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Removal of nitrogen and phosphorus simultaneously from sanitary wastewater of Yasouj in pilot-scale in 5-stage Bardenpho process

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The removal of nitrogen and phosphorus from wastewater has become an emerging worldwide concern because these compounds cause eutrophication in natural water. In this study the feasibility of 5-stage Bardenpho process for the phosphorus and nitrogen removal from sanitary wastewater of Yasouj was investigated. For this purpose, a Modified Bardenpho pilot plant was designed and operated for 12 months. Hydraulic retention time, solid retention time, recycle sludge rate and recycle flow rate are parameters which were evaluated during operation of the pilot plant and the optimum amounts of them were determined. Experimental results showed that the removal efficiencies of chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP) in optimum condition were approximately 73%, 90%, 93% and 75%, respectively. The maximum percentage of TP removal was 85%.Studies showed that solid retention time, hydraulic retention time of the 1staeration tank and recycle flow rate have had a significant influence on the performance of 5-stage Bardenpho process. Statistical Paired t-test showed that the average nitrates removal rate (p = 0.039) and phosphate removal rate (p =0.015) in solids retention time of 10 days and 20 days were significantly different.

Keywords: 5-stage Bardenpho process, Total phosphorus, Total nitrogen, Sludge retention time, Hydraulic retention time

1. INTRODUCTION

Phosphorus (P) is the limiting nutrient for algal production. Excessive P discharge into confined water bodies often results in severe eutrophication problems (e.g., overgrowth of aquatic plants, harmfulalgal blooms, depletion of dissolved oxygen, and decline of aquatic life) Jeon and Yeom [1]; Lu HL et al. [2]; Yang et al. [3].Many countries have legislated and enforced regulations limiting for P discharge levels to 0.1 mg/L or less Zheng et al. [4]. As the main anthropogenic P discharge source Kuzawa et al. [5]; Mandel et.al [6] , the secondary effluent of a sewage treatment plant is characterized by P levels of 1.0–2.0 mg/L in the anaerobic-anoxic-oxic (A2/O) process Saad and Hamoundi [7] or ~8 mg/L in conventional activated sludge process Holt et al. [8]. In both cases, P is present mostly as orthophosphate. Therefore, P removal technology has been of central concern for sewage tertiary treatment processes in recent decades.

Biological phosphorus removal is a biological process in which alternation of anaerobic and aerobic stages favors biophosphorus (bio-P) or PAOs, which are the heterotrophic organisms that are responsible for biological phosphorus removal. In the anaerobic stage, bio-P organism does not grow Ahao et al. [9], but convert readily available organics material (i.e., acetate and propionate) to energy-rich carbon polymers called poly-hydroxyl alkanoates (PHAs). Biophosphorus organisms use energy during acetate uptake and its conversion to PHA De-Bashan and Bashan [10]. This energy is generated through breakdown of polyphosphate (poly-P) molecules, which results in an increase in phosphate concentration in the anaerobic stage (i.e., phosphorus release). Polyphosphate is made up of many phosphate molecules combined together. Magnesium and potassium ions are concurrently released to the anaerobic medium with phosphate. In addition, for bio-P organisms to produce PHA, a substantial amount of reducing power is required Adam et al. [11].

The reducing power is generated from the breakdown of glycogen, another form of internal carbon storage Smolders et al. [12]. In the aerobic zone, PAOs can oxidize previously stored PHAs to obtain energy Mino et al. [13]. The energy and the carbons are used for growth and maintenance requirements. Under aerobic conditions, energy reserves are restored through phosphate uptake and polymerization Barnard [14]. The effluent from the EBPR reactors, is now low in phosphorus, and all the phosphorus stored in the biomass can now be wasted through regular solid wastage. This result takes place in a net phosphorus removal from the system and the wastewater

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In addition, a portion of the energy and carbon is used to restore the glycogen stores for the reactions to continue when mixed liquor is recirculated to the head of the anaerobic zones.

The 5-stage Bardenpho process consists of the4-stage process with an anaerobic zone added to the front of the system Carliell et al. [15]. A nitrate-rich liquor is recycled from the first aerobic stage to the first anoxic zone Van Loosdrecht et al. [16]. The RAS is recycled from the clarifier to the beginning of the anaerobic zone. Since the nitrates in the RAS are typically low (from 1 to 3 mg/L), they do not have the potential to significantly interfere with the phosphorus removal process. The second anoxic zone for complete denitrification Zhu et al. [17]. The Bardenpho process was originally developed for nitrogen removal, and, with the addition of an anaerobic zone at the head of the process configuration, successful phosphorus removal was ensured, Barnard [18]. The modified bardenpho has an internal mixed liquor nitrate recirculation stream (NO3-R), providing continued feed of nitrate into the anoxic zone. Similar phosphorus removal response is achieved in the modified bardenpho process; however, significantly lower effluent nitrogen concentrations can be achieved Randall & Barnard [19]. Again, depending on the COD:P ratio of the influent, the PHAs stored in the anaerobic zone will determine how much phosphorus will be taken up in the later zones under the presence of the electron acceptors nitrate and oxygen Barnard et al. [20]. The aim of this study is to determine the optimal conditions for biological phosphorus removal from sanitary wastewater of Yasouj during the operation of a 5-stage Bardenpho pilot plant for 12 months.

