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ENHANCED COD AND NUTRIENT REMOVAL EFFICIENCY IN A HYBRID INTEGRATED FIXED FILM ACTIVATED SLUDGE PROCESS[*]

A. A. AZIMI, B. HOOSHYARI,[**] N. MEHRDADI AND GH.NABI BIDHENDI

Faculty of Environment, Tehran University, Tehran, I, R. of Iran
Email: hooshyari_b@yahoo.com

Abstract– Nowadays, innovative processes especially processes with integrated growth (combined attached and suspended growth) such as moving bed biofilm reactor (MBBR) and integrated fixed film activated Sludge (IFAS) are being used successfully for new construction and upgrading existing wastewater treatment plants. Increasing the hydraulic capacity, COD and nutrients removal from the effluent are the two main targets of applying these processes. In this research the efficiency of a new version of IFAS reactor was studied at pilot plant scale in Ekbatan municipal WWTP in Tehran, Iran. In this new reactor (which is called H-IFAS reactor) aerobic, anoxic and anaerobic zones were designed in a single reactor and, as a result, the conditions of doing nitrification, denitrification, phosphorus removal and increasing BOD removal rate in the reactor were optimized in comparison with IFAS and MBBR. The media used in this reactor was Bee-Cell2000 with a total specific surface area of 650 m^2/m^3. In optimum conditions, the organic degradation rate of the anaerobic and aerobic zone with an average temperature of 23.48 °C OLR=22.5 kg COD/m^3 day for the anaerobic zone and OLR 8.66 kgCOD/m3 day for the aerobic zone, was equal to 3.56 and 6.22 kgCOD/m^3 day respectively. Nitrification and denitrification rate of media with an average temperature of 23.48 °C, HRT=1.26 hr was equal to 532.77, 723.42 and 168.4 gN/m^3 day respectively. Biological phosphorus removal rate of the reactor at the best operational conditions with a phosphorous loading rate of 243 g P-PO4 /m^3 day, an average temperature of 23.48 °C, and HRT 27 min was equal to 168.4 g P-PO4 /m^3 day.

Keywords– H-IFAS, nitrification, denitrification, phosphorus removal, municipal wastewater, biofilter, biofilm

1. INTRODUCTION

The status of the wastewater treatment industry is one of continual flux as wastewater treatment requirements at any given time determined by a variety of external constraints. The capacity and performance of a municipal wastewater treatment facility is a moving target which is influenced by existing population and industrial input, projected growth rates in both of these variables, current regulatory requirements and anticipated regulatory changes arising from the need to provide additional protection to the aquatic environment [1, 2].

Over the last 50 years, the treatment of municipal wastewater has evolved from primary treatment for significant suspended solids and nominal BOD removal, through secondary biological treatment which enhanced both solids and BOD removal to tertiary upgrades, the most common of which have involved chemical addition for phosphorous removal and effluent filtration. The most recent concern of regulators and environmentalists is the release of nitrogen to receiving waters; either total nitrogen due to its contribution to eutrophication or ammonia due to its toxicity to aquatic life. As existing permits come up for renewal or new plants are needed, it is becoming increasingly common for permits to require the control of either ammonia-nitrogen or total nitrogen release. The upgrading of an existing activated sludge

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[**] Corresponding author

plant to provide increased treatment capacity can be an expensive proposition. Traditionally, it has involved the installation of an additional aeration basin and/or clarifier volume. This approach also requires a significant period of time to proceed through pre-engineering studies, permitting, design, tendering, construction and commissioning. In some cases, the additional land required for physical expansion may not be available. There is a growing interest among wastewater treatment plant owners to investigate more cost-effective retrofit techniques which utilize the existing tankage and facilities rather than building new structures. Today, the most common reasons for considering an upgrade are either to provide additional capacity for BOD removal to accommodate increased influent loadings, or for improved nitrogen control to meet more stringent regulatory requirements. Innovative technologies such as hybrid, integrated fixed-film activated sludge (H-IFAS) systems using integrated-growth support surfaces such as moving media offer potential cost-effective solutions to address both of these requirements. As shown in Table 1, H-IFAS reactor can be used for some different applications such as increasing the efficiency of nutrient (N & P) removal, new WWTP construction and also upgrading the existing WWTP, not only for increasing the capacity of BOD removal, but also removal of the nutrients [1-3].

