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DETERMINATION OF DESIGN CRITERIA OF AN H-IFAS REACTOR IN COMPARISON WITH AN EXTENDED AERATION ACTIVATED SLUDGE PROCESS

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ABSTRACT

Advanced compact wastewater treatment processes are being looked for by cities all over the world as effluent standards are becoming more stringent and land available for treatment plants more scarce. In this investigation, a new biofilm process for this purpose was studied. The design and operational criteria of a full scale extended aeration activated sludge system was compared with an H-IFAS reactor which has been operated at a pilot scale. The objective was to define the feasibility of using the H-IFAS (Hybrid Integrated Fixed Film Activated Sludge) reactor for upgrading the existing wastewater treatment plants with conventional processes. The results showed that besides the considerable difference between the organic loading of the two processes, H-IFAS reactor has a very good capability to reduce simultaneously the concentration of nitrogen and phosphorus. Organic degradation rate in extended aeration and H-IFAS systems were 0.3 and 6.22 kgCOD/m^3.day at 23.48°C, respectively. Nitrification, denitrification and phosphorus removal rate for the H-IFAS reactor were 343.28 g N/m^3.day, 338.17 gN/m^3.day, and 204.78g$PO4^-$P/m^3.day, respectively. At the same conditions, these criteria for extended aeration activated sludge processes were obtained as 75gN/m^3.day, 28.5 gN/m^3.day and 7 gPO_4-P/m^3.day), respectively.

Key words: IFAS, MBBR, H-IFAS, biofilm, nitrification, denitrification, biological phosphrous removal, extended aeration

INTRODUCTION

The activated sludge process is a suspended culture system that has been in use since the early 1900_s. The process derives its name from the fact that settled sludge containing living, or active, microorganisms is returned to the reactor to increase the available biomass and speed up the reactions. It may be either a completely mixed or plug flow process. The process is aerobic, with oxygen being supplied by dissolution from entrained air Extended Aeration (EA) is one of the modifications of the activated sludge process in which aeration time is increased to about 24 hours. The major advantage of this configuration is that the rate at which waste activated sludge is removed from the process approaches zero. The treatment efficiency decreases, however, and the power costs for aeration are higher (Asano, 1998). Primary treatment is usually eliminated. Some disadvantages of EA activated sludge process can be considered as follows:

- Does not remove colour from industrial wastes and may increase the colour through formation of highly coloured intermediates through oxidation
- Does not remove nutrients, tertiary treatment is necessary
- Problem of getting well settled sludge Recycle biomass keeps high biomass concentration in aeration tanks allowing it to be performed in technologically acceptable detention times

Regarding the above problems with activated sludge processes, finding some alternatives which have the advantages of activated sludge process and on the other hand does not include its disadvantages and can improve their efficiencies in a better way, is the first primitive. (Lancaster *et al.*, 1991). Biofilm reactors such as MBBR

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(Moving Bed Biofilm Reactor) and IFAS (Integrated Fixed Film Activated Sludge) are some well known alternatives which have been used in the last decades and have had some excellent and reliable removal efficiencies for different pollutants. IFAS systems add the benefits of fixed film systems into the suspended growth AS process. AS has process flexibility and provides a high degree of treatment. Fixed Film processes are inherently stable and resistant to organic and hydraulic shock loadings. Placing fixed film media into AS basins combines the advantages of both of these systems. The additional biomass provided by placing fixed film media directly into the suspended growth reactor does not increase clarifier solids loading (a factor that often limits the treatment capacity of existing AS systems). IFAS technology addresses the need for increasing AS plant capacity, with little or no added tankage, because of the additional fixed biomass. The fixed biomass also contributes to the ability of the process to respond to organic or hydraulic shock loads and to recover from upsets. There are several types of media used to fix the biomass in the AS basin. They include "Dispersed Media "entrapped in the aeration basin" and "Fixed Media". The use of Submerged Fixed Film in the biological treatment of wastewater has been in practice for well over 60 years.(Molla *et al.*, 2003). The process was staged with intermediate clarifiers, had low return sludge capability, and the total Hydraulic Residence Time (HRT) was typically 1.7 to 3 hours. This process was stable and responded well to load fluctuations without significant operator attention. However, with no Return Activated Sludge (RAS) provision, it lacked the range of control of AS. Also, the fixed panels did not facilitate oxygen diffusion, good mixing, or energy efficiency. Eventually, this concept gave way to current AS practices. In the following decades, hundreds of installations employing Submerged Fixed Film were introduced internationally, although relatively little work was completed in the US. The small footprint and ease of operation of Submerged Fixed Film systems were the primary benefits driving the use of this technology. In the 80's and 90's, work began in the US on the integration of Fixed Film and AS technologies. Because of today's increasingly stringent effluent requirements, high tank age expansion costs, and reduced funding options, increased attention is focusing on IFAS technology solutions, both in fixed and dispersed media (Sriwiriyarata *et al.*, 2005). H-IFAS reactor is a new version of IFAS system in which aerobic, anaerobic and anoxic zones are designed and constructed in one reactor for achieving a relative full capacity of nitrification, denitrification, phosphorous removal and also high removal efficiency of carbonous organic compounds. Ozonation process was used simultaneously in the aerobic zone to increase the efficiency removal of TKN, COD and BOD_5. In the meantime, because of combining the different zones in the reactor and its vertical configuration, the reactor space requirement is too low and a very small footprint is needed in this system (Andreottola *et al.*, 2000).

