up-flow	Up-flow	Up-flow
HRT hr	3	1.5	2	1	0.12

Table 2: Characteristics of AnoxKaldnes K_5 the used carrier

Material	Polyethylene
Shape	Chips
Density	0.95 g cm^{-3}
Diameter	25 mm
Thickness	4 mm
Specific biofilm surface area m^2/m^3	800

Sampling and analysis

Samples were collected from influent and effluent for the pilot plant during April 2014 to July 2014. Temperature, dissolved oxygen and pH were measured in each reactor. Samples were analyzed immediately after filtration through 0.45 μm filter paper. Phosphorus PO_4-P, Nitrate NO_3-N, Nitrite NO_2-N and Ammonium NH_4-N were measured in accordance with the Standard Method for Examination of Water and Wastewater [12].

Results and Discussion

Phosphorus removal:

A biological phosphorus removal process utilizes bacterial capabilities for their capability to take up phosphorus as they grow in the system. This process is considered the enhanced biological phosphorus removal (EBPR). The bacteria responsible for P removal are phosphorus accumulating organisms (PAOs) which play a significant role in phosphorus removal [13, 14].

Figure 3 shows the variation of influent and effluent PO_4-P for the MBBR system as function with time. The influent concentrations of PO_4-P fluctuated within the range of 2.70 to 13.8 mg/L. Nevertheless, the average value of PO_4-P of effluent discharged from of this system was shown to meet the Iraqi National standards (Regulation 25 of 1967) equal to 3 mg /L. The average removal efficiency for MBBR was 76.79% (Figure 4). It can be observed that the PO_4-P removal efficiencies was good expect the period from 17^{th} to 20^{th} of April due to the different biomass concentration and the period from 22^{th} to 29^{th} of June due to breakdown diver. The reported results of other previous studies showed that the average phosphorus removal efficiency reached 65% [15] and 95.8% [16]. It appears that this result higher due to the aerobic phosphate removal rate that may have good correlation with the anaerobic phosphate release rate [16].

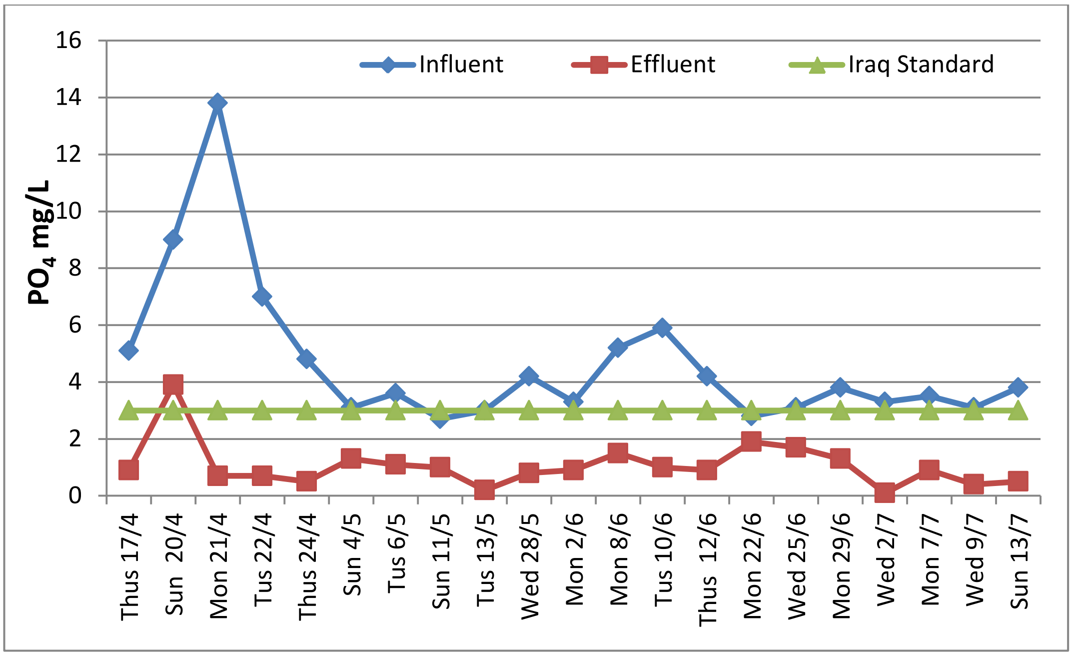

Figure. 3 Influent and Effluent PO_4-P concentrations

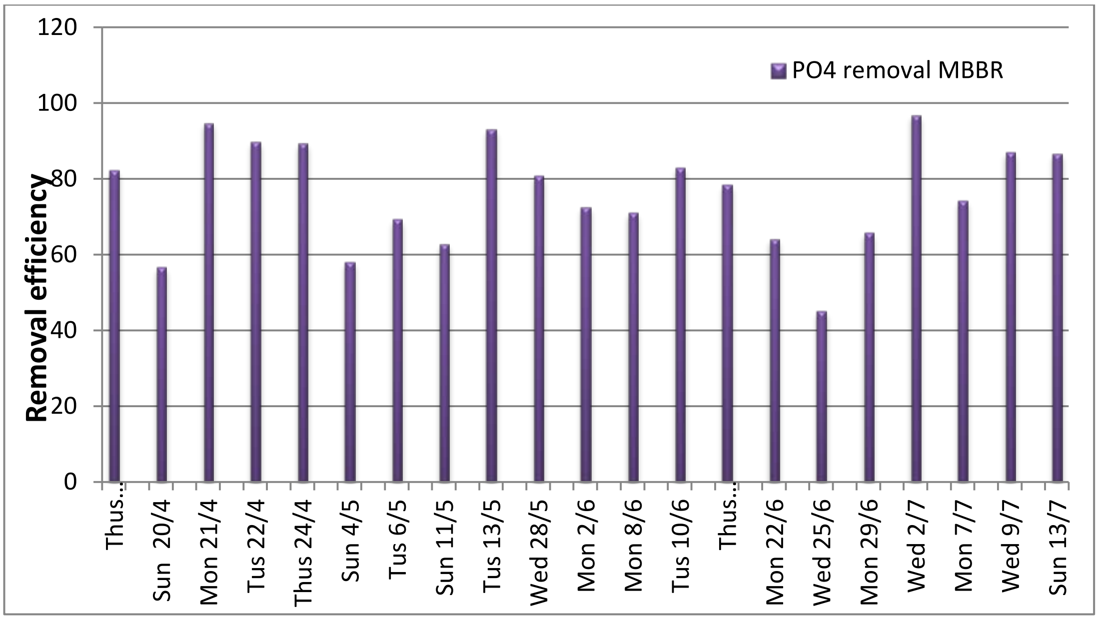

Figure.4 The phosphate removal efficiency

Nitrogen removal

Total nitrogen removal in wastewater treatment plants is commonly and most economically achieved in a two stage-system, nitrification and denitrification. Nitrification transforms ammonia to a more oxidized nitrogen compound such as nitrite or nitrate, which is then converted to nitrogen gas in the subsequent denitrification process. Nitrification and denitrification are usually carried out in different reactors because nitrification occurs under aerobic conditions while denitrification prevails in the absence of oxygen [17].

In the MBBR system the influent concentration of NH_4-N varied from 32.5 to 52.1 mg/L, corresponding to the effluent of 1.31 to 15.9 mg/L as shown in Figure 5. Approximately 82% of NH_4-N converted to nitrate and nitrite nitrogen as shown in the Figures.5, 6 and 7 Therefore, the nitrogen compounds in the effluent appeared mostly in the form of nitrate and nitrite nitrogen. This indicates that the nitrification process was perfectly achieved.

Figure 8, shows that the average removal efficiency of TN (as N) reached 70%. This result agrees with the findings of other authors who reported that under the optimum operating condition the average removal efficiency for NH_4 was 71%, [15]. This may be one of advantage of using MBBR process is to achieve nitrification denitrification.

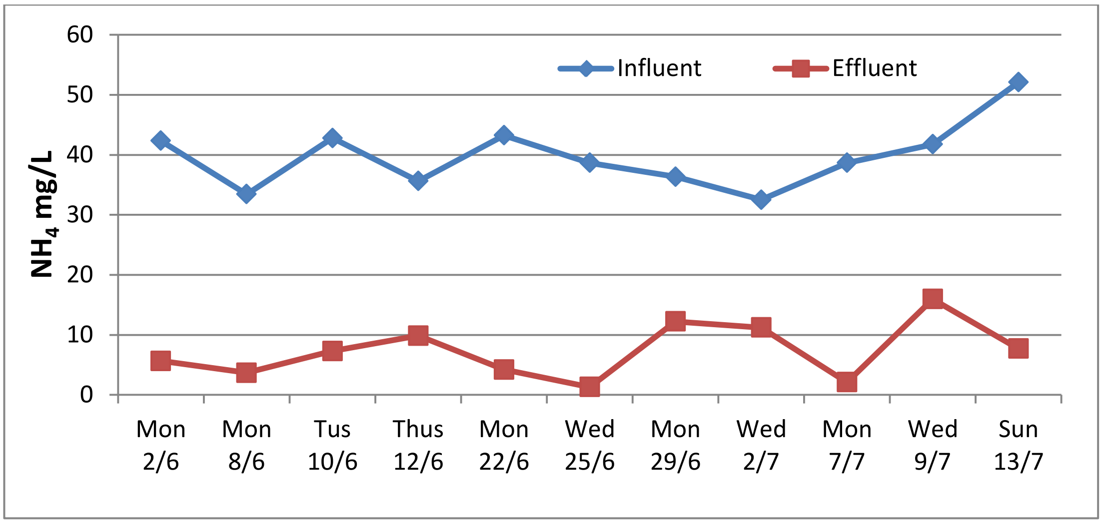

Figure. 5 The influent & effluent NH_4-N concentrations

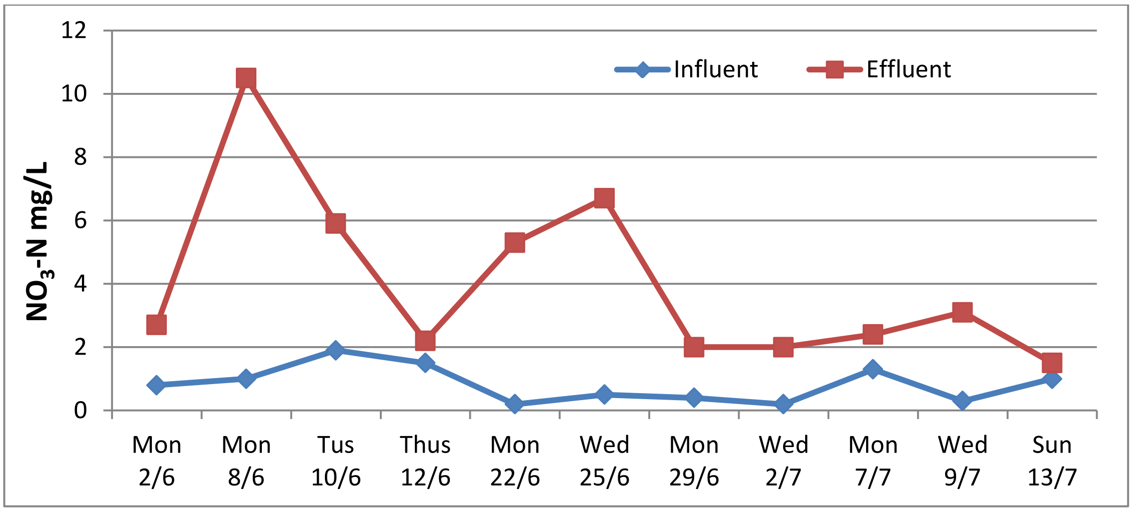

Figure. 6 The influent & effluent NO_3-N concentrations

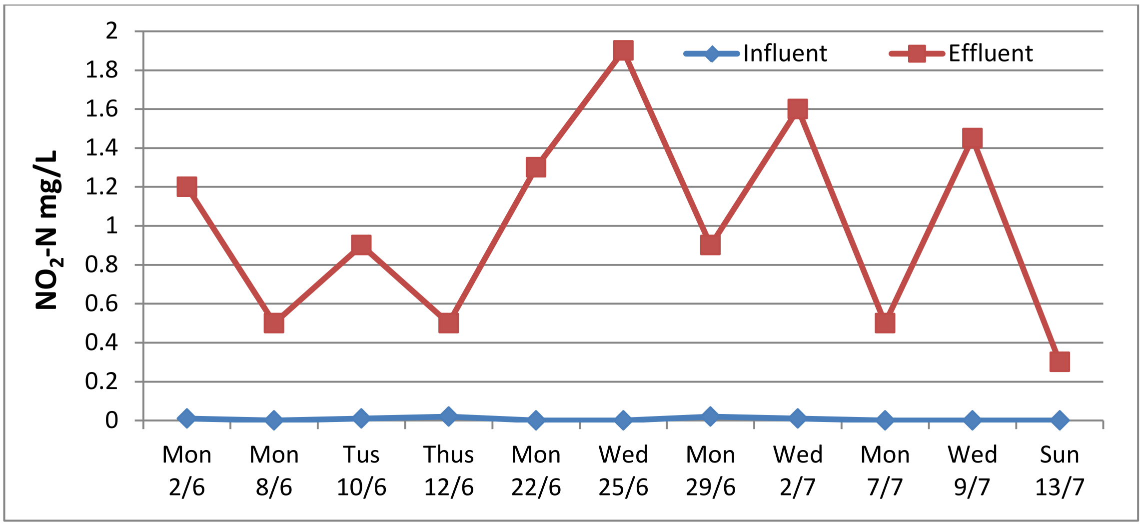

Figure. 7 The influent & effluent NO_2-N concentrations

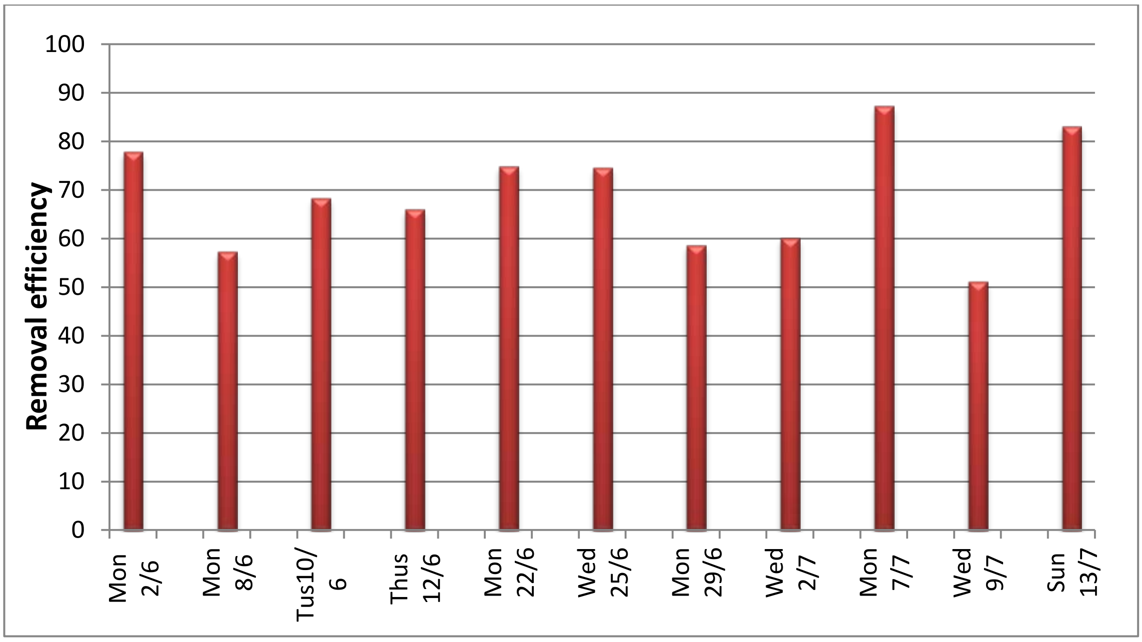

Figure.8 The TN removal efficiency

CONCLUSIONS

• The performance of MBBR systems shows good removal of pollutants from wastewater according to measured parameters (PO_4) with average removal efficiency reached to 76.79%.

• In terms of TN removal, the average removal efficiency was 70%. This finding is probably related to the fact that the biofilm attached on the carriers enhanced the increase in the overall sludge age, thus allowing better nitrification performances.

• It was concluded that (MBBR) can be an excellent alternative for upgrading and optimizing existing municipal wastewater treatment plants.

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