2. EXPRIMENTAL

2.1. Study area

Yasouj lies in the latitude/longitude 30°40′/51°36′. Yasouj has a moderate cold climate. The sanitary wastewater treatment plant of Yasouj consists of screening chamber, two aeration lagoons and three sedimentation lagoons. Surface aerators provide required air for respiration of aerobic microorganisms living in aeration lagoons Fig. 1. Treated wastewater discharges to Beshar River.

Fig 1. Sewage treatment plant of Yasouj.

2.2. Characteristics of influent wastewater to pilot plant

The characteristics of influent sanitary wastewater are summarized in Table 1.

As can be seen in table 1, the characteristics of sanitary wastewater have significant changes in different times because of periodic discharge of septic wastewaters from existing septic tanks in border city.

2.3. Design and operational parameters of 5-stage Bardenpho pilot plant

This pilot plant is designed for flow rate of 12 L/hr. This pilot consists of anaerobic tank, 1st anoxic tank, 1st aerobic tank, 2nd anoxic tank, 2nd aerobic tank and sedimentation tank. The design and operational parameters of the pilot plant are summarized in Table 2.

2.4. Analytical methods

COD, total nitrogen and total phosphorus are measured according to Standard Methods(8) .All reagents used for analysis of COD, nitrates and phosphate purchase from the HATCH Company. The pH of the wastewater is measured with a 720A pH meter (Orion).

Table1. Characteristics of input wastewater to the pilot plant

Parameter	Maximum concentration (mg/L)	Average concentration (mg/L)	Minimum concentration (mg/L)
COD	1890	728	346
BOD	531	378	182
pH	7.6	7.0	6.4
TP	26.3	18.2	12.4
TN	29.8	24.1	4.9

Table2. Design& operational parameters of5-stage Bardenpho pilot plant

SRT (Day)	MLSS(mg/l)	Hydraulic Retention Time (hr)			RAS %	Internal recycle ratio %
		Anaerobic	Anoxic	Aerobic		
10-20	3000-4000	0.5-1.5	1^{st}: 1-3 2^{nd} stage:2-4	1^{st}: 4-12 2^{nd} stage:0.5-1	50-100	200-400

3. RESULTS AND DISCUSSION

3.1. Effect of operational parameters on COD removal

Analyze of raw wastewater samples shows that COD of raw wastewater has a remarkable variation and changes from 400 mg/L to more than 1500 mg/L. This widespread COD change represents high organic loading shocks. Influent wastewater COD **and treated wastewater COD in pilot plant is shown** in Fig. 2. Also, the COD removal efficiency is shown in Fig. 3.

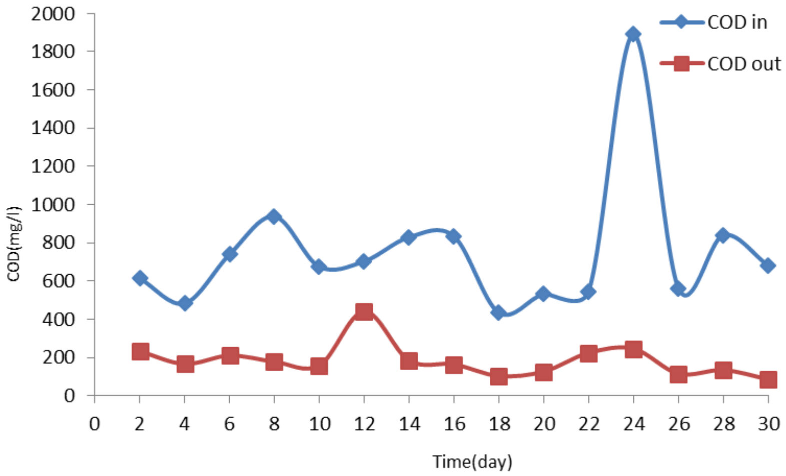

Fig. 2. Variation of influent and effluent COD versus different days.

