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ORIGINAL RESEARCH PAPER

Optimization of Aeration for Improving Performance of Hospital Wastewater Treatment Plant

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ABSTRACT

The present descriptive cross-sectional study was conducted by altering the type of blowers in the wastewater treatment system of Abuzar Hospital in Ahvaz during the first and second quarters (6 months). In every month, inlet raw wastewater, aeration tank one, and effluent were sampled in one week (Saturday-Friday), which resulted in harvesting a total of 42 samples. Then, they were assessed based on the techniques provided in the book entitled "standard methods for evaluating water and wastewater", and data were evaluated through employing statistical analyses. The average removal efficiency of total and organic phosphorus, phosphate, and ammonia in the effluent was respectively determined 46.47, 34.45, 18.14, and 68.49 before starting up a new aeration system, which reached 69.36, 76.21, 65.09, and 96.53 during the second period, respectively. In addition, the average concentration of nitrate varied from 21.79 to 44.11 mg/l, while that of nitrite changed from 0.04 to 0.03 mg/l. Further, an increase (39.19 to 67.19%) was observed in the average nitrogen removal efficiency in effluent. Based on the results, EAAS process was efficient in eliminating nitrogen and phosphorus by using the helicoidal pumps of aeration blowers and regulating aeration rate. Thus, aeration plays an effective role in activated sludge systems despite the microorganism diversity in aeration tank sludge. The produced effluent was consistent with Iran national standards in terms of the parameters under study, especially phosphorus and nitrogen, and can be discharged into the environment.

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1. Background

Nowadays, environmental protection is considered as an essential issue (Nikpour et al., 2020; Heidari Farsani et al., 2021; Mehrdoost et al., 2022; Bakhshizadeh et al., 2022). Additionally, the industrial, agricultural, and domestic wastewater are known among the important causes of environmental pollution (Fataei , 2017; Zangeneh et al., 2021; Noori Mashiran; Tabari et al., 2021 Masoumi and Yengejeh, 2020). Inattention towards wastewater treatment operations can lead to contamination of water and soil resources and, consequently, infectious and chronic diseases (Bahmanpour et al., 2017; Panyasit et al., 2022). In this regard, wastewater treatment process majorly aims at minimizing the harmful compounds. The methods applying biological processes are widely applied in treating the different types of wastewater with high organic load, among which activated sludge process is one of the oldest and more conventional techniques (Fataei et al., 2013; Esmaeilzadeh et al., 2020; Smarzewska et al., 2021; Karimipour et al. 2021). The initial goal of biological wastewater treatment includes nitrogen and phosphorus removal (Kazemi Noredinvand et al., 2016; Farsani et al., 2022; Verijkazemi and Yengejeh, 2022). Eutrophication is the most serious factor for water quality, which leads to many problems such as creating taste and odor in water, which depends mainly on the presence of nitrogen and phosphorus in wastewater (Shahandeh and jalilzadeh, 2018; Amini Fard et al., 2019; Mahdavi et al., 2020).

The improper performance of aeration in biological wastewater treatment processes always results in losing energy, eliminating organic matter and nutrients like nitrogen and phosphorus compounds ineffectively, and affecting the efficiency of the treatment system adversely (Ahari et al., 2019; Fekri et al., 2021;Ghanbari Tapeh et al.,2022; Hosseinzadeh and Parvaneh, 2020; Jafari et al., 2017). Further, 30-75% of total energy consumption in activated sludge processes is related to aeration, which can decrease significantly because of lacking to optimize most aeration systems for unsteady flow rate and oxygen demand. The optimum dissolved oxygen (DO) control strategies for aeration systems, facilities, and DO optimization in wastewater treatment plants can lead to a significant enhancement in productivity, energy saving, and sustainable improvement. The measures extend the longevity of aeration equipment and increase the quality of effluent and activated sludge (Kusiak et al., 2013; Zhang et al., 2019; Ebadi et al., 2021).

Regarding the Extended Aeration Activated Sludge (EAAS) process, all of the sludge produced in sedimentation tank is returned to the aeration one. The wastewater and effluent treatment plants designed with extended aeration method usually operate without odor and problem if they are handled appropriately, along with treating wastewater excellently (McCarty et al., 2011; Mohammadi and Fataei, 2019). In the activated sludge wastewater treatment system, the required air oxygen and energy rates vary by altering the concentration of inlet wastewater parameters (ammonium or ammonia) (Pittoors et al., 2014).

Based on the above-mentioned issues, the present study sought to assess the performance of the extended aeration system related to the wastewater treatment system of Abuzar hospital in Ahvaz, especially nitrogen and phosphorus removal efficiency, by changing aeration and modifying the type of aeration pumps.

In the study, the qualitative parameters of effluent such as biochemical (BOD) and chemical oxygen demand (COD), sludge volume index (SVI), temperature, DO (aeration tank), and pH were measured over the first and second quarters in order to evaluate effluent quality during sampling.

2. Materials and Methods

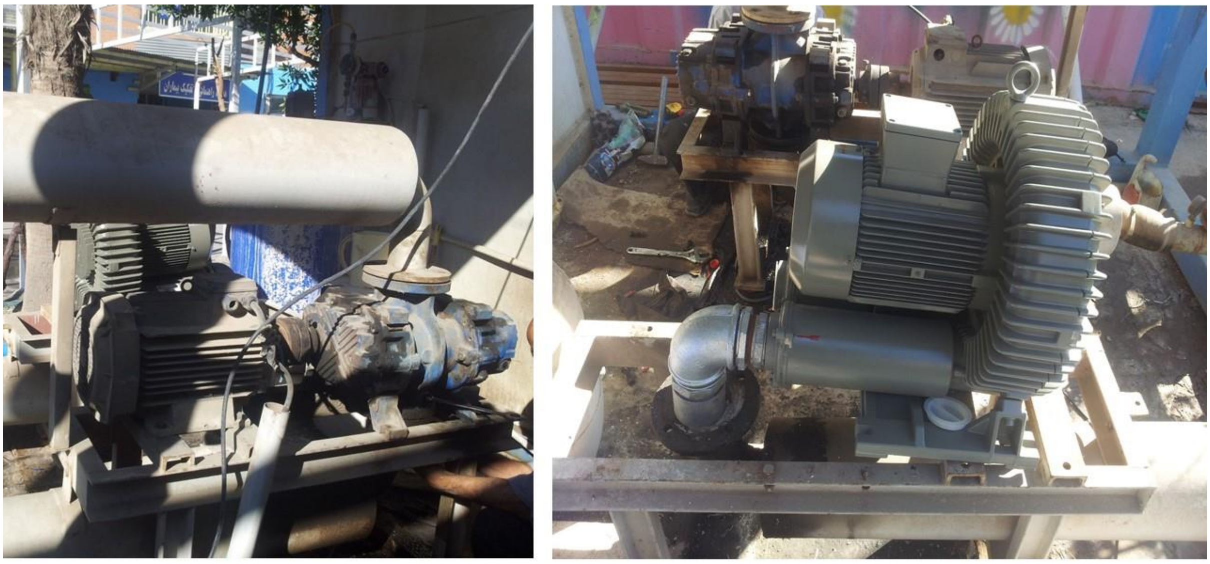
In this descriptive cross-sectional study, the wastewater treatment system of Abuzar Hospital in Ahvaz was examined by changing the type of blowers during the first and second quarters (6 months). To this end, inlet raw wastewater, aeration tank one, and effluent were sampled in one week (Saturday-Friday) of each month. The samples were transferred to laboratory for analysis and the results were recorded as average. In addition, the parameters and variables were selected by considering the similar research, as well as the financial and temporal resources of this study. All experiments were performed based on the techniques presented in the book entitled "standard methods for the examination of water and wastewater". Therefore, spectrophotometer was utilized for assessing ammonia, nitrate, and nitrite, and phosphorus was examined through employing ammonium molybdate method. Further, a total of 42 samples were harvested. Furthermore, Excel software was applied for analyzing the data such as averaging, determining the range of values, and graph drawing.

The Spectrophotometer was utilized for assessing ammonia, nitrate, and nitrate, and phosphorus was examined through employing ammonium molybdate method. BOD and COD, (Standard Methods for The Examination of Water and Waste Water.2005.2510). The wastewater treatment package of the hospital included sludge pump, and aeration, secondary sedimentation, and chlorination tanks. The intended treatment system used activated sludge technique and extended aeration system using the blowers equipped with pump at 2700 RPM rotational speed.

Given that engine and gearbox in this type of pumps are separate and are connected with a shaft, the pump efficiency is less influenced by atmospheric factors, and leads to a decrease in the aeration efficiency in the treatment system. Due to the problems of applying this type of blowers such as high energy consumption and noise, this study assessed the change in aeration system and its role in nitrogen and phosphorus removal.

1.2. Characteristics of the studied aeration system with helicoidal blower

The aeration process using the diffusers possessing the helicoidal blower in which engine and gearbox are connected and lead to mixing by a 3-inch tube in aeration tank is associated with less voice, as well as the occupation of smaller space and rotational speed of 4870 RPM compared to the linear blower of old system (Fig.1). The type of pump used in the system is LEO viera with a power of 2700RPm, with a separate motor and gearbox structure, which has a low aeration efficiency and an annoying sound. By converting it to an automatic screw pump with a direct motor type (electrogen) Zan Tabriz Company) with a power of 4870rpm, the system was adjusted and aerated more appropriately.



linear blower in old system (before the change) **Helicoidal blower in the system under study (After the change)**

Fig 1. Aeration pump condition

3. Results

Each sampling step took about one month. The qualitative parameters of inlet raw wastewater were determined during June-August. After replacing linear blower with Helicoidal ones, the parameters were again measured in September-November. Table 1 summarizes the inlet and outlet concentrations of each step.

In the first quarter, the average total and organic phosphorus removal efficiency in effluent was respectively determined 46.47 and 34.45% (appropriate aeration by using an air pump with the the rotational speed of 2700 RPM). However, the use of helicoidal pump at 4870 RPM rotational speed changed the efficiency to 68.69 and 76.01%, respectively. Additionally, an increasing trend was observed in the total and organic phosphorus removal efficiency during September-November compared to the June-August (Fig 2-3).

Regarding phosphate removal, the removal efficiency was achieved 18.14% over the first quarter, while it reached 65.09% after starting up the new aeration system. In this regard, the efficiency was ascending in September-November compared to the June-August (Fig .4).

Based on the results in Fig. 5, a reduction was obtained in the average ammonia concentration from 8.21 mg/l over the first quarter to 0.87 following the start-up of the new aeration system. Furthermore, the ammonia concentration exhibited a decreasing trend in the second quarter, which reached below standard limit (2.5).

The average ammonia removal efficiency in effluent varied from 49.68 to 53.96% by using the mentioned helicoidal pump (fig.6).

As displayed in Figs. 7 and 8, the average nitrate and nitrite concentration is respectively determined 21.79 and 0.04 mg/l over the first quarter, which altered to 44.11 and 0.30 mg/l after applying the new aeration system, respectively(table.1). During the two quarters, the average nitrite level is lower than the standard limit (10) and no significant change was observed in this regard.

Finally, the average nitrogen, BOD5, and COD removal efficiency was respectively attained 39.19, 63.18, and 43.78% before starting up the new aeration system, which enhanced to 67.19, 87.93, and 87.65% during the second quarter, respectively (Figs. 9-11).

Table 1. Qualitative parameters and pollutant removal efficiency over the intended period by

	Before change			After change		
	June	**May**	**July**	**August**	**September**	**October**
Design and operation parameters						
SVI (ml/g)	67.71	102	48	104	64	95
Quality parameters of raw wastewater (inlet)						
Total phosphorus (TP)/ mg/l	7.49	8.64	8.57	7.64	7.7	7.55
Organic phosphorus	166.57	193.71	179.28	223.71	154.57	197.71
Phosphate	3.56	5.44	6.28	5.34	5.62	5.48
Ammonia (NH3)	24.03	22.38	36.73	29.1	20.11	18.24
Nitrate (NO3)	2.39	2.62	3.55	4.61	5.98	8.23
*Nitrite (*NO2)	0.05	0.06	0.06	0.06	0.05	0.09
Quality parameters of wastewater entering the aeration tank						
Total phosphorus (TP)/ mg/l	4.42	6.86	8.3	7.54	7.62	7.62
Organic phosphorus	1.36	1.97	2.24	2.27	2.24	1.8
Ammonia (NH3)	20.05	20.67	20.23	2.22	16.18	19.09
Nitrate (NO3)	2.35	2.19	3.48	4.44	6.28	7.24
*Nitrite (*NO2)	0.04	0.04	0.05	0.04	0.02	0.05
Quality parameters of raw wastewater (outlet/ effluent)						
Total phosphorus (TP)/ mg/l	4.87	1.78	5.53	2.68	1.52	2.68
Organic phosphorus	0.64	1.62	1.74	0.6	0.48	0.54
Phosphate	2.8	4.36	5.38	2.03	1.66	2.38
Ammonia (NH3)	16.54	4.91	3.2	2.3	0.25	0.07
Nitrate (NO3)	18.39	24.12	22.87	36.7	25.58	44.11
Nitrite (NO2)	0.04	0.05	0.04	0.05	0.02	0.03

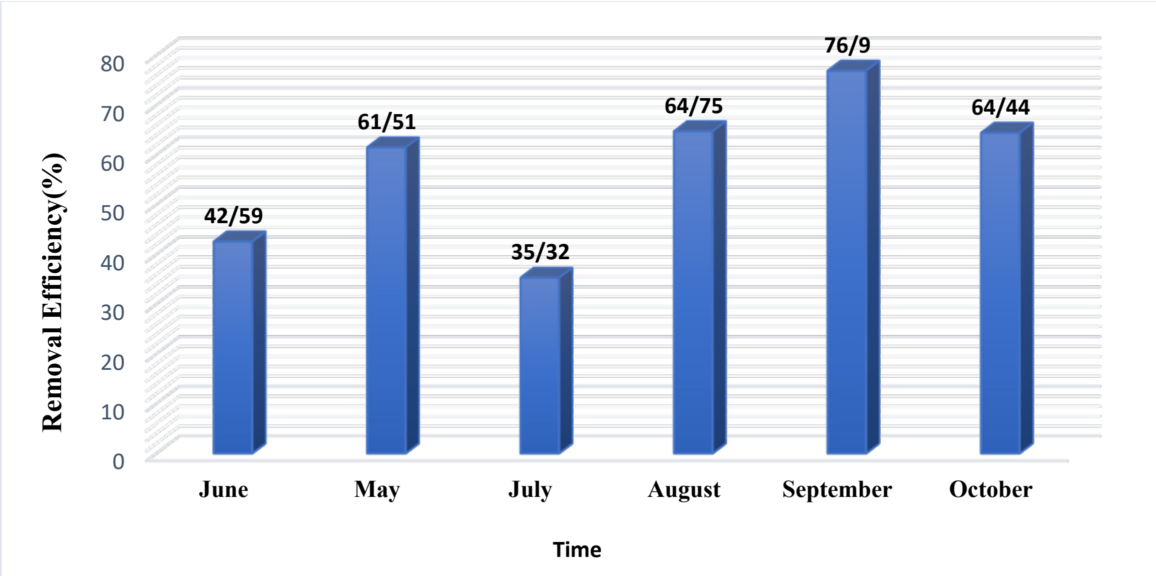


Fig 2. Monthly average of total phosphorus removal efficiency in the sampling months

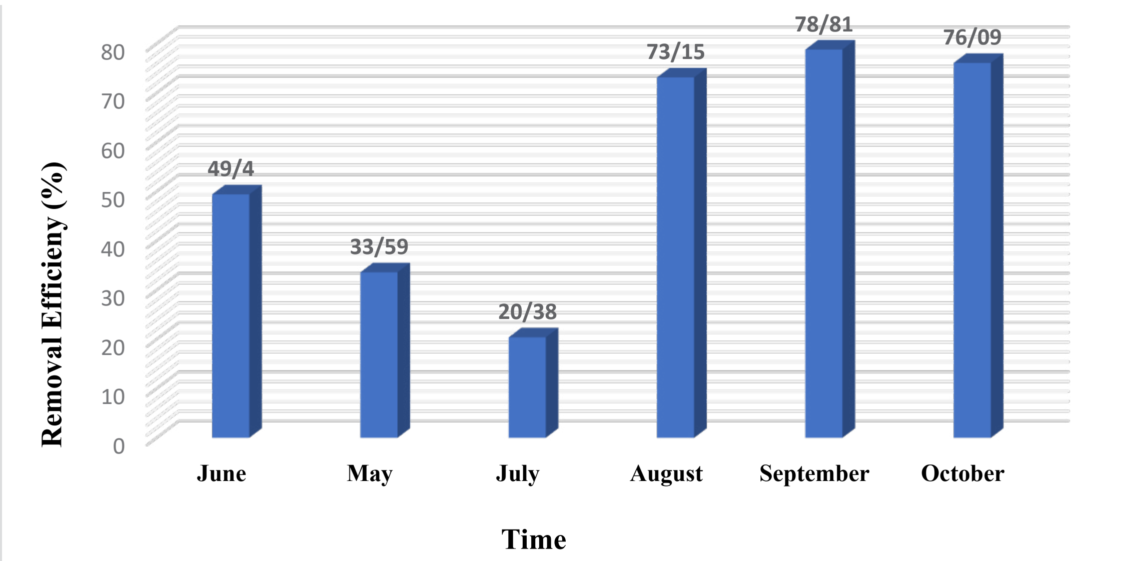


Fig 3. Monthly average of organic phosphorus removal efficiency during the sampling months

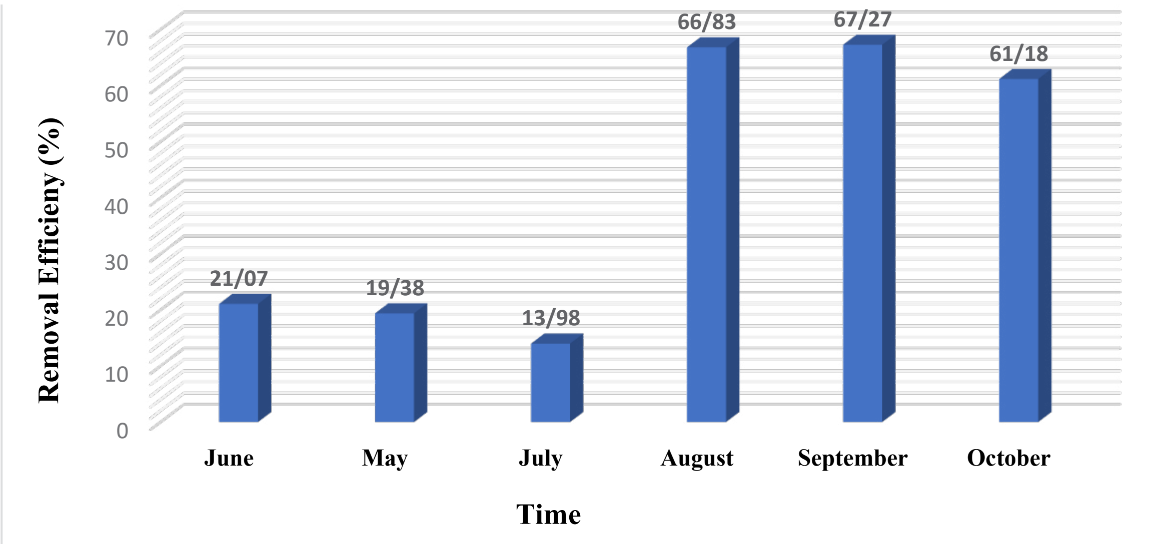


Fig 4. Monthly average of phosphate removal efficiency in the sampling months

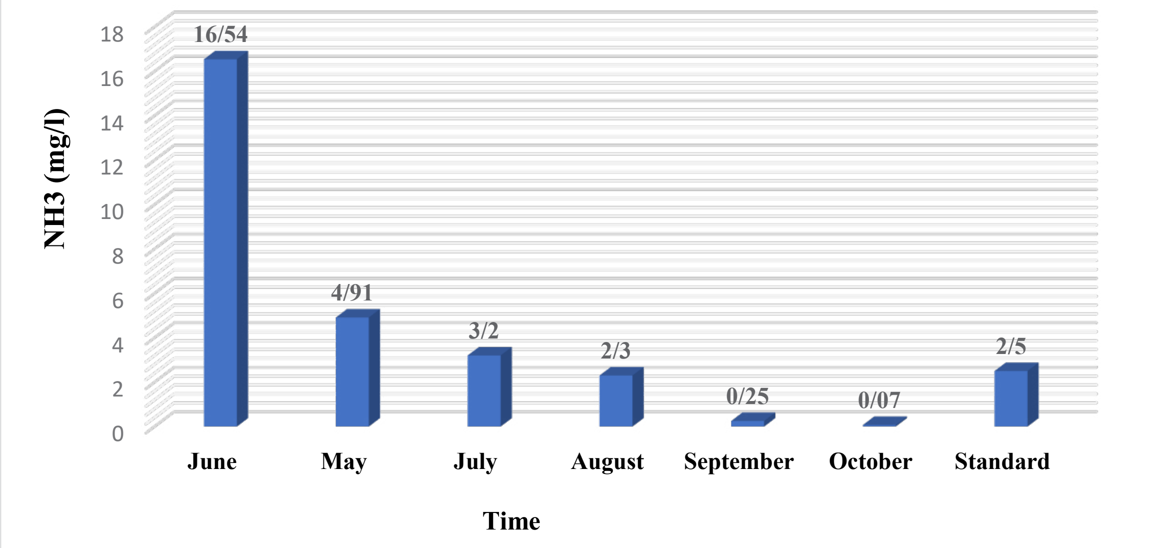


Fig 5. Average ammonia concentration in the effluent during the sampling months

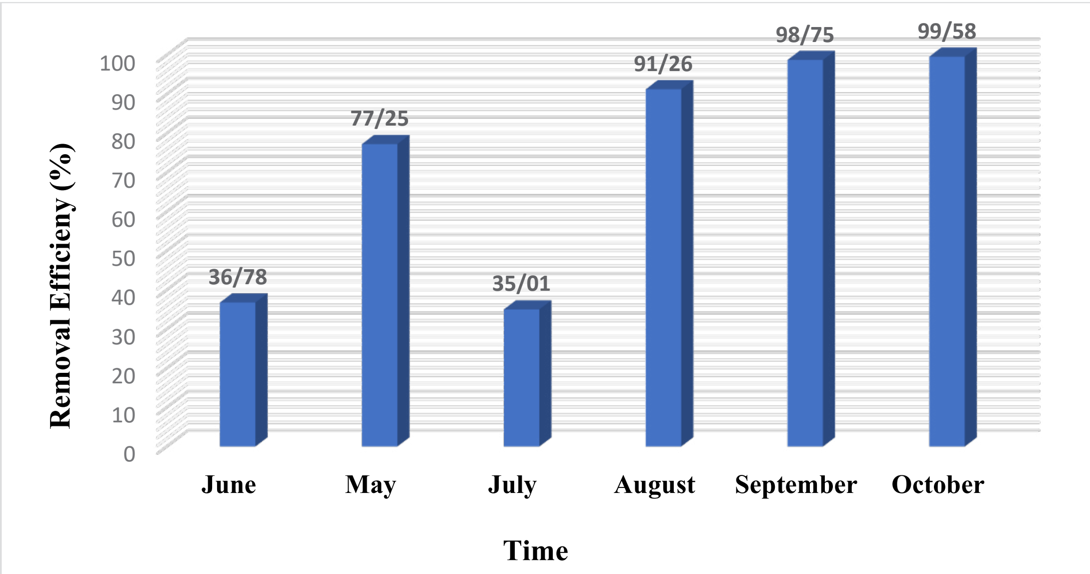


Fig 6. Monthly average of ammonia removal efficiency in the sampling

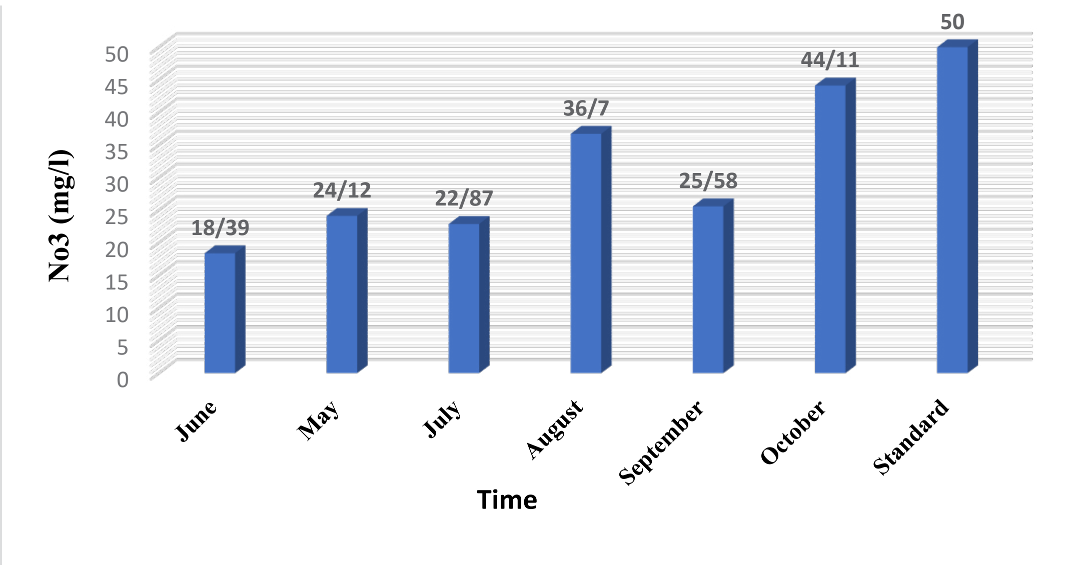


Fig 7. Average nitrate level in the effluent of the intended treatment system in the sampling months

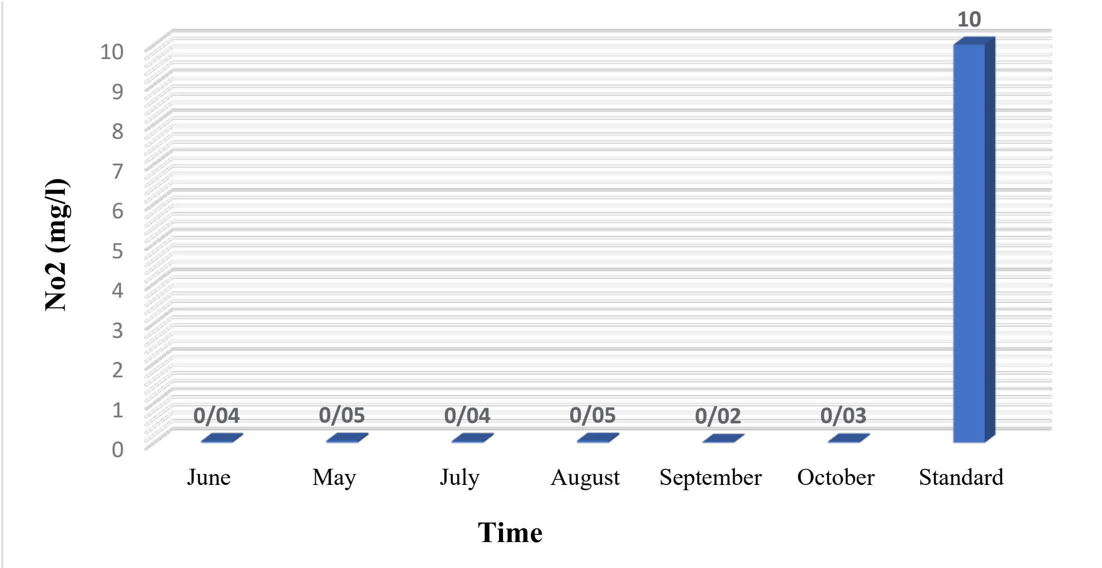


Fig 8. Average nitrite concentration in the effluent of the intended treatment system during the sampling months

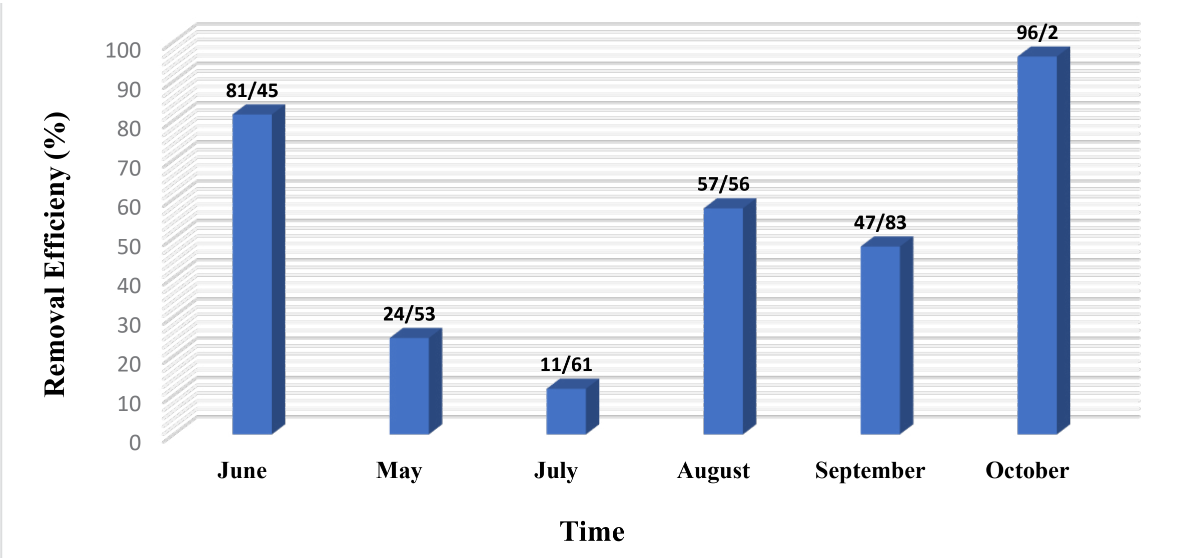


Fig 9. Monthly average of nitrogen removal efficiency in the sampling months

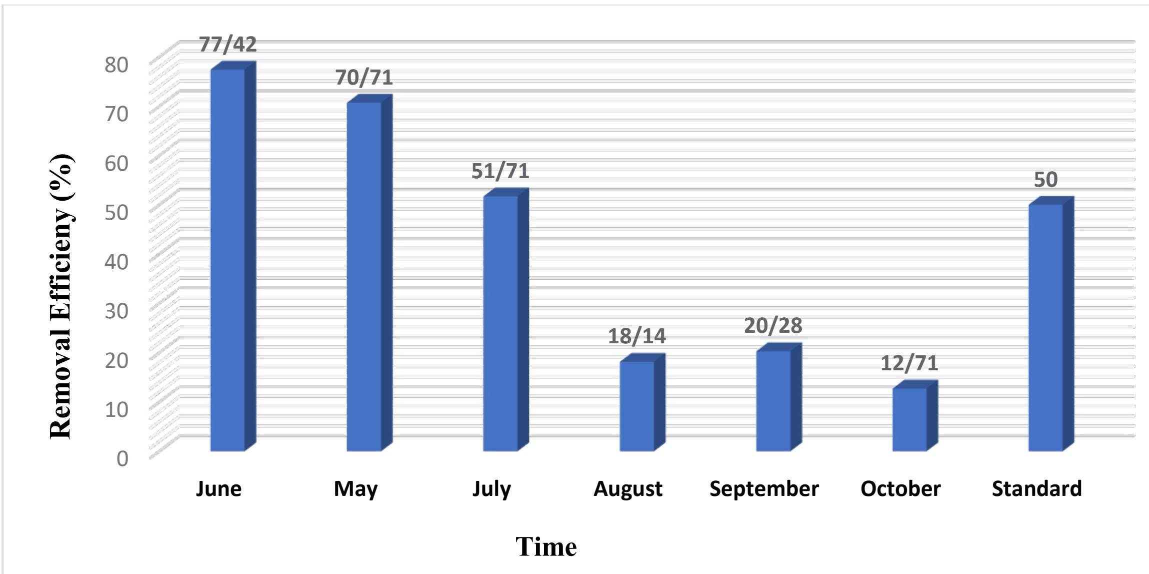


Fig 10. Monthly average of BOD5 removal efficiency in the sampling months

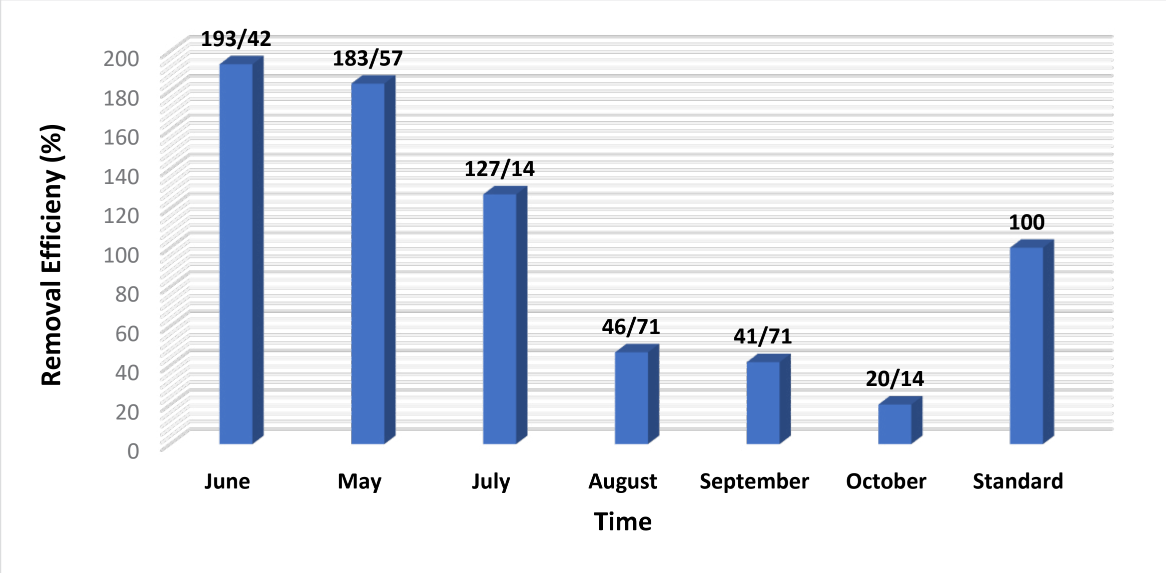


Fig 11. Monthly average of COD removal efficiency in the sampling months

4. Discussion

Based on the results, the extended aeration-based treatment system in which linear blower with the rotational speed of 2700 RPM aerates appropriately could eliminate 46.47% of total phosphorus. However, the removal efficiency varied to 68.69% by replacing helicoidal blower at 4870 RPM rotational speed during the second quarter.

Over the first quarter, the average organic phosphorus removal efficiency in the effluent of the intended treatment was determined 34.45%, which altered to 76.01% during the next quarter. In addition, an increase was observed in the average phosphate removal efficiency (18.14 to 65.09%) by starting up the new aeration system. The phosphate concentration reached below the standard level of 2.5 in the second quarter.

The application of the new aeration system resulted in changing the nitrate and nitrite level in effluent from 21.79 and 0.04 to 44.11 (below the standard level of 50) and 0.03 mg/l, respectively.

Further, the average nitrogen removal efficiency in effluent was determined 39.19% in the first quarter, which increased to 67.19% by utilizing the new aeration system. In addition, average ammonia concentration and removal efficiency varied from 8.21 mg/l and 49.68% during the first quarter to 0.87 mg/l and 53.96% following the start-up of helicoidal blower, respectively.

The use of biological systems and aeration equipment and initial analysis of wastewater, as well as determining the amount of inlet pollutants can significantly help apply aeration systems. In fact, the contaminant level in raw wastewater may be such that the environmental standards can be met by utilizing simple and appropriate systems such as activated sludge one. In the present study, the level of pollutants was measured in raw wastewater and new aeration equipment was used by comparing the costs incurred on wastewater treatment system (Torabi et al., 2013).

SVI is considered as one of the parameters applied for evaluating the sedimentation properties of sludge in wastewater treatment plant. The lower values of SVI represent the desired condition of sludge for sedimentation, while the higher ones illustrate the presence of filamentous bacteria in sludge, as well as its poor sedimentation properties, and consequently filamentous bulking. In fact, the suitable range of SVI is 50-150 mg. Regarding this study, the maximum and minimum SVI was obtained 104 mg/l in January and 48 mg/l in December, respectively (Crites and Tchobanoglous , 1998; Matteus, 200; Bitton , 2005). Based on the results of the studies on the simultaneous removal of nitrogen and phosphorus, an enhancement in aeration results in eliminating more nitrogen and phosphorus. However, phosphorus removal efficiency declines when aeration takes above 3 hours due to insufficient acidification (Pirsaheb et al., 2015), which is in line with the results of the present study which reflected a decreasing trend in phosphorus and nitrogen removal by using new aerators and aerating more than 3 hours. Another study focused on optimizing aeration and wastewater treatment in a reactor located in north China and examined DO distribution and flow rate. The results of analyzing the types of microorganisms with different performances demonstrated that DO leads to the ability simultaneous elimination of nitrogen and phosphorus (Ai et al., 2020). Regarding the results related to DO measurement in the present study, the DO level of aeration tank was determined 7 mg/l in the first quarter, which is greater than the standard limit and indicates energy lose. During the second quarter, this level reached 1-2 mg/l, which exhibits energy loss prevention.

Some researchers reported that the microbial diversity of activated sludge results in improving nitrogen and phosphorus removal efficiency significantly by conducting a study in the the Wuhan University of Science and Technology, China. They referred to the ability of some bacteria such as Pseudomonas stutzeri ADP-19 to eliminate 96.5% of NH4+ (N) and 73.3% of PO4- (P) at the concentrations of 20 and 100 mg/l under aerobic conditions (Li et al., 2021; Chi et al., 2021). In the present study, 85 and 97% of carbon and nitrogen were respectively removed based on examining microorganism count in the sludge of aeration tank and comparing the results of a study at high aeration frequency (15 per h) during a short period (1 hour) and continuous aeration. An increase was observed in the nitrogen and phosphorus removal by activated sludge microorganisms. Various studies and technologies have been performed regarding nitrogen, phosphorus, and organic matter removal. For example, the results of a study using electrolysis method demonstrated that more nitrate (49.54%) and phosphorus (74.25%) are eliminated by changing electrical plates at the current intensity of 0.02 mA/cm2 and electrolizing for 24 hours due to an increase in nitrate and phosphorus uptake by autotrophic bacteria, hydrogen gas released in cathodes, and ions produced from iron anode, leading to an improvement in effluent quality. Thus, future research is suggested to evaluate the role of autotrophic bacteria on the amount of nitrate and phosphorus removal (Yousefi et al., 2013). Other researchers outlined that the enhanced biological phosphorus removal (EBPR) based on the amounts of orthophosphate release, and uptake, synthesis, and consumption of polyhydroxyalkanoate by using 3,5-dichlorophenol (DCp) as an inhibitory compound reflected the posibility of preventing EBPR by applying organic carbon resource and sludge(Beidaghdar et al., 2022). Additionally, the rise of aeration period from 1.5 to 4 hours fails to affect the results significantly. They found greater phosphorus removal by increasing aeration period, and utilizing carbon resource and activated sludge based on the amounts of orthophosphate release in the activated sludge systems (Gao et al., 2018). The results of the present study represented that aeration period above three hours failed to reduce phosphorus removal highly. Regarding the COD removal efficiency of activated sludge system, zazoli et al. obtained the efficiency of 2.98% in the Golestan province (Feng et al., 2021). However, the average COD concentration and removal efficiency in the effluent of this study varied from 168.04 mg/l and 43.78% to 36.18 mg/l and 87.65% by changing aeration system, respectively. Further, two studies reported an improvement (to 79%) in the BOD removal efficiency of activated sludge process after optimization (Yousefi et al., 2013). However, the BOD5 removal efficiency in effluent was determined 63.18% over the first quarter of the present study (<minimum standard efficiency), which reached 87.93% following the start-up of the new aeration system (>minimum standard efficiency). Therefore, its efficiency level is desirable, which can be related to an enhancement in aeration status and proper direction. Finally, environmental standards can be achieved by altering aeration systems and equipment and simple and appropriate systems such as activated sludge one. Energy optimization is a high priority in high energy consumption systems (Ghalambaz and jalilzadeh, 2020). Aeration processes can account for 60 percent or more of the overall power consumption at a wastewater treatment plant. Consequently, the recent introduction of direct-drive, high-speed, turbo blowers to the wastewater market has been of great interest with respect to potential energy savings, as well as other ancillary benefits (Bell and Abel, 2011). The results demonstrate that the optimized intermittent aeration is a reliable option to enhance the treatment performance of organics and nitrogen at a lower operating cost (Wu et al., 2016). So, estimating the cost of energy consumption resources is not a priority in this study, but due to the continuous failure of the type of pump and flowmeter used in the system and the increase in the cost of its repair and maintenance, as well as the use of manpower to turn the pump on and off, changing the type of pump and aeration system can be considered as factors to save costs mentioned.

5. Conclusions

Based on the results, the average total and organic phosphorus, phosphate, and ammonia removal efficiency in the effluent of the wastewater treatment system of Abuzar Hospital changed from 46.47, 34.45, 18.14, and 49.68% to 69.36, 76.21, 65.09, and 96.53% by starting up the new aeration system, respectively. The values were higher than those of the activated sludge systems without biological phosphorus removal. After varying aeration system and increasing rotation speed (4870 RPM), the frequency of continuous aeration was regulated in aerobic conditions, organic matters were decomposed in the presence of aerobic microorganisms, and the obtained energy was consumed for producing new cell and vital activities. Organic matter was oxidized to carbon dioxide and water by enhancing aerobic oxygen to prepare the energy required for bacteria activities. Accordingly, the low biodegradable organic matter resulted in eliminating nutrients such as nitrogen and phosphorus. Thus, it is proposed that future research assess the kinetic coefficients and their relationship with the optimization in the system for the generalization and feasibility of utilizing the results of this study.

Ethical Considerations

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Conflict of interest:

The authors declare that they have no conflict of interest.

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Authors' contributions

Conceptualization and supervision, methodology, investigation, data analysis: Zhra hazarian; Writing – original draft, writing – review & editing, data collection: All authors.

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