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Performance Evaluation of the Extended Aeration Activated Sludge System in the Removal of Physicochemical and Microbial Parameters of Municipal Wastewater: A Case Study of Nowshahr Wastewater Treatment Plant

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ABSTRACT

Introduction: Extended aeration activated sludge system has a lower sludge production than other activated sludge processes. Due to its high hydraulic retention time (HRT), the tolerance of this process is higher than the shocks caused by increased organic loading rate. The main objective of this study is to evaluate the performance of the aeration system in removing physicochemical and microbial parameters from the wastewater of Nowshahr, Iran.

Materials and Methods: This is a descriptive-analytical study that was carried out in the wastewater treatment plant of Nowshahr during 6 months. The parameters BOD_5, COD, TSS, total coliform (TC) and fical coliform (FC) were measured, and also the MLSS, F/M ratio, SVI, HRT and θc were measured in aeration basin. Data were analyzed using the Excel software and SPSS (Pearson correlation test and one-sample *t*-test), and $P < 0.05$ was considered significance level.

Results: The average removal efficiency of BOD_5, COD, TSS, TC and FC was 57.7%, 61.4%, 70.8%, 84.6% and 84.3% respectively. The θc, HRT, SVI, F/M and MLSS in the aeration basin were obtained, respectively, 5.64 day, 25 h, 48.83 ml/g, 0.28 day^{-1} and 180 mg/L. In addition, the average output of parameters in the hot months of the year was higher than those in the cold months.

Conclusion: According to the results, the Nowshahr wastewater treatment plant has the adequate efficiency to produce effluent in accordance with environmental standards for discharge into surface water and consumption in agriculture.

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Introduction

Water supply and reduction in water quality is one of the global concerns that will unexpectedly increase due to increasing population, urbanization and improved living standards, advances in technology, and climatic changes, and as a result water demand will increase not only for domestic consumption, but also for agricultural and industrial uses [1-3].

In many places, fresh water is not enough to meet rising demands, so alternative water sources should be sought out. Along with increased water consumption, the volume of the produced wastewater also increases [4, 5], and urban wastewater treatment can be replaced as a significant source of water. This reduces not only fresh water consumption but also the amount of wastewater produced and discharged to the environment [6- 8].

The extended aeration activated sludge system is one of the most commonly used wastewater treatment methods that are currently being widely used in Iran [9], Chile [10] and Estonia [11]. In this process, the hydraulic flow regime is complete mix. The amount of sludge produced in this process is lower than that produced in other activated sludge processes. In addition, the sludge obtained from this method is stable and dry and is well dehydrated and dried. High hydraulic retention time (about 18-36 hours) increases the tolerance of the process to shocks caused by increased organic loading, and uniformization is well done [12].

The extended aeration activated sludge process is similar to that of the conventional piston flow process, with the exception that the extended aeration process is used in the endogenous phase of the bacterial growth curve, which requires less organic loading and longer aeration times. Because of the longer aeration period in comparison with other activated sludge processes, the cost of energy used in this process is comparatively higher [13]. Among the activated sludge systems, the highest BOD removal rate with 98-90% efficiency has been obtained for the extended aeration process [14] that is widely used for the treatment of small communities' wastewater [15, 9]. Considering the advantages of the extended aeration activated sludge system, it is the most common method for healthy treatment of wastewater of residential complexes, villas, hotels and resorts, restaurants, hospitals and health centers, labor camps, and offices in factories, organizations, and corporations [16].

In the study conducted by Takdastan et al. conventional activated sludge system was converted to the extended aeration for increasing the removal efficiency [17].

The study of Pirsaheb et al. showed that the extended aeration activated sludge system had a higher efficiency for COD (73.33%) removal and linear alkyl benzene sulfonate (96.7%) compared to conventional activated sludge process [15].

The aim of this study is to evaluate the performance of the extended aeration activated sludge system in removing physicochemical and microbial parameters in the Wastewater Treatment Plant of Nowshahr, north of Iran.

Materials and Methods

This descriptive-analytical study was carried out in the Wastewater Treatment Plant of Nowshahr for 6 months (from 22 December, 2015 to 21 June, 2016). The system used in the wastewater treatment plant is basically the extended aeration activated sludge system. The construction of the treatment plant was started in an area of 10 hectares in 1997 and it began to work in 2008. The wastewater production per capita for the treatment plant has been determined to be 140 liter/day.

The number of treatment plant modules in the first phase is 4 and the capacity of each module is 10,000 m^3. The population covered by each module is about 40,000 people. The population covered by the treatment plant in the first phase is 150,000 people. The discharge capacity of the treatment plant is 10,000 m^3/day. Average input flow to the treatment plant is 8100 m^3/day.

Briefly, the structure of the treatment plant includes a screen, a pumping station, a grit chamber, two aeration basins, and four sedimentation basins. The sludge dewatering and thickening system are strain filtration and gravity thickening, respectively. Disinfection of the output effluent is carried out with sodium hypochlorite. In the wastewater treatment plant, solid waste and large materials in the wastewater are separated by two mechanical and a manual solid waste collectors. The grit chamber unit in this system is of aeration type. The number of basins is two and the dimensions of each basin are 2.7 m × 20 m × 3.4 m. Aeration time is 24 hours, each basin is 20 m × 60 m and the wastewater height is 3.5 m. Each module has two aeration basins. The type of system studied is high speed surface aerator. In the first module of the treatment plant, 6 high-speed, surface aeration systems are used. The volume of the aeration basin is 8400 m^3. For sedimentation of the suspended solids and floc in the effluent after the aeration unit, a secondary sedimentation unit is placed. The number of sedimentation basins determined for each executive module is 4 with an area of 8 m × 24 m. The surface load in the unit is $13m^3/m^2$ per day.

The grab sampling was done at intervals of one week at 8-11 am in December, January, February, March, April, and May. A total of 96 samples were collected from raw input wastewater, output effluent and aeration basins. In order to evaluate the performance of the treatment plant, the 5-day biochemical oxygen demand (BOD_5), the chemical oxygen demand (COD), total suspended solids (TSS) and microbial parameters total coliform (TC), fecal coliform (FC) of raw input wastewater and output effluent and sludge age (θ_C), hydraulic retention time (HRT), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge volume index (SVI) and food-to-mass (F/M) ratio were measured in the aeration basin and also X_r (the MLSS of sludge reverse line), Q_w (discharged sludge flow), Q (input wastewater) and V (aeration basin volume) were measured.

For physicochemical tests, polyethylene containers (1 L) were used and for microbiological tests, glass containers (300 mL) were used for sampling. The experiments were carried out according to the water and wastewater testing standards [18].

Finally, graphs were drawn using Excel 2010 software and one-sample *t*-test (P < 0.05) in the SPSS version 23 was used for data analysis. The Pearson correlation coefficient was used to determine the correlation between BOD_5 and COD of output effluent.

Results

The changes of BOD_5, COD, TSS, TC and FC during the study period in the wastewater treatment plant are shown in Figures 1-5.

Figure 6 illustrates the removal efficiency of pollutants and pathogens during the months of sampling. The average overall results from the analysis of input and output wastewater treatment plant analysis and their comparison with the the standards of the Iranian Environmental Protection Agency are shown in Tables 1-2 shows the mean values obtained from the measurement of design and operational parameters during the sampling in the treatment plant.

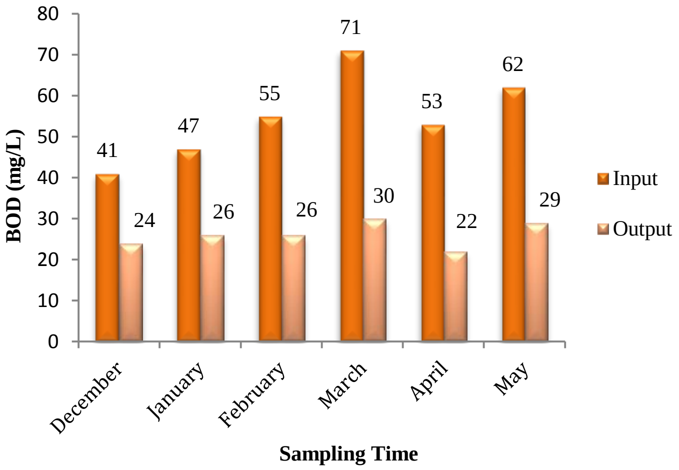

Figure 1: The trend of changes in BOD_5 in the input and output wastewater treatment plant

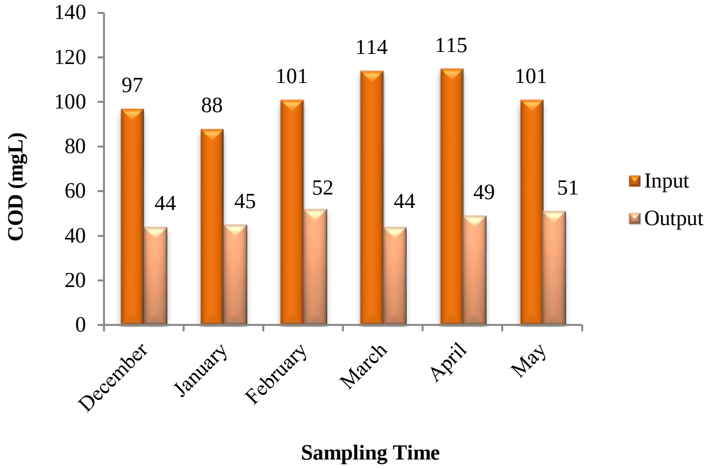

Figure 2: The trend of changes in COD in the input and output wastewater treatment plant

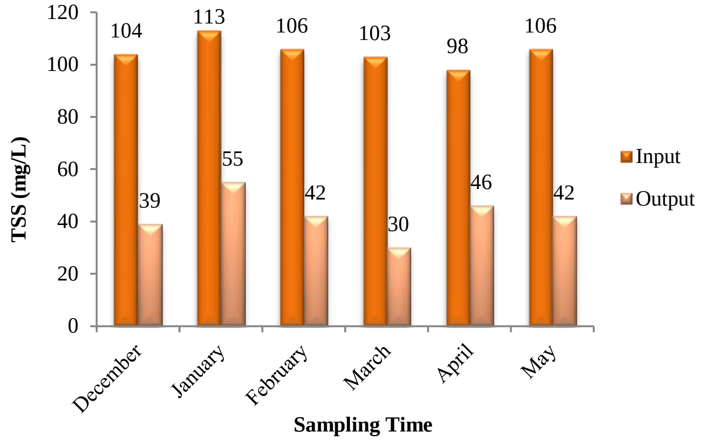

Figure 3: The trend of changes in TSS in the input and output wastewater treatment plant

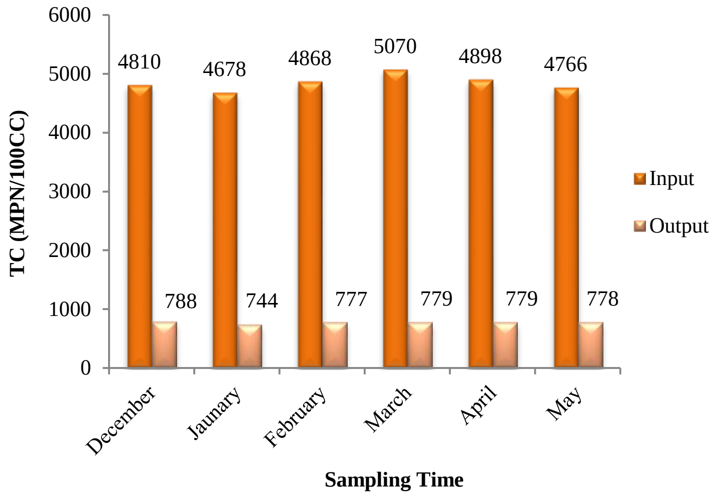

Figure 4: The trend of changes in total coliform in the input and output wastewater treatment plant

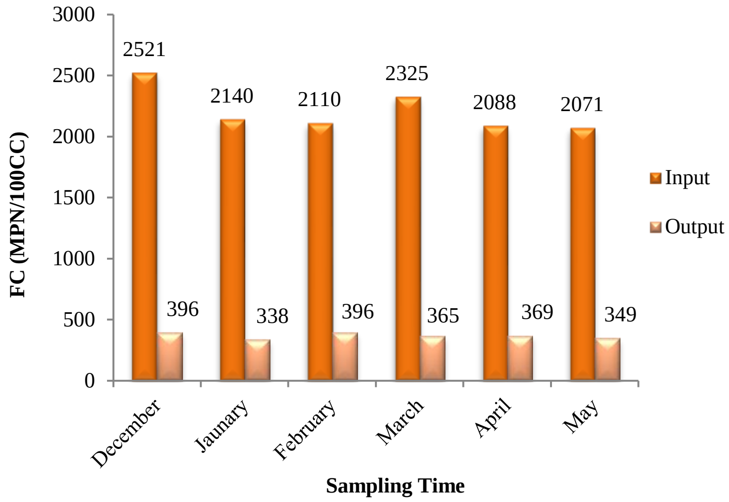

Figure 5: The trend of changes in fecal coliform in the input and output wastewater treatment plant

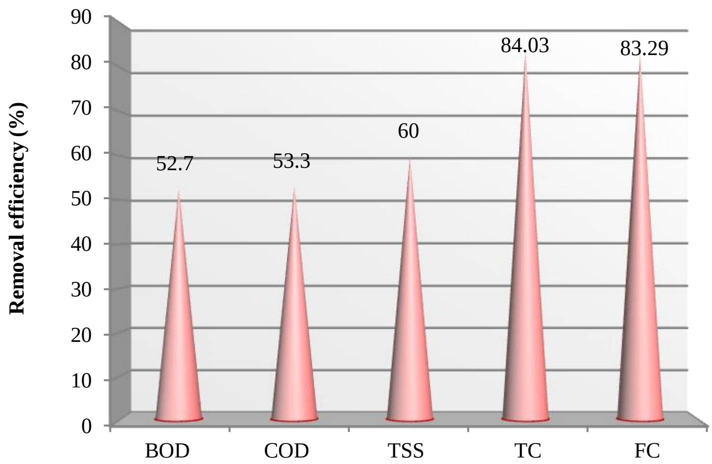

Figure 6: The mean removal efficiency of the studied parameters in Nowshahr Wastewater Treatment Plant

Table 1: The results of the analysis of input and output wastewater during 6 months and *P* values for the studied parameters

Parameter	Input Wastewater	Output Effluent	Environmental Protection Agency Standards			
	Average ± SD*	Average ± SD*	Discharge to Surface Waters (mg/L)	Pvalue	Agricultural Use (mg/L)	Pvalue
pH	7.36 ± 0.147	7.79 ± 0.06	-	-	-	-
COD (mg/L)	102.66 ± 10.32	47.5 ± 3.6	60	P < 0.001	200	P < 0.001
BOD_5 (mg/L)	54.83 ± 10.66	26.16 ± 2.99	30	P < 0.02	100	P < 0.001
TSS (mg/L)	105 ± 4.89	42.3 ± 8.21	40	P < 0.5	100	P < 0.001
TC(MPN/100 cc)	4848.33 ± 133.6	774.16 ± 15.3	1000	P < 0.001	1000	P < 0.001
FC (MPN/100 cc)	2209.16 ± 178.35	368.83 ± 23.8	400	P < 0.02	400	P < 0.2

* Standard deviation

Table 2: The mean values of the results obtained from the measurement of design and operational parameters during the sampling period (6 months)

Parameter	December	January	February	March	April	May	Average ± SD*
MLSS(mg/L)	160	185	190	180	183	179	179.5 ± 10.32
MLVSS(mg/L)	101	130	134	125	129	123	123.66 ± 11.75
SVI(ml/gr)	48	49	52	53	44	47	48.83 ± 3.31
Q (m^3/day)	7980	7995	8113	8023	8023	8118	8042 ± 59.31
F/M(day-1)	0.17	0.23	0.28	0.39	0.28	0.33	0.28 ± 0.07
HRT(hour)	25	25	24.85	25.13	25.13	24.84	24.99 ± 0.127
Xr (mg/L)	618	565	579	547	552	532	565.5 ± 30.28
Qw (m^3/day)	509	515	526	509	506	509	512.33 ± 7.31
(day) θ_C	6.54	5.34	5.48	5.43	5.49	5.56	5.64 ± 0.44

* Standard deviation

Discussion

Continuous control and monitoring of the treatment process, especially biological processes, is essential because the change in various parameters such as pH, MLSS, input organic loading input and etc. is very effective on the performance of the treatment system [19, 20]. The results of this study showed that the removal efficiency of pollutants during the months March, April and May was higher than the cold season. The main reason for the further removal of pollutants in warm seasons is the higher activity of microorganisms at high temperatures. Therefore, the removal efficiency of biological compounds in the warmer seasons seems to be higher. The study of Pirsaheb et al. showed that the removal efficiency of COD and TSS for the extended aeration system in warm seasons and during the months March to August was higher than in the cold season, which is consistent with the results of the current study [15]. In this study, the average removal efficiency of contaminants BOD_5, COD, TSS, TC and FC was 52.7%, 53.3%, 60%, 84.03% and 83.29% respectively. The study of Zazouli et al. on the treatment of industrial wastewater in Agh Ghalla, Golestan, showed that the removal efficiency of BOD_5, COD and TSS was 96.66%, 98.2% and 97.6% respectively [21]. Shahmoradi et al. reported the removal efficiency of 41.48% and 83.74% for respectively COD and BOD_5 in the treatment of wastewater in Bojnourd [22]. In another study, Mohammadi et al. obtained removal efficiency of 3.90%, 93.9% and 86.4% for COD, BOD_5 and TSS respectively [23]. By comparing the removal efficiency of the pollutants studied in this system with other similar studies, it is observed the removal efficiency is relatively lower, which can be due to low concentrations of input pollutants. According to the results of statistical analysis (Pearson correlation test), there was a significant relationship between the concentrations of output BOD_5 and output COD in all months of sampling ($P < 0.05$). The pH of the output effluent was higher than that of the input wastewater in all cases. Statistical analysis also showed that the Nowshahr wastewater treatment plant could remove BOD_5, COD, TSS, TC and FC in accordance with the standards of the Iranian Environmental Protection Agency and the concentrations of the above pollutants were lower than the standard levels and all the parameters were compatible with the standards of discharge to surface water and agricultural consumption, except for the TSS, which was higher than the respective standard for discharge to surface water. The results of this study showed that the amount of BOD_5 and COD in the wastewater of Nowshahr is categorized as a weak wastewater with respect to the severity of contamination.

One of the reasons for this problem is that during the construction and design of the wastewater collection network, the amount of water (groundwater and surface water) leakage is high in the collection network due to the high level of groundwater and the flow of surface water to the network due to inappropriate design, which dilutes the wastewater [24]. In addition, due to low population density around the network and because most buildings of the city are villas, few subscribers are connected to the network throughout the collection network. The average MLSS of the aeration basin was obtained 180 mg/L. In the activated aeration system, the MLSS varies from 1,500 to 5,000 mg/L, which is significantly different from the current standards. The F/M ratio is one of the important indicators for operation of wastewater treatment plants. The mean F/M ratio in this study was obtained 0.28 day^{-1}. It was expected that, given that the wastewater treatment system studied is an extended aeration activated sludge system, the result for the F/M ratio be 0.15-0.05 day^{-1} [25], but the obtained result is higher than this amount and within the range of conventional activated sludge system (0.2-0.4 day^{-1}) [17]. The F/M ratio is controlled by the amount of sludge. The high amount of sludge contributes to an increase in the F/M ratio, and therefore, the MLVSS concentration in the output effluent is increased and the sludge will become turbid. On the other hand, the low levels of fungal sludge reduce the F/M ratio, thus causing organisms to survive hunger [26]. Therefore, considering these results, it can be concluded that the amount of sludge in the system should be reduced to adjust this index. SVI is one of the parameters used to investigate the sedimentation properties of wastewater treatment sludge. The mean SVI value in the wastewater treatment plant of Nowshahr during six months in our study was determined 48.83 ml/g. This figure is not in the range 50-150 that represents the range of this operation parameter for activated sludge system, indicating an undesirable condition of sludge for sedimentation. The pinpoint floc results from the conversion of sludge flocs into small components that can pass through the active sludge unit along the wastewater. It is argued that the filamentous bacteria are the main reason for the activated sludge flocs formation, and therefore the presence of a low number of filamentous decreases the strength of the flocs and, as a result, leads to weak sedimentation and release of turbid wastewater [21].

In this study, the output effluent formed bubbles, and The HRT was obtained 25 h that is within the usual range of activated aeration systems (18-36 h) design. Sludge age or cell retention time (θ) is another design parameter and an operational index related to the F/M ratio. The amount of this index for the activated aeration system is between 20-30 days. During the six months in our study, the average value of this index was 5.64 days, which is much lower than the standard and within the usual range of conventional activated sludge system design and complete mix (4-15 days). This index shows that the duration of sludge presence in the aeration tank is very short; in other words, it can be concluded that because the MLSS in the aeration tank is very low, this index is low.

In this study, the average BOD_5/COD ratio was 0.5. The amount of this ratio in municipal raw wastewater is 0.4 - 0.8 and in municipal output effluent is 0.3-0.1. This ratio is higher than the standard ratio obtained for the output effluent of the wastewater treatment plant of Nowshahr. This result reflects that some amounts of non-biodegradable materials, growth-inhibiting materials, and organic matter that are resistant to degradation exist in the wastewater of Nowshahr that can be due to the entry of wastewater into the collection system.

Conclusion

This study showed that the produced effluent was compatible with the Iranian Environmental Protection Agency standards for physico-chemical (COD, TSS and BOD_5) and microbial (TC and FC) parameters and therefore can be used for agricultural purposes or discharge into surface water. The results of this study also showed that the three important parameters in design and operation, i.e., F/M, HRT, and θ_C, exhibited the behavior of the conventional activated sludge, extended aeration system, and conventional aeration system, respectively. As a result, due to inappropriate operation, all design parameters, except for HRT, did not match the design criterion for an extended aeration activated sludge system.

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Conflict of interest

The authors declare that they have no conflicts of interests.

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