MATERIALS AND METHODS

A: Ekbatan Wastewater Treatment Plant

Ekbatan wastewater treatment plant which was selected to setup the H-IFAS reactor and was working with extended aeration activated sludge process, is situated at the south west of Tehran. The general information of the system are summarized in Table 1. In Table 2, some process parameters of aeration basins are given.

Table 1: General information of Ekbatan wastewater treatment plant

parameters	unit	amount
Average Daily Flow(design)	m^3/h	1000
Average hourly Flow(actual)	m^3/h	835
Maximum hourly flow	m^3/h	900
Aerator power consumption	kWh	22.5
Aeration basin dimensions (for each basin)	m	48×32×5.6
Coverage population (design)	capita	100000
Present population	capita	85000

Table 2: Aeration basins process characteristics

Equipment	Basin no.1	Basin no.2
Total Aerators (unit)	6	6
Aerators at operation (unit)	4	3
HLR (h)	15	15
Average Daily DO (mg/L)	0.9	0.8
Average MLSS (mg/L)	3000	3000
Average MLVSS (mg/L)	2400	2400
SVI (mL/g)	260	260

B: H-IFAS Pilot Plant System

The pilot plant of H-IFAS reactor was built according to the scheme in Fig. 1. 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 fed to the reactor in an upflow continuous manner. In order to control the content of media in each zone some stainless steel meshes were installed between these parts. The aerobic and anoxic zones were separated with an impermeable metallic wall. The upper part of the walls consisted of some meshes which directed 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 to provide an appropriate mixing. The wastewater and the air flow were supplied in a counter current manner to ensure proper contact time. Aeration was supplied with a side channel blower and aeration rate was measured and monitored by an air flow meter. In the meantime a wastewater flow meter was used as well to define the flow rate 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. In aerobic processes, the biofilm carrier movement was caused by the agitation set up by the air keeping the carriers moving. In the aerobic reactors, fine bubble aeration system was installed. The media fill fraction in anaerobic, aerobic and anoxic zones were selected as 60%, 55% and 55% , respectively. A recycling flow from anoxic zone was directed to aerobic zone for alkalinity recovery and pH adjustment. The experiments were implemented in eight phases based on media locations and quantities and COD/TP/TKN ratios. The Bee-Cell2000 media was chosen as the fixed film media for this investigation which was made from Polystyrene and was specifically designed with a high internal (protected) specific surface area to maximize attached growth potential but with sufficient void space to minimize plugging. The media consisted of two concentric cylinders connected by internal walls along the length of the media. The overall dimensions were 22 mm in diameter and 15 mm in length. The internal surface area was 388 m^2/m^3 and total surface area was 650 m^2/m^3. Only the protected internal surface area was considered for design purposes (Table 3).

Table 3: Bee-Cell 2000 moving media specifications

Technical Specifications	Bee-Cell2000
Material	Polystyrene, high impact
Specific surface area	650 m2/m3(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 cm^2
Percentage of hollow space	87 %
Colour	Natural white

Raw wastewater characteristics which were adopted from Ekbatan Wastewater Company's Laboratory Archive are presented in Table 3. The reactor was operated during 8 phases in 8 months (from June 19th, 2005 to March 18th, 2006) and the samples were collected , tested and analyzed for measuring physico-chemical and bacteriological parameters.

Both systems (H-IFAS and EA activated sludge) were operated and monitored for over 8 months to allow reactor to reach steady state conditions, and then at least three runs of steady state data were collected from each compartment during each phase of experiments. At steady state, mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN) and total phosphorus (TP) were measured. The MLSS, MLVSS, TKN, TP, and COD were analyzed in accordance with Standard Methods for the Examination of Water and Wastewater, 19_{th} Edition, 1995.

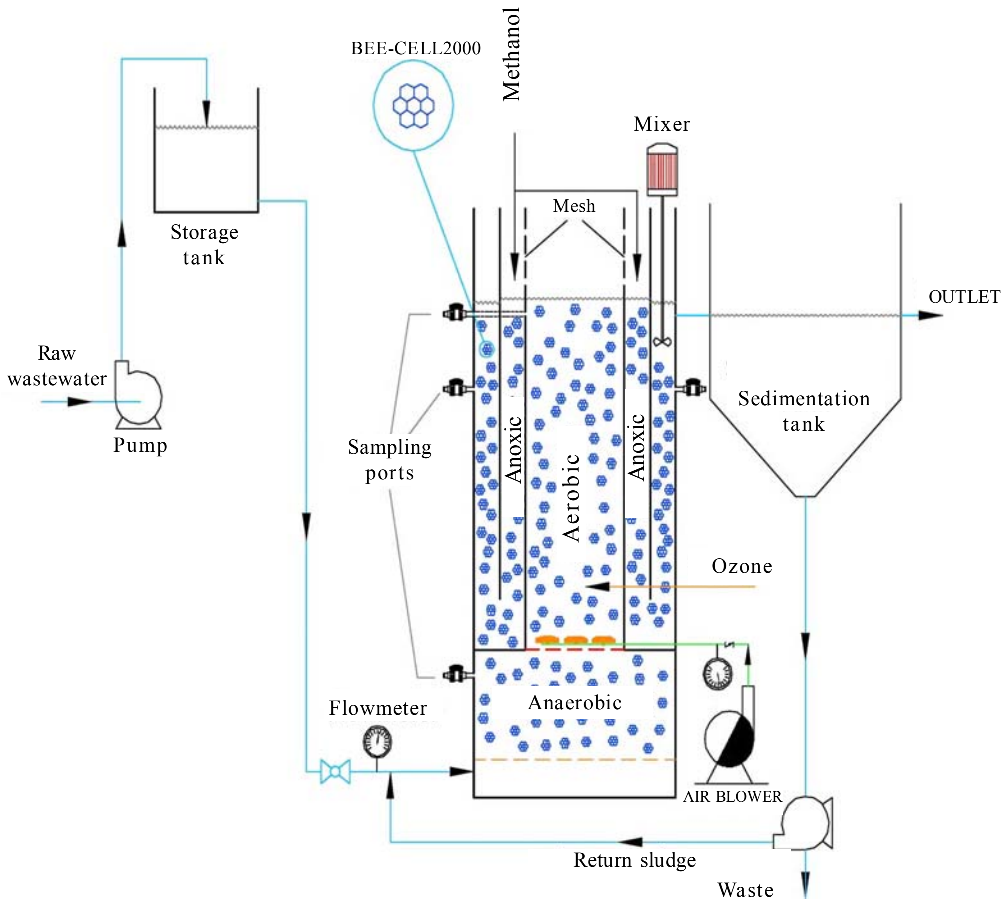

Fig. 1: The schematic diagram of the H-IFAS pilot-plant

Table 4: Raw wastewater characteristics

Parameters	2005									2006		
	Apr.	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
pH	7.47	7.77	7.71	7.79	7.8	7.73	7.8	7.9	7.7	7.7	8	7.8
TS(mg/L)	661	569	625	657	667	649	613	657	665	704	660	763
TSS(mg/L)	180	236	252	206	211	197	200	200	180	205	143	219
BOD5(mg/L)	171	170	143	154	148	170	115	148	158	155	85	195
COD (mg/L)	222	312	245	234	220	245	259	189	180	269	285	237
TKN (mg/L)	45	46	42	47	46	47	48	46	47	40	43	40
TP (mg/L)	9.55	16.1	12.2	14	15	4.33	13	13	13	12	10	8.9

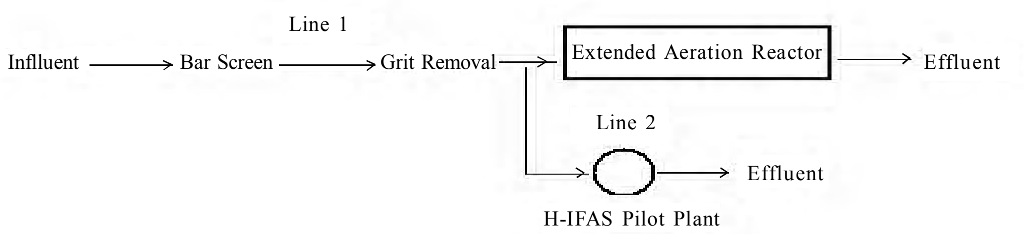

Fig. 2. The schematic flow-diagram of the full-scale and pilot-plant system at Ekbatan WWTP

RESULTS

BOD and COD Removal

BOD and COD removal in H-IFAS and extended aeration systems have been shown in Fig. 3 and Fig. 4. 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 kgCOD/m^3.day was equal to 3.56 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=8.66 kgCOD/m^3.day was equal to 6.22 kg COD/m^3.day. With regarding to Fig. 5 and 6, organic degradation rate of the extended aeration activated sludge process at temperature of 23.48 °C and OLR=0.3 kgCOD/m^3.day was equal to 0.26 kgCOD/m^3.day.

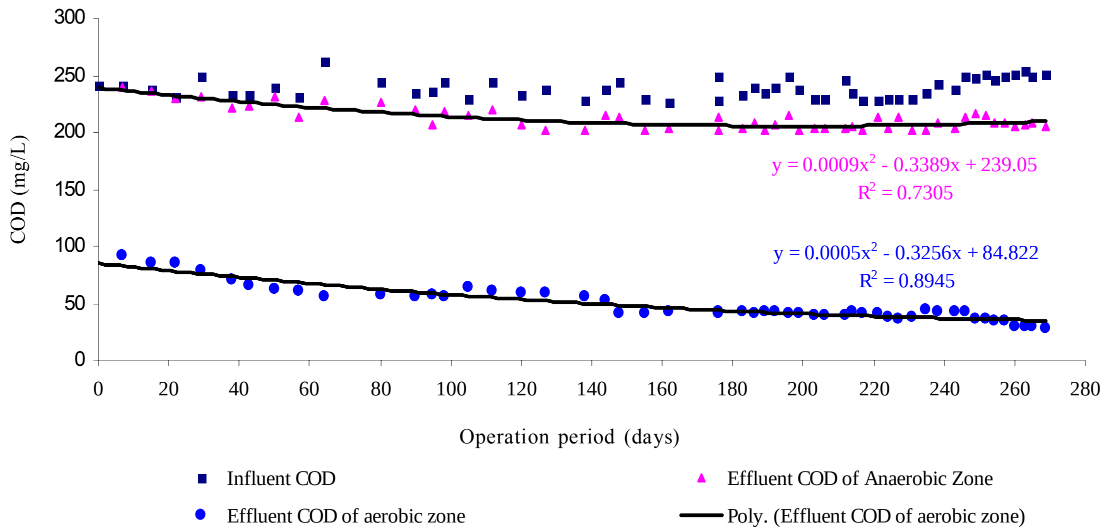

Fig. 3: COD removal efficiency in anaerobic and aerobic zones of H-IFAS reactor

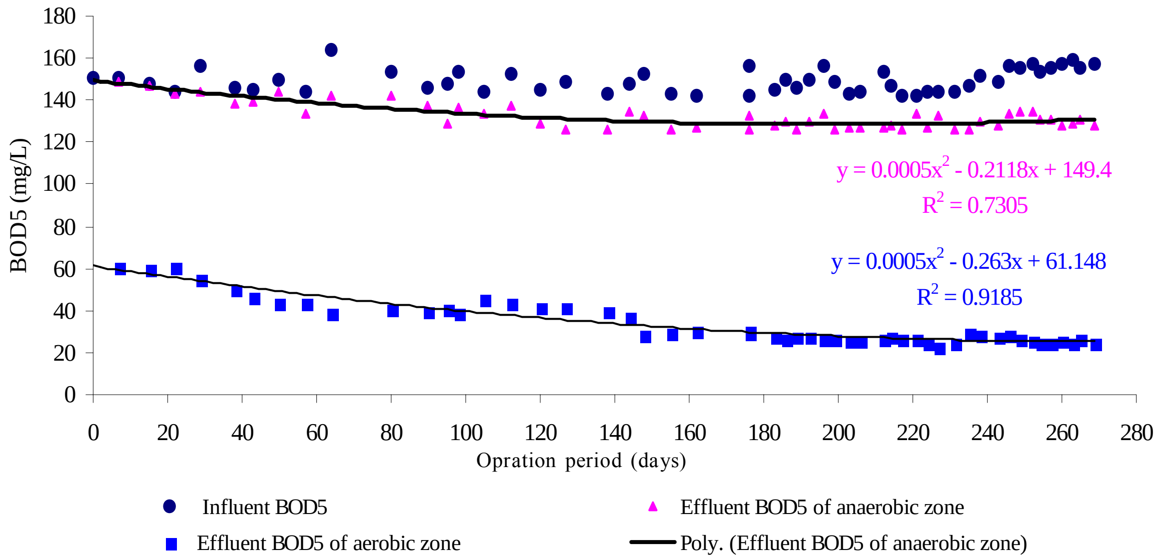

Fig. 4: BOD_5 removal efficiency in aerobic and anaerobic zones of H-IFAS reactor

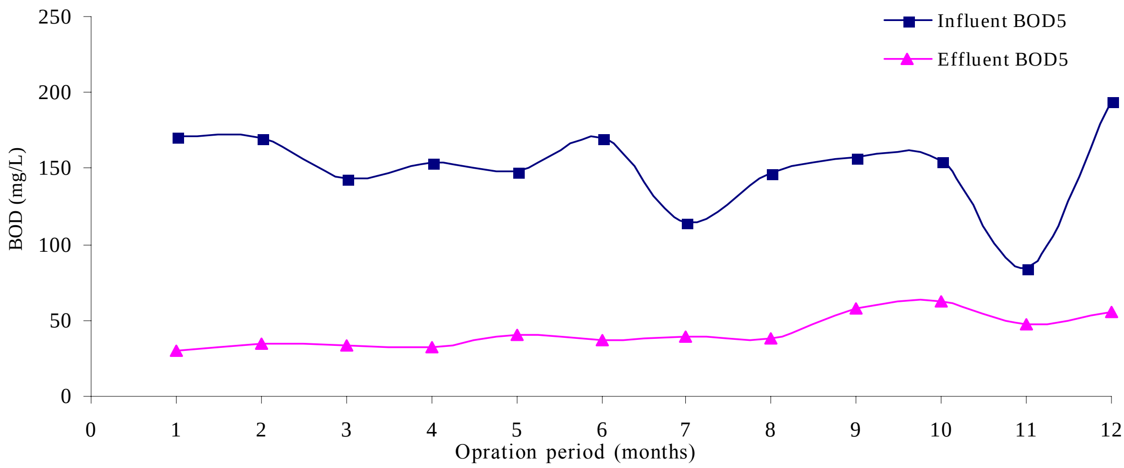

Fig. 5: BOD_5 removal efficiency in extended aeration activated sludge system (Ekbatan WWTP)

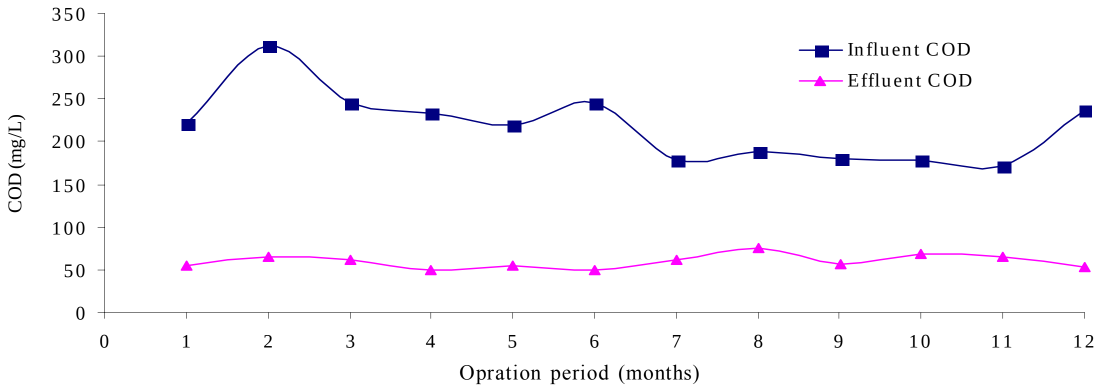

Fig. 6: COD removal efficiency in extended aeration activated sludge system (Ekbatan WWTP)

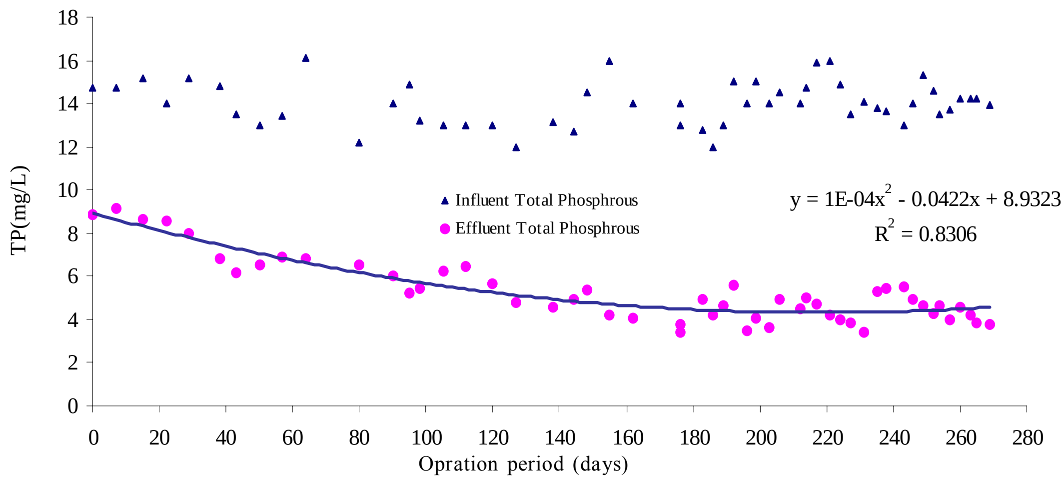

Fig.7: Phosphorous removal rate in different phases of H-IFAS reactor operation

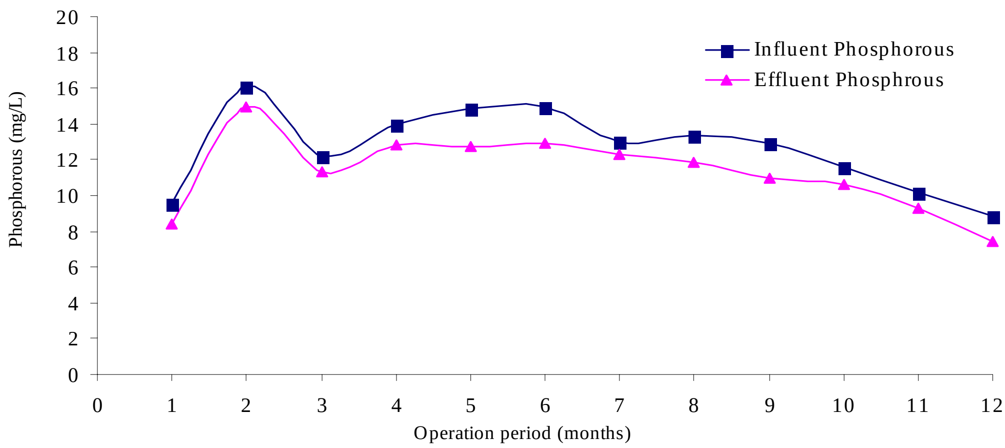

Fig. 8: Phosphorous removal rate in Extended Aeration Activated Sludge System (Ekbatan WWTP)

phosphorus removal

Biological phosphorus removal rate of the reactor at optimized operational conditions with a phosphorous loading rate of 243.57 gP-PO_4/m^3.day , an average temperature of 23.48 °C and HRT= 27 min was equal to 204.78 gP-PO_4/m^3.day. Since the rate of return sludge from the clarifier was controlled and adjusted by an automatic timer, it was tried to test and study the effect of returning sludge rate on the efficiency of phosphorous removal in the reactor. 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. With regarding to Fig. 8 phosphorus removal rate in Ekbatan WWTP, was obtained 7 g PO_4-P/m^3·day

Nitrification Efficiency

In optimized conditions, 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 and nitrogenous organic loading rate of 628.56 gTKN/m^3.day was equal to 343.28 gTKN/m^3.day (Fig. 9 and Fig. 10). Regarding to Fig. 9 nitrification rate of E.A. activated sludge process at Ekbatan WWTP with the same conditions was obtained as 75 gN/m^3.day.