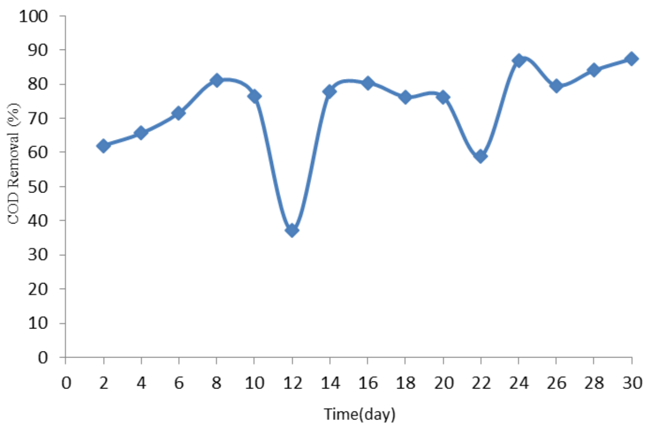

Fig. 3. COD removal efficiency in different operational days.

As shown in Fig. 2, COD suffers significant changes; however, COD of treated wastewater (effluent of pilot plant) is approximately constant. As shown in Fig. 2 and Fig. 3, despite fluctuations in COD of raw wastewater, the average removal efficiency of COD is 73% and average concentration of COD effluent from pilot plant is 233 mg/L. The maximum removal efficiency of COD is 89% that occurs when the hydraulic retention time of 1st aerobic tank is 12 hr. Besides, when the hydraulic retention time of 1st aerobic tank decreases to 4 hr, the COD removal efficiency inclined to 80% which shows that the hydraulic retention time of 1st aerobic tank doesn't have a significant effect on COD removal efficiency. The negligible effect of the hydraulic retention time of 1st aerobic tank is appointed in the work of Emara Mostafa et al. [21] . *Emara* work shows that COD removal efficiency in different hydraulic retention time of 1st aerobic tank (4-12 hr) is approximately constant. The reason of this is that a significant part of influent COD (60-70%) is removed in anaerobic and anoxic tanks. However, the hydraulic retention time of aerobic tanks in some processes have an important influence on COD removal such as MBR process. The removal efficiency of BOD in all conditions is more than 59% and maximum BOD removal efficiency is %90.

3.2. Effect of operational parameters on TP and TN removal

The concentration of TP in influent and effluent wastewater of pilot plant is shown in Fig. 4. Also, the TP removal efficiency is shown in Fig. 5.

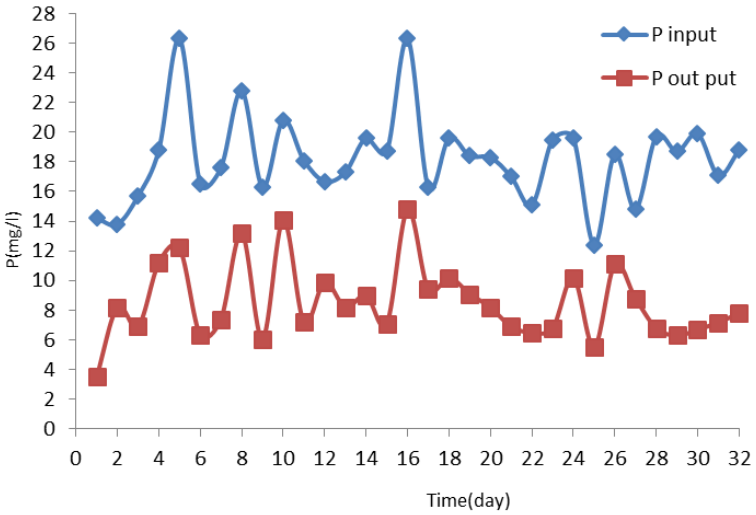

Fig4. Variation of influent and effluent TP versus different days.

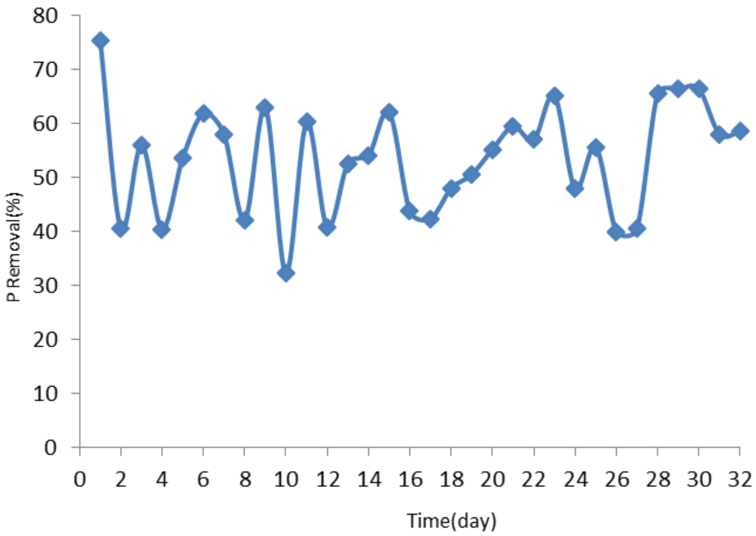

Fig. 5. TP removal efficiency in different operational days.

As shown in Fig. 4, the effluent concentration of TP is a function of influent concentration. As a result, with increases of influent concentration of TP, the effluent concentration of TP increases, too.

The average concentration of TP and TN in the treated wastewater are 7.9 mg/L and 8.2 mg/L, respectively. The maximum removal efficiency of TP and TN are 75% and 93%, respectively. Experimental results show that increase of recycling flow from 1st aeration tank to 1st anoxic tank has a strong effect on TN removal in the pilot plant. This experimental data is shown in Table 3.

Table3. TN removal efficiency in different recycling flow rate

Recycling flow rate (%)	Average removal efficiency of TN (%)
200	56.7
400	49.9

Nitrate concentration in return sludge (from sedimentation tank to anaerobic tank) because of consumption of readily biodegradable COD by nitrifier bacteria, has a significant influence on the TP removal from wastewater. Researches show that high concentration of readily biodegradable COD can increase the TP removal efficiency.

Furthermore, sludge retention time (SRT) can effect on TP and TN removal from wastewater. While increasing SRT from 10 days to 20 days increases TN removal efficiency from 55% to 67%, TP removal efficiency declines from 55% to 46%. This event is related to the mechanism of bacteria metabolism in different SRT. With increase of SRT, bacteria need less concentration of nutrients such as phosphorus for metabolism.

3.3. Effect of pH on TP removal

The influent and effluent wastewater pH is shown in Fig. 6. The range of pH variation is about 6.5-7.5 which is pertinent to biological activities. As shown in Fig. 6, the change of effluent wastewater pH is a function of influent wastewater pH and biological activity doesn't change this parameter significantly.

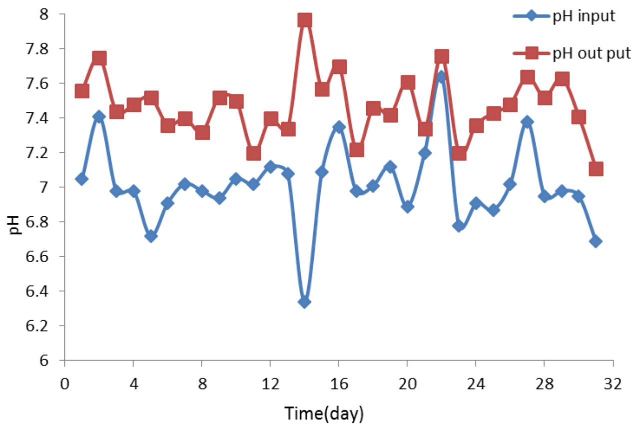

Fig. 6. Influent and effluent wastewater pH in different operational days.

In other words, the alkalinity concentration of influent wastewater which prevents significant change of pH is sufficient.

pH parameter has significant effect on TP removal in biological processes and in this work the effect of pH changes on TP removal efficiency is studied that these results are shown in Fig. 7. As shown in Fig. 7, the best amount of pH for TP removal is 7.5.

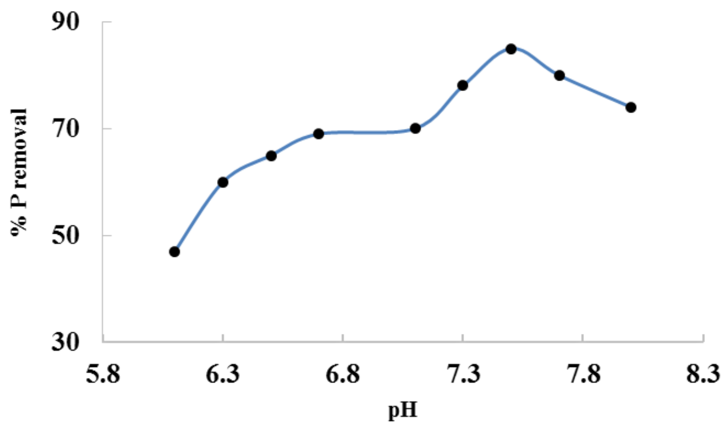

Fig. 7. Effect of pH on removal efficiency of TP.

4. CONCLUSION

In this work, the removal of TN and TP from sanitary wastewater of Yasouj in a 5-stage Bardenpho pilot plant in different operation conditions are evaluated. Hydraulic retention time, solid retention time, recycle sludge and recycle flow are parameters which are evaluated during operation of the pilot plant and the optimum amount of these parameters are determined. Experimental results show that the removal efficiencies of COD, BOD, TN and TP are approximately 73%, 90%, 93% and 75%, respectively. The maximum percentage of TP removal is determined as 85%.

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