The H-IFAS process can be a less expensive alternative for upgrading existing wastewater treatment plants to increase the capacity of the organic loading removal rate and nitrification, and if needed, denitrification and phosphorous removal. Although relatively new, pilot-plant studies show that the process is reliable, achieving effluent ammonia and nitrate concentrations comparable to or better than other biological removal options in about one fifth of the tank volume. The H-IFAS process does this by combining fixed-film and suspended activated sludge processes. It involves adding media to the aeration basins so microbes have more surface area on which to grow and, in combination with MLSS, nitrify wastewater. Although the MLSS equivalent concentration can reach 6000 mg/L or more, the attached growth does not exert excessive solids loading rates on final clarifiers because it remains in the aeration basin. The H-IFAS system operates just like a conventional activated sludge system, so no special operator attention is needed. As with a conventional system, MLSS is settled and thickened in final clarifiers and most is returned as return activated sludge (RAS), with some waste to maintain a target suspended sludge age. In most cases, a suspended sludge age of 4 to 5 days at near 10°C is sufficient to achieve nitrification, because the real sludge age (including attached growth) is probably at least twice that. The H-IFAS process is similar to a moving bed biological reactor (MBBR), except that the MBBR lacks significant MLSS and RAS.

Table 1. Applications of H-IFAS reactor [1]

Applications of H-IFAS system	
Process	Design considerations
New plant construction	• Design tank and aeration system geometry to incorporate fixed or dispersed media • Add equipment for dispersed media reactor, if selected.
Existing plant retrofits	•Add pre-fabricated fixed modules to aeration tanks. • Evaluate aeration for increased BOD removal and biomass respiration. • Add equipment for dispersed media reactor, if selected.
Nitrification/ denitrification conversions	• Add biomass to increase Solids Retention Time (SRT) to value needed for nitrification and convert to appropriate BNR process. • Add modules to provide more biomass without additional tankage.
Phosphorus removal	• With designing an anaerobic zone at the beginning of the reactor and returning sludge to the anaerobic zone, biological phosphorus removal and NH_3-N& COD concentration reduction can be achieved.

2. MATERIALS AND METHODS

a) Reactor system

As shown in Fig. 1, the H-IFAS reactor was set up at Ekbatan WWTP in Tehran, Iran. The system comprised an anaerobic (300 L), an aerobic (850 L) two anoxic zones (850 L), and a clarifier. The raw wastewater was fed to an elevated storage tank by a centrifuge pump from the grit chamber downstream and raw wastewater is fed to the reactor in an upflow manner. In order to control the content of media in each zone, stainless-steel meshes were installed between these parts. The aerobic and anoxic zones were separated with an impermeable metallic wall. Of course the above part of the walls consisted of some meshes which direct the flow to the anoxic zones. All anaerobic, aerobic and anoxic zones were filled up with moving media, and in anoxic zones two mixers were used for the provision of a complete mixing. The wastewater and the air flow were supplied in a concurrent manner to ensure proper contact time. Aeration was supplied with a side channel blower and the aeration rate was measured and monitored by an air flowemeter. In the meantime a wastewater flowemeter is used as well to define the flow of influent raw wastewater which was fed to the reactor in each operation phase. The rate of return sludge from the clarifier was controlled and monitored by a full automatic timer which controlled the flow and time of sludge returning in each phase. Two centrifugal pumps were used for transferring raw wastewater to the storage tank and another one for returning sludge to the anaerobic zone.

The H-IFAS reactor was based on integrated (attached and suspended) biomass technology for acidification, nitrification, denitrification and phosphorus removal. As said, the anaerobic zone of the H-IFAS reactor was constructed as a high-rate anaerobic reactor filled up with Bee-Cell2000 moving media where the complex organics compounds from the wastewater were converted to readily biodegradable components. According to media technical specifications and bench scale and pilot-plant studies, the media fill fraction in anaerobic, aerobic and anoxic zones was selected 60%, 50% and 50% respectively. A recycling flow from the anoxic zone is directed to the aerobic zone for alkalinity recovery and pH adjustment in the aerobic zone. The experiments were implemented in nine phases based on media locations, media quantities, and COD/TP/TKN ratios. As it was shown in Table 2, Bee-Cell2000 media was chosen as the fixed film biocarrier for this investigation which is made of Polystyrene, high impact and is specifically designed with a high internal (protected) specific surface area to maximize the attached growth potential but with sufficient void space to minimize plugging. The media consists of two concentric cylinders connected by internal walls along the length of the media. The overall dimensions are 22 mm (0.9) and 15 mm (0.6) in length. The internal surface area is 388 m^2/m^3 (120 ft^2/ft^3) and total surface area is 650 m^2/m^3 (198 ft^2/ft^3). Only the protected internal surface area is considered for design purposes [3].

b) Wastewater characteristic

Influent raw wastewater which was fed to the reactor in the operation period of the research has been given in Table 3. These data, which were adopted from the Wastewater Company's Laboratory information, were related to raw wastewater characteristics pumped from the downstream of the grit chamber of the Ekbatan WWTP.

c) Experimental setup

The reactor was operated during 9 phases in 8 months (from 12 July, 2005 to 12 March, 2006) and grab samples were collected, tested and analyzed for measuring physico-chemical and bacteriological of effluent parameters of aerobic, anaerobic and anoxic zones. All experiments in 9 phases were conducted in a quasy-steady state condition. Raw wastewater qualitative and quantitative data were adopted from Ekbatan WWTP laboratory information archives. The methods of sampling and different experiments were quite the same as the ones that were used in the research.

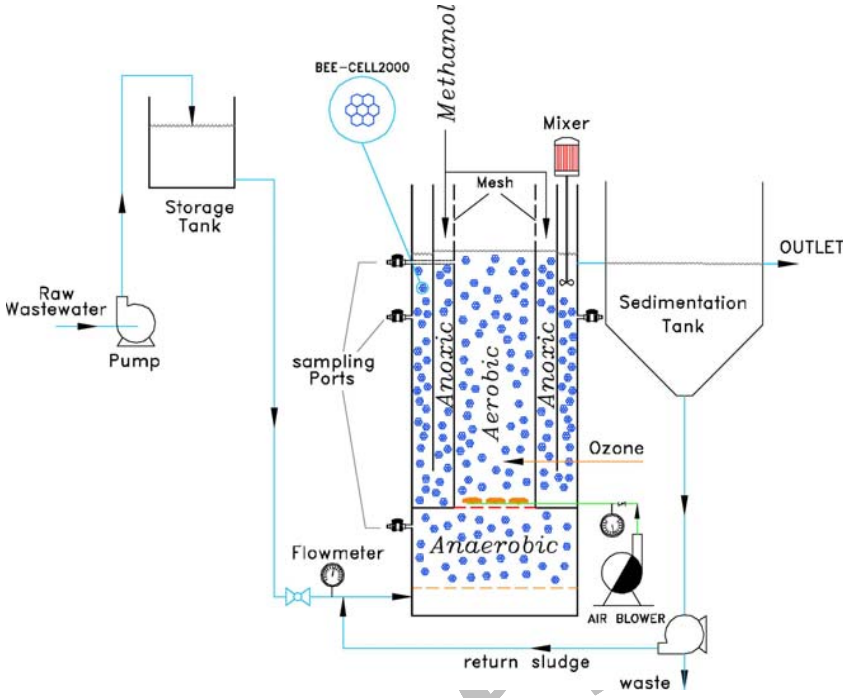

Fig. 1. The schematic of H-IFAS reactor

Table 2. Bee-Cell 2000 moving media specifications [3]

Technical specifications	Bee-cell2000
Material	Polystyrene, high impact
Specific surface area	650 m^2/m^3(198 ft^2/ft^3)
Maximum fill	Up to 75%
Weight per m^3	Max. 140 kg/m^3
Number of units per m^3	361,000
Surface per unit	18 c ^{m2}
Percentage of hollow space	87 %
Color	Natural white

Table 3. Raw wastewater characteristics

Parameters	2005									2006			Avg.
	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
T °C	21.1	25.6	25.6	26.1	26	26.5	25	22	22	21	22	22	24
pH	7.47	7.77	7.71	7.79	7.8	7.73	7.8	7.9	7.7	7.7	8	7.8	7.8
TS (mg/l)	661	569	625	657	667	649	613	657	665	704	660	763	658
TSS (mg/l)	180	236	252	206	211	197	200	200	180	205	143	219	202
BOD5 (mg/l)	171	170	143	154	148	170	115	148	158	155	85	195	151
COD (mg/l)	222	312	245	234	220	245	259	189	180	269	285	237	243
TKN (mg/l)	45	46	42	47	46	47	48	46	47	40	43	40	45
TP (mg/l)	9.55	16.1	12.2	14	15	4.33	13	13	13	12	10	8.9	12

The systems were operated and monitored for over 8 months to allow them to reach steady state conditions, and then at least three runs of steady state data were collected from each system during each phase of experiments to characterize each of them. At steady state, chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), total phosphorus (TP), anions (nitrite, nitrate and phosphate), and cations (ammonia-N) were measured. TKN, TP, and COD were analyzed in accordance with standard methods [4].

d) Analytical procedure

The biochemical oxygen demand (BOD5), chemical oxygen demand (COD), suspended solids (SS) total kjeldahl nitrogen (TKN), total phosphorus (TP) and pH of influents and effluents, mixed-liquor suspended solids (MLSS), and excess sludge, were determined by using standard methods for the examination of water and wastewater [4].The percentage of volatile solids was calculated and then used to determine the total volatile solids on the media. Solid retention time (SRT), or sludge age, was determined by measuring the average residence time of the suspended microorganisms (suspended bio-sludge) in the system. F/M was presented as a ratio of BOD5 loading and the total bio-sludge of the system.

3. DISCUSSIONS AND RESULTS

Efficiency of the reactor for COD and nutrient removal can be analyzed as follows:

a) Anaerobic (acidification) zone

The anaerobic zone of this reactor was designed as an anaerobic moving bed reactor (AMBR). In anaerobic digestion, it can be defined as a situation where the reducing equivalents are generated from glycolysis accumulate and get channeled into the production of higher carbon-chained volatile fatty acids (VFAs) other than formate and acetate [5, 6]. Hydraulic overloading occurs whenever the effective retention time, which is defined as reactor volume over its feed flow rate, is reduced to a point where the microorganisms cannot reproduce before being washed out [7]. Two types of disturbances that were imposed to the AMBR were organic and hydraulic alterations, and provided the conditions of phosphrous removal. The aims of this study were to observe the performance and response of the AMBR in dealing with these disturbances. The anaerobic zone contains media which the biofilm forms. The bed is moving with the aims to maximize biomass concentration in the reactor without clogging and to achieve the optimum biofilm thickness for good mass transfer [7-9]. The use of relatively light carriers result in retaining the active biomass in the reactor with the minimum energy required for carrier movement. The raw wastewater with nitrogen and phosphorus compounds was treated at various hydraulic retention times (HRT). Regarding Fig. 2, one can see that designing an anaerobic zone at the lower part of the reactor not only had a good efficiency for COD removal efficency [Organic degradation rate of anaerobic zone (0.18 cubic meter of this media was held in anaerobic zone) with an average temperature of 23.48 °C, HRT=27 min and OLR=22.5 kg COD/m^3 day was equal to 3.56 kgCOD/m^3 day] and saving in energy demand, but also had a slight effect on the ammonia removal rate (it is assumed, because of ANAMMOX phenomena occurring). Anaerobic zone also controls the shocks of excessive hydraulic and organic loading rates [10-12].

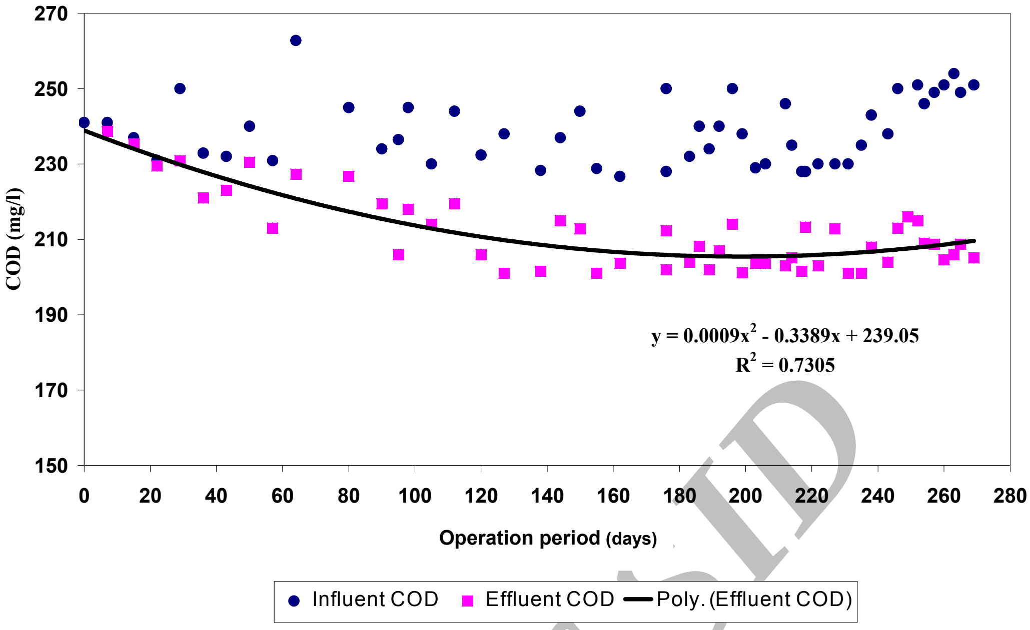

Fig. 2. COD removal efficiency of anaerobic zone during the operation period

b) Aerobic (Nitrification and COD removal) zone

Figure 3 shows the influent and effluent COD concentration variations during the operation period and consequently nitrification rate per support area with respect to effluent N-NH4 concentration with a 4-6 mg/l dissolved oxygen (DO) range. The organic degradation rate of the aerobic zone (0.4675 m^3 of this media was held in aerobic zone) with an average temperature of 23.48 °C, HRT=1.26 hr and OLR=8.66kgCOD/m^3.day was equal to 6.22 kgCOD/m^3.day [2, 13].

There are several major factors that influence the kinetics of nitrification. These are organic loading, hydraulic loading, temperature, pH, dissolved oxygen concentration, and media. In this study, nitrification was studied in the pilot scale biofilm reactor (H-IFAS) equipped with a fine bubble aeration system. With regard to the technical specifications of the media and also similar studies with kaldnes-k1, the media (Bee-Cell2000) fill fraction of the aerobic zone of the reactor was selected by 50 %. The biofilm system offers the achievement of high biomass age that is very important for the nitrification process. Raw wastewater was used as the source of N-NH4. It was found that nitrification is clearly oxygen limited at higher ammonia concentrations. For the unlimited conditions the DO/ [N-NH4] ratio in the reactor should be at least 4. Refs. [2, 14, 15] found that this type of reactor could be modeled as CSTR. The oxygen concentration as well as the velocity of the air, and consequently the hydrodynamic conditions in the reactor, were controlled by the air supply. With increasing air supply the concentration of oxygen and air velocity in the reactor increased and external mass transport resistance decreased. Ref. [16] presented a simplified design of biofilm processes using normalized loading curves. The design is based on the parameters that are characteristic for the biological process and parameters that define hydrodynamic conditions in the reactor. This concept can be used for the design of biofilm reactors for nitrification [17, 18]. Higher concentration of organic compounds in the nitrification zone leads to a competition for oxygen in the biofilm between heterotrophic (COD elimination) and autotrophic (nitrification) organisms. In this research, the nitrification rate was obtained at an optimum range by using a well-designed media with a high specific surface area. In phase 8, in which we had the best operational conditions, the nitrification rate of media (0.4675 cubic meter of this media was held in aerobic zone) with an average temperature of 23.48 °C, HRT=1.26 hr was equal to 532.77gN/m^3 day.

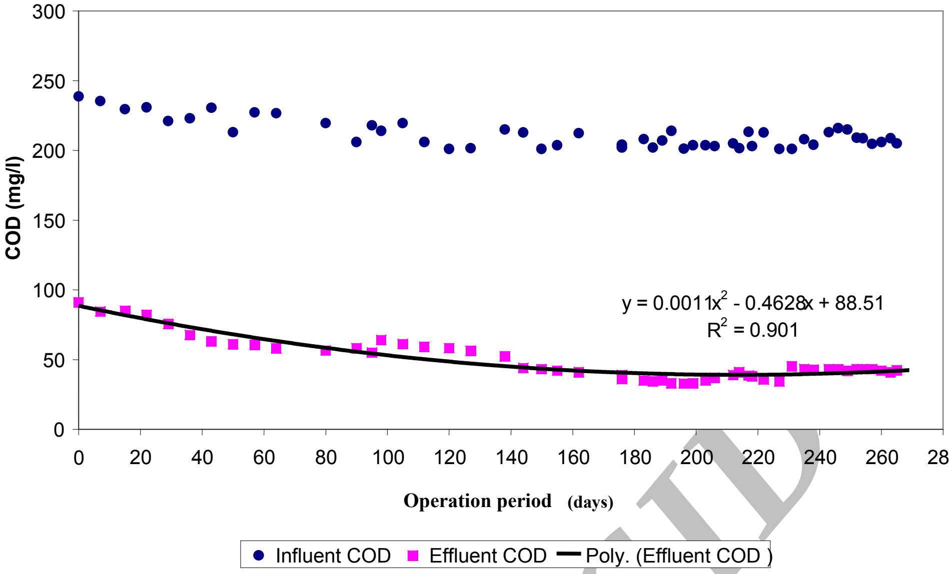

Fig. 3. COD removal efficiency of aerobic zone during the operation period

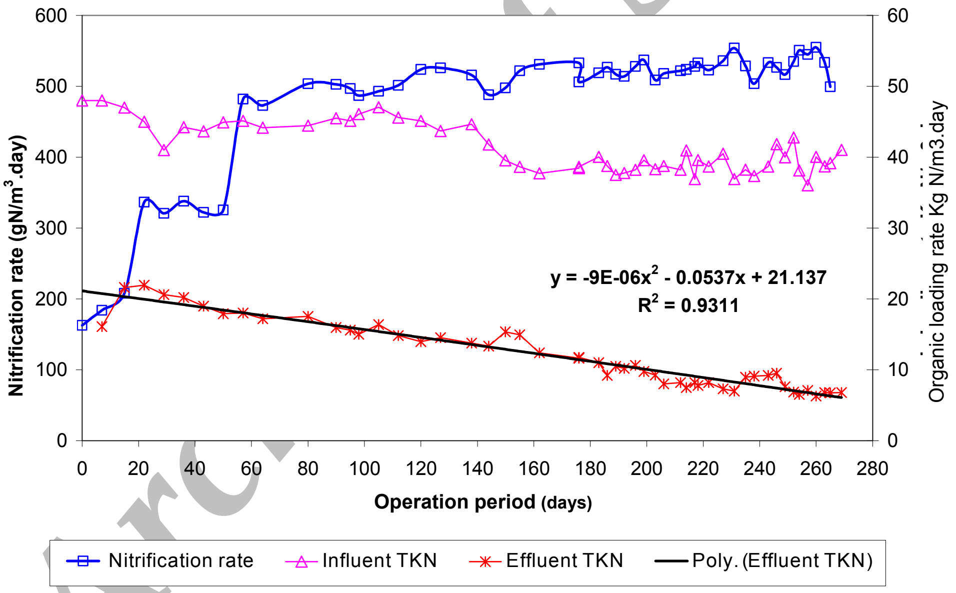

Fig. 4. Influent and effluent TKN concentration variations during the operation period and nitrification rate of the reactor

c) Anoxic (denitrification) zone

Denitrification was studied in the pilot-plant study biofilm reactor. Effluent of aerobic zone was used as the source of N-NO3 and methanol with the dosage of 5-10 mg/l served as the readily biodegradable carbon source as the electron acceptor. Anoxic zones consist of two separated parts with equal volumes which are situated on both lateral sides of the reactor. The denitrification rate was of half-order in the N-NO3 concentration range 15-30 mg/l when COD was in excess. Some similar results for denitrification in biofilm reactors with dispersed media [20-22]. Considering Fig. 5 the denitrification rate of media (0.4675 cubic meter of this media was held in anoxic zones) with an average temperature of 23.48 °C, HRT=1.26 hr was equal to 723.42 gN/m^3 day.

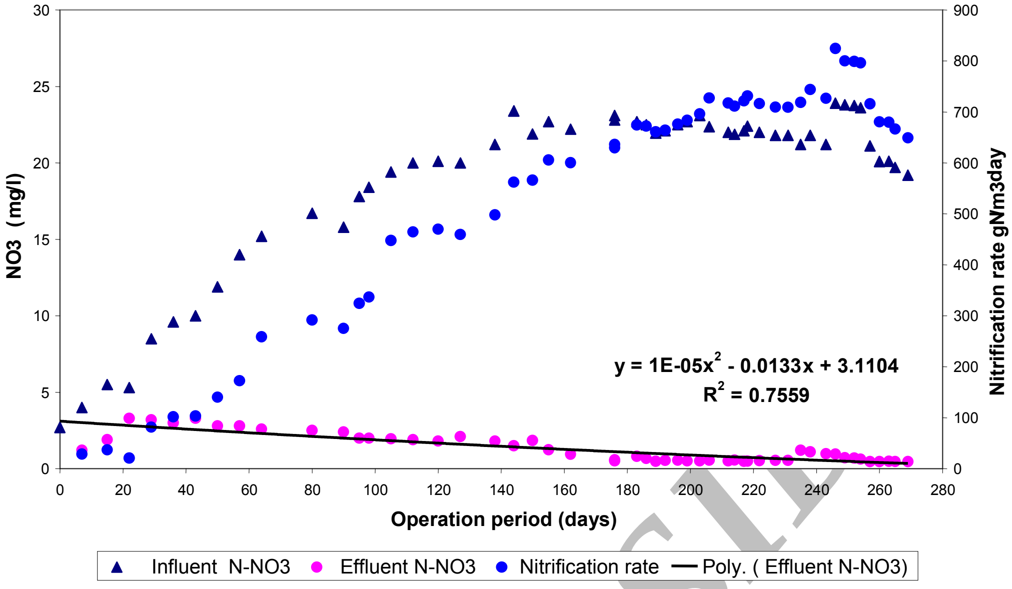

Fig. 5. Denitrification rate of the media in the anoxic zone

d) Phosphrous removal

Phosphorus appears in wastewater as orthophosphate, polyphosphate and organically bound phosphorus, the last two components usually accounting for up to 70 percent of the influent phosphorus. Microbes utilize phosphorus during cell synthesis and energy transport. As a result, 10 to 30 percent of the influent phosphorus is removed during traditional mechanical/biological treatment [20-23]. When enhanced phosphorus removal is desired, the process is modified, so that the sludge is exposed to both anaerobic and aerobic conditions. Then certain microorganisms, capable of storing phosphorus (in the form of polyphosphates), metabolize it for energy production and cell synthesis, resulting in the removal of phosphorus from the system through the waste activated sludge. A2O and modified UCT processes were operated to treat municipal wastewater [17, 18]. In this research an A2O process was simulated in the H-IFAS reactor with the difference being that anaerobic, anoxic and oxic zones were designed and constructed in a single reactor. Having separated different zones in the reactor, good efficiencies could have been achieved in pollutants (COD, NH3-N, NO2-N, NO3-N, and TP and so on) removal. Application of biofilm carriers in the reactor increased the population of autotrophic microorganisms which have an important role in nitrification, denitrification and biological P-removal [11, 24-26]. As shown in Fig. 6, biological P-removal in the reactor had a good stability. On the other hand, the efficiency of the reactor in comparison with the other conventional processes is quite different. Namely, although the volume of the reactor is limited and the compactness of the system has a very small footprint, the capability of the process in this reactor is reliable and it has a very good efficiency for removing phosphorus from raw wastewater. Biological phosphorus removal rate of the reactor at the best operational conditions(phase 8) with a phosphorous loading rate of 243 g P-PO4 /m^3 day , an average temperature of 23.48 °C and HRT 27 min was equal to 168.4 g P-PO4 /m^3 day. Since the rate of return sludge from the clarifier was controlled and adjusted by an automatic timer the effect of the returning sludge rate on the efficiency of phosphorous removal in the reactor was tested and surveyed. It was shown that the best result for P-removal efficiency occurred when the rate sludge return was about 15% of the influent flow rate.

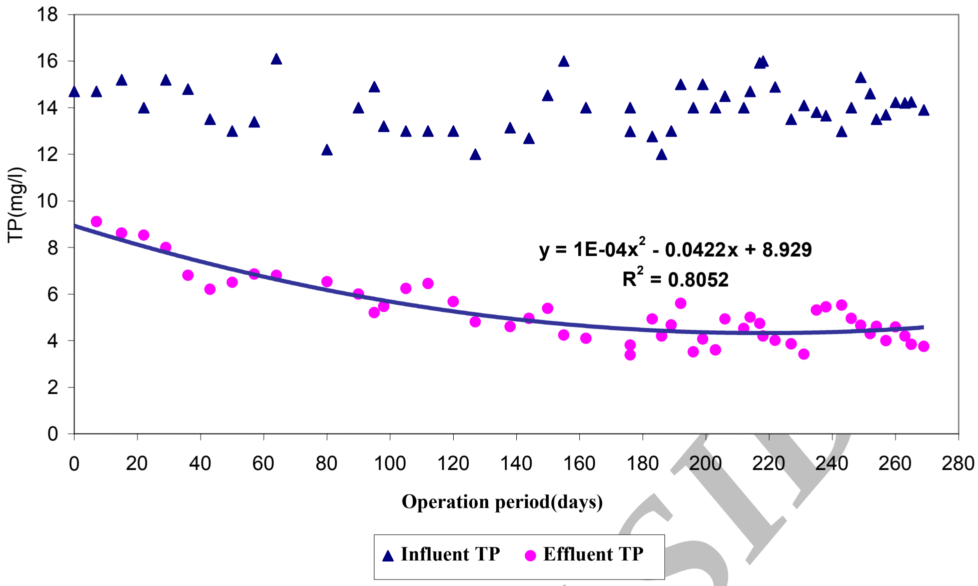

Fig. 6. Phosphorous removal rate in different phases of the reactor operation

4. CONCLUSIONS

Regarding the results which were obtained from the reactor, the following conclusions can be drawn:

- Organic degradation rate of anaerobic zone (0.18 cubic meter of this media was held in anaerobic zone) with an average temperature of 23.48 °C, HRT=27 min and OLR=22.5 kg COD/m^3 day was equal to3.56 kgCOD/m^3 day.
- Organic degradation rate of aerobic zone (0.4675 cubic meter of this media was held in aerobic zone) with an average temperature of 23.48 °C, HRT=1.26 hr and OLR=8.66kgCOD/m^3 day was equal to 6.22 kgCOD/m^3 day.
- Nitrification rate of media (0.4675 cubic meter of this media was held in aerobic zone) with an average temperature of 23.48 °C, HRT=1.26 hr was equal to 532.77gN/m^3 day.
- Denitrification rate of media (0.4675 cubic meter of this media was held in anoxic zones) with an average temperature of 23.48 °C, HRT=1.26 hr was equal to 723.42 gN/m^3 day.
- Biological phosphorus removal rate of the reactor at the best operational conditions with a phosphorous loading rate of 243 g P-PO4 /m^3 day, an average temperature of 23.48 °C and HRT 27 min was equal to 168.4 g P-PO4 /m^3 day.
- Municipal wastewaters can be successfully treated in a three-stage (aerobic–anaerobic–anoxic) moving bed bioreactor with Bee-Cell2000 media used as biomass support.
- H-IFAS reactor has more flexibility than extended aeration on flow fluctuations.
- Reduction in COD depended on mean residence time *t*, ratio of bio-carrier to reactor volume (media: reactor volume), air velocity and media specification. For set *t* and media: reactor volume, the COD removal initially increased monotonically, and then decreased with an increase in air velocity.
- The H-IFAS process can be a less expensive alternative for upgrading existing wastewater treatment plants to increase the capacity of organic loading removal rate and nitrification and if needed, denitrification and phosphorous removal.

In fact, the successful operation of the H-IFAS reactor, as indicated by the measured COD, was further supported, well within the expected range, removals of ammonia and phosphorus.

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