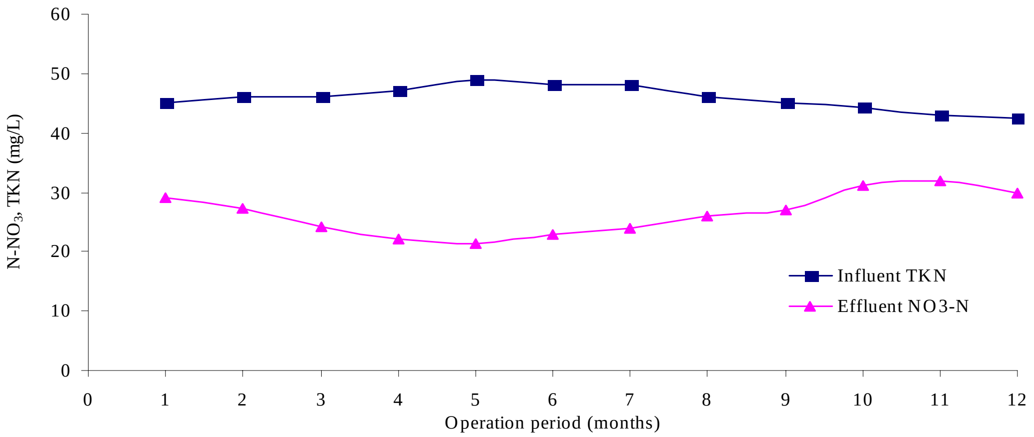

Fig. 9: Nitrification process in extended aeration activated sludge process

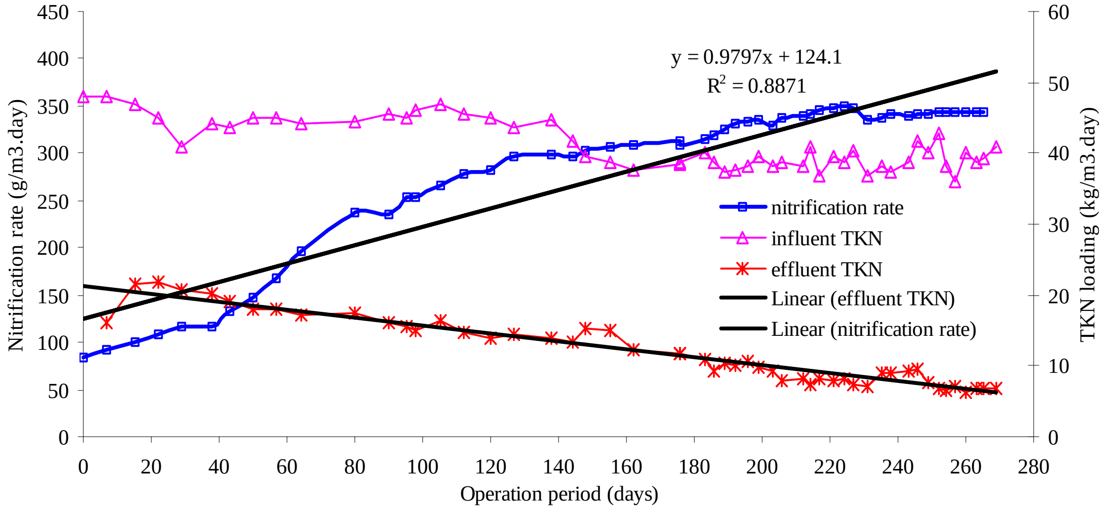

Fig. 10: Nitrification process in H-IFAS reactor

Denitrification Efficiency

Considering Fig. 11, 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 and nitrogenous organic loading rate of 347 gN-NO_3/m^3.day was equal to 338.17 gN-NO_3/m^3.day.

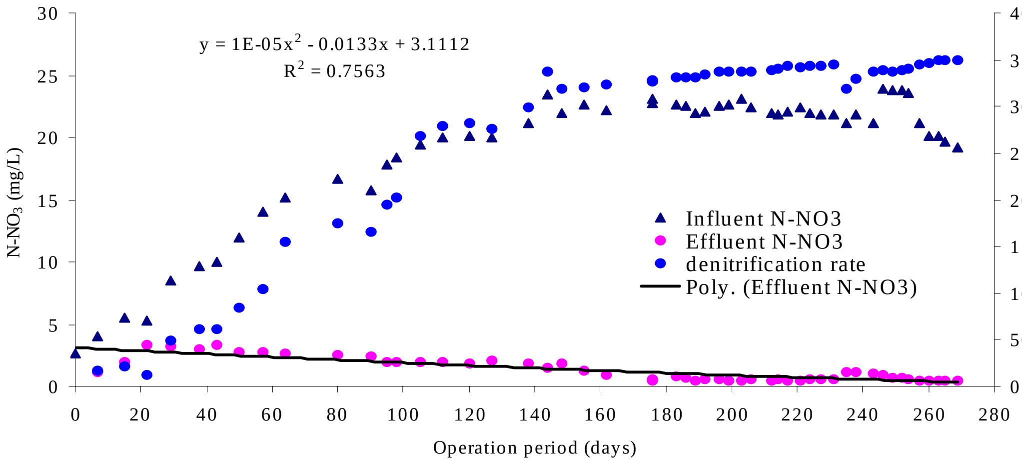

Fig. 11: Denitrification efficiency in anoxic zone of the H-IFAS reactor

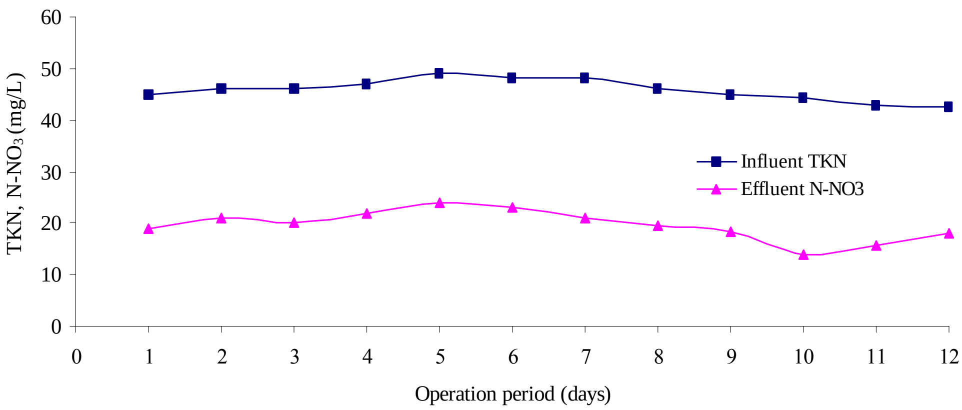

Fig. 12 : Denitrification efficiency in extended aeration activated sludge system

DISCUSSION

As shown in Fig. 3 and 4, BOD and COD removal efficiencies in H-IFAS plant were constant with changes in influent flow. In fact H-IFAS reactor had more flexibility on flow fluctuations. The results of this investigation clearly showed that H-IFAS can be successfully accomplished in three stage (aerobic-anaerobic-anoxic) systems. With regarding to the obtained results, the H-IFAS reactor's carbonaous organic removal efficiency is much higher (at least 5-6 times) than EA activated sludge process efficiency. Consequently for a constant influent flow we can have a much more compact system. This matter provides the conditions of making a good economical saving in construction and operation of the system. Phosphorus appears in wastewater as orthophosphate, polyphosphate and organically bound phosphorus.The last two components accounting usually 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 (Barlindhaug *et al*., 1996). 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

(Heukelekian *et al*.,1999) operated A2O and modified UCT processes, respectively; to treat a municipal wastewater. In this research an A2O process was simulated in the form of an H-IFAS reactor with this difference that anaerobic, anoxic and oxic zones were designed and constructed in a single reactor. Having separated different zones in the reactor, good efficiencies of pollutants removal have been achieved. Application of biofilm carriers in the reactor increased the population of autotrophic microorganisms which have an important role in nitrification, denitrification and biological Premoval. Phosphorus removal in this reactor was provided by returning settled sludge from the clarifier to the lower part of the reactor which is an AMBR . As it was shown, the process of P-removal in this reactor had a good stability in spite of increasing the HLR in the process of time. On the other hand the efficiency of the reactor in comparison with the other conventional processes was quite different. Namely, although the volume of the reactor was limited and the compactness of the system caused a very small footprint, but the capability of the process in this reactor was reliable and it had a very good efficiency for removing phosphorus from raw wastewater.

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 regarding to technical specifications of the media and also similar studies with kaldnes-k1 media by Halvaard Odegaard in 1989 (Ødegaard *et al*., 1998), the media fill fraction of aerobic zone was 55 %. 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 $N\text{-}NH_4$. Figure 9 shows nitrification rate per support area with respect to effluent $N\text{-}NH_4$ concentration with 4-6 mg/L dissolved oxygen (DO) range. There was a gradual transition from a first order nitrification at low concentrations of ammonia to half order and to zero-order at higher concentrations of ammonia. Similar results for nitrification in biofilm reactors were obtained. It was found that nitrification is clearly oxygen limited at higher ammonia concentrations. For the unlimited conditions the $DO/[N\text{-}NH_4]$ ratio in the reactor should be at least 4.

Oxygen concentration as well as the velocity of the air and consequently the hydrodynamic conditions in the reactor was controlled by the air supply. With increasing air supply, the concentrations of oxygen and air velocity in the reactor increased and external mass transport resistance decreased. Levine *et al*.,1985 presented a simplified design of bio film processes using normalized loading curves. Design was 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 bio film reactors for nitrification (Munch *et al*., 1990). Higher concentration of organic compounds in the nitrification zone leads to a competition for oxygen in the bio film between heterotrophic (COD elimination) and autotrophic (nitrification) organisms. In this research, nitrification rate was obtained at an optimum range by using a well designed media with high specific surface area and designing an anaerobic zone at the lower part of the reactor. Effluent of aerobic zone was used as the source of $N\text{-}NO_3$ to the anoxic zone and methanol with the dosage of 5-10 mg/L served as the readily biodegradable carbon source as the electron acceptor. Anoxic zones consisted of two separated parts with equal volumes which were situated on both lateral sides of the reactor. Denitrification rate was of half-order in the $N\text{-}NO_3$ concentration range of 15-30 mg/L when COD was in excess. Some similar results for denitrification in biofilm reactors with dispersed media were obtained by Hallvard Ødegaard (Ødegaard *et al*., 2002). Nutrient removal (P & N) in H-IFAS reactor with efficiency of 80-90% was much more desirable than the efficiency of EA activated sludge process.

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