ORIGINAL PAPER

Upgrading of Tafresh municipal wastewater treatment plant (TMWTP) using the Modified Ludzack-Ettinger (MLE) process

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ABSTRACT

The present study aimed to evaluate the treatment efficiency of the modified Ludzack-Ettinger (MLE) process using the conventional activated sludge (CAS) in Tafresh city, located in Iran during October-December 2016 (before upgrading) and October-December 2017 (after upgrading to the MLE process). The measured parameters in the study included chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD_5), nitrate-nitrogen, total suspended solids, phosphate, dissolved oxygen, ammonium-nitrogen, and pH. According to the obtained results, the treatment efficiency of the MLE process based on the BOD_5 and COD was 92.11% and 91.20%, respectively. On the other hand, the treatment efficiency of the CAS process (before upgrading) based on the BOD_5 and COD removal was 48.55% and 56.76%, respectively. Therefore, it could be concluded that the MLE process was able to successfully upgrade wastewater treatment services.

Keywords: Activated sludge, Tafresh city, Treatment plant, Wastewater

Introduction

Municipal wastewater is a major source of water pollution across the world, and municipal wastewater treatment is essential to the protection of the environment and water resources. Among various municipal wastewater treatment systems, conventional activated sludge (CAS) processes are used increasingly in Iran. In this regard, the removal of nitrogen and phosphorous compounds using wastewater treatment processes is of paramount importance in the competitiveness of various wastewater treatment processes.

The modified Ludzack-Ettinger (MLE) process is the activated sludge modification of wastewater treatment systems, which differs from the CAS process. This method is highly effective in the reduction of nitrogen and phosphorus compounds and has numerous benefits for the environment.[1-5] According to the study by Liu *et al.*, the MLE process could be applied for wastewater treatment, and the removal efficiency of total nitrogen (TN) and total phosphorus (TP) was estimated at 76% and 56%, respectively.[2] On the other hand, the removal efficiency of nitrogen and phosphorus through the CAS process is typically less than the MLE activated sludge process.

The MLE process consists of an anoxic tank and an aeration tank (Fig. 1). In this process, nitrification occurs in the aeration zone, and the sludge-containing nitrate that is produced in the aeration tank is sent to the anoxic zone. Following that, the organic matter in the influent wastewater provides the electron donor for the biochemical reactions using nitrate as the electron acceptor instead of oxygen. This costly, efficient process is also known as denitrification, which occurs in the anoxic tank.[6] Several studies have indicated that the MLE process is a nitrification-denitrification system with high capacity in nitrogen removal (85%), as well as the minimum relative capital, operations, and maintenance costs.[7-9] In this

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regard, Xin Wu reported that the MLE process is a proper method for fluent TKN/COD ratios (COD>0.10 mg N/mg).[8]

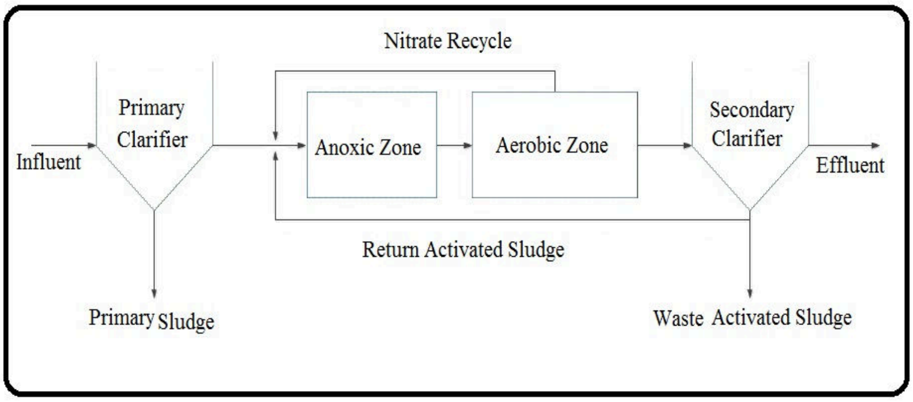

Fig. 1. Flow schematic of MLE process

Every experimental approach has specific advantages and limitations. The main advantages of the MLE process over the CAS process include the reduction of CH_4 emission during the nitrification stage,[10] improved sludge settleability,[1] enhanced biological phosphorous removal,[11] extensive application for denitrification or biological nitrogen removal,[6] and reduced aeration demand in the aerobic zones.[12] Furthermore, the major limitation of the MLE process over the CAS process is the high overall costs of the installation, operation, and maintenance of a proper pumping system and energy use.

The present study aimed to evaluate the treatment efficiency of the MLE process in the removal of chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and nitrate-nitrogen (NH_3-N) and compare the results with the CAS process previously used in Tafresh Municipal Wastewater Treatment plant (TMWTP). It is notable that evidence is scarce regarding this subject in Iran, and our findings may lay the groundwork for the wide application of the MLE process by new engineers.

Materials and Methods

This study was conducted in Tafresh city, Iran during October-December 2016 (before upgrading to MLE) and October-December 2017 (after upgrading to MLE). The efficiency of TMWTP and impact of upgrading on the removal efficiency of the mentioned treatment plant were investigated as well. Currently, the wastewater flow to the treatment plant is approximately 3,252 m^3/d, and the process in this treatment plant was based on the CAS before the upgrade. The system upgrading was carried out within the framework of implementing the MLE process.

Simple random sampling was performed to select 15 days in each autumn season in 2016 (before upgrading) and 2017 (after upgrading). During each sampling session, 30 samples were collected at the influent and effluent of the wastewater treatment plant at 10:00 AM-2:00 PM. Afterwards, the samples were analyzed in accordance with the recommended standards of the APHA.[13] The analyzed parameters included COD, BOD_5, NO_3-N, TSS, phosphate (PO_4-P), temperature (T °C), dissolved oxygen (DO), ammonium-nitrogen (NH_4-N), and pH.

The typical characteristics of the TMWTP influent are presented in Table 1. The results of effluent parameters were compared with the effluent standard for municipal wastewater in order to assess the criteria compliance. Since the TMWTP effluent is discharged into the river, its treatment in accordance with the appropriate standards is of utmost importance.

Data analysis was performed in Excel (Microsoft Office 2013) and SPSS version 19.0

(SPSS Inc., Chicago, IL, USA) using paired t-test to compare the phases before and after the upgrading of the system and one-sample t-test to compare the measurements with the standard values.

Table 1. Typical characteristics of raw municipal wastewater of Tafresh

Variable	SD	Mean	n
T (°C)	1.03	19.82	15
PH	0.06	7.73	15
TSS (mg/L)	20.29	246.26	15
BOD_5 (mg/L)	39.92	303.13	15
COD (mg/L)	42.93	563.66	15

Results and Discussion

Initially, the normality of the measured data was assessed and controlled using the Kolmogorov-Smirnov test at the confidence level of $P<0.05$ for the significant differences with normal distribution, and the results were indicative of the normal distribution of the data. Therefore, parametric analyses were applied in the present study.

According to the obtained results, the mean concentrations of the BOD_5 and COD of the TMWTP influent (before upgrading) were 303.13±20.88 and 563.66±41.13 mg/l, respectively. After upgrading to MLE, these values were estimated at 303.25±48.64 and 561.38±42.10 mg/l, respectively. Therefore, it could be inferred that the mean concentrations of BOD_5 and COD were highly similar before and after upgrading at the entrance of the treatment plant (Table 2). Moreover, the mean concentrations of the BOD_5 and COD of the treated wastewater at TMWTP were 155.66±32.40 and 244.13±55.08 mg/l before upgrading, respectively. After upgrading to MLE, these values were determined to be 23.93±10.39 and 49.40±26.83, respectively. Therefore, it could be concluded that the mean concentrations of BOD_5 and COD were not similar before and after upgrading at the end of the treatment system (Table 2).

Table 2. Results of paired T-test analysis used for assessment of influent wastewater to TMWTP before and after upgrading

Kind of fluent	Factor	Before upgrading				After upgrading				t	p-value
		n	Mean	SD	BOD_5/COD Ratio	n	Mean	SD	BOD_5/COD Ratio		
Influent	BOD_5 (mg/L)	15	303.13	20.88	55%	15	303.25	48.64	54%	0.119	0.906
	COD (mg/L)	15	563.66	41.13		15	561.38	42.1		0.03	0.976
Effluent	BOD_5 (mg/L)	15	155.66	32.40	64%	15	23.93	10.39	48%	14.993	0.001
	COD (mg/L)	15	244.13	55.08		15	49.40	26.83		12.309	0.001

Significant; $P < 0.05$

Table 3 shows the treatment efficiency of TMWTP before and after upgrading to MLE. Accordingly, the treatment efficiency of the MLE process based on the BOD_5 and COD was 92.11% and 91.20%, respectively. Under such circumstances, the treatment efficiency of the CAS process based on the BOD_5 and COD removal before upgrading was 48.55% and 56.76%, respectively. Table 4 shows the improvement of TMWTP as a result of plant upgrading.

Table 3. Treatment efficiencies of TMWTP (before and after upgrading)

Upgrading	Variable	Influent		Effluent		TE (%)
		n	Mean	n	Mean	
Before upgrading	BOD_5 (mg/L)	15	303.13	15	155.66	48.55
	COD (mg/L)	15	563.66	15	244.13	56.76
After upgrading	BOD_5 (mg/l)	15	303.25	15	23.93	92.11
	COD (mg/L)	15	561.38	15	49040	91.20

TF: Treatment Efficiency

Table 4. Improvement of TMWTP after upgrading than before

Variable	Treated wastewater		Improvement (%)
	Before upgrading	After upgrading	
BOD_5 mg/L)	155.66	155.66	84.63
COD (mg/L)	244.13	244.13	79.76
TSS (mg/L)	136.40	136.40	81.82
NO_3-N (mg/L)	29.09	29.09	-1.44
PO_4-P (mg/L)	3.08	3.08	70.78
NH_4-N (mg/L)	60.61	60.61	86.77

Table shows the characteristics of the treated wastewater at TMWTP before and after upgrading. Accordingly, the mean concentrations of BOD_5, COD, TSS, and NH_4-N after upgrading at TMWTP were 23.93±10.39, 49.40±26.83, 24.80±17.93, and 8.02±5.42 mg/l, respectively. Before upgrading, these values were estimated at 155.66±32.40, 244.13±55.08, 136.40±40.45, and 60.61±1.56 mg/l, respectively. Other similar results are presented in Table 5.

Table 6 shows the comparison of the characteristics of the treated municipal wastewater at TMWTP before and after upgrading. Accordingly, the mean concentration of COD in the treated wastewater before and after system upgrading was 244.13±55.08 and 49.40±26.83 mg/l, respectively, which demonstrated a significant difference in this regard between the experimental groups ($P<0.05$). Other similar results are presented in Table 6.

Table 5. Characteristics of Tafresh treated wastewater

	Variable	n	Mean	SD	Min	Max
Before upgrading	T	15	18.27	1.63	15.30	21.00
	pH	15	7.61	0.12	7.39	7.75
	TSS (mg/L)	15	136.40	40.45	80.00	223.00
	BOD_5 (mg/L)	15	155.66	32.40	110.00	203.00
	COD (mg/L)	15	244.13	55.08	182.00	332.00
	DO (mg/L)	15	0.62	0.18	0.40	0.86
	NO_3-N (mg/L)	15	29.09	4.88	21.60	36.23
	PO_4-P (mg/L)	15	3.08	1.36	1.15	4.34
	NH_4-N (mg/L)	15	60.61	1.56	58.24	63.36
After upgrading	T	15	18.78	2.17	16.50	22.30
	pH	15	7.68	0.08	7.59	7.85
	TSS (mg/L)	15	24.80	17.93	8.00	75.00
	BOD_5 (mg/L)	15	23.93	10.39	10.00	50.00
	COD (mg/L)	15	49.40	26.83	30.00	130.00
	DO (mg/L)	15	1.13	0.26	0.93	1.75
	NO_3-N (mg/L)	15	29.51	7.84	12.70	42.08
	PO_4-P (mg/L)	15	0.90	0.63	0.23	2.13
	NH_4-N (mg/L)	15	8.02	5.42	3.14	20.80

Table 6. Comparison of characteristics of Tafresh treated wastewater in each autumn season of the year 2016 (before upgrading) and 2017 (after upgrading to MLE system)

Variable	Mean ± SD		T-value	P-value
	Before upgrading	After upgrading		
T (°C)	18.27±1.63	18.78±2.17	0.759	0.461
pH	7.61±0.12	7.68±0.08	1.888	0.080
TSS (mg/L)	136.40±40.45	24.80±17.93	9.719	0.001*
BOD_5 (mg/L)	155.66±32.40	23.93±10.39	14.362	0.001*
COD (mg/L	244.13±55.08	49.40±26.83	11.900	0.001*
DO (mg/L)	0.62±0.18	1.13±0.26	7.114	0.001*
NO_3-N (mg/L)	29.09±4.88	29.51±7.84	0.160	0.875
PO_4-P (mg/L)	3.08±1.36	0.90±0.63	5.141	0.001*
NH_4-N (mg/L)	60.61±1.56	8.02±5.42	35.412	0.001*

*: Significant; $P < 0.05$; COD, BOD_5, TSS, NH_4-N, PO_4 and DO

An important step in the current research was to compare the results with the reference values. To this end, the mean values of the studied variables were compared to the current standards in Iran for the safe disposal of wastewater into rivers. The results of t-test analysis are presented in Table 7. The results of the analysis indicated a highly significant difference between the TSS value of the treated wastewater before and after upgrading (P<0.05) compared to the maximum permissible limits for wastewater disposal into rivers in Iran (Table 7). In fact, the TSS value of the effluent remained within the standard range after upgrading, while the TSS value of the effluent was below the regulation value for wastewater disposal into rivers before upgrading. The other results in this regard are presented in Table 7. Various interpretations have been discussed in the following sub-sections.

Effects of the MLE upgrading on BOD_5 and COD

According to the results of the present study, the removal rates of BOD_5 and COD in the MLE process were more than 92% and 91%, respectively. Similar results have also been reported by a similar research regarding the application of membrane bioreactors (MBRs) for wastewater treatment.[14, 15] Accordingly, the MBR system was able to remove more than 96% and 93% of BOD_5 and COD from municipal wastewater, respectively. In addition, the application of MBRs in wastewater treatment plants is often highly costly in Iran. Therefore, we did not use the device in the studied area, and the MLE process was preferred due to its simplicity and relative cost-effectiveness. Furthermore, the results of both methods were remarkably similar.

Table 7. Comparison of tafresh treated wastewater characteristics (before and after upgrading) to DoE standards

	Factor	n	Mean	SD	Standard value	t-value	P-value
Before upgrading	pH	15	7.61	0.12	6.5-8.5	28.70	0.001*
	TSS (mg/L)	15	136.40	40.45	40	9.23	0.001*
	BOD_5 (mg/L)	15	155.66	32.40	30	15.02	0.001*
	COD (mg/L)	15	244.13	55.08	60	12.95	0.001*
	DO (mg/L)	15	0.62	0.18	2	30.21	0.001*
	No_3-N (mg/L)	15	29.09	4.88	50	16.56	0.001*
	PO_4-P (mg/L)	15	3.08	1.36	6	8.30	0.001*
	NH_4-N (mg/L)	15	60.61	1.56	2.5	143.99	0.001*
	T (°C)	15	18.27	1.63	†		
After upgrading	pH	15	7.68	0.08	6.5-8.5	40.37	0.001*
	TSS (mg/L)	15	24.80	17.93	40	3.28	0.005*
	BOD_5 (mg/L)	15	23.93	10.39	30	2.26	0.040*
	COD (mg/L)	15	49.40	26.83	60	1.53	0.148
	DO (mg/L)	15	1.13	0.26	2	12.87	0.001*
	No_3-N (mg/L)	15	29.51	7.84	50	10.11	0.001*
	PO_4-P (mg/L)	15	0.90	0.63	6	31.25	0.001*
	NH_4-N (mg/L)	15	8.02	5.42	2.5	3.94	0.010*
	T (°C)	15	18.78	2.17	†		

† Based on Iranian Department of Environment (DoE) standards, the temperature of entrance water to surface water resources such as river, lake or stream should not drop or raise temperature of mentioned source more than 3 °C at radius of 200 meters from its entrance

*Significant; P < 0.05; COD, BOD_5, TSS, NH_4-N, PO_4, pH and DO

Effects of the MLE upgrading on nitrogen compounds

Several studies have been focused on the removal of ammonium-nitrogen from municipal and industrial wastewater.[14, 15] In this framework, the main feature of the MLE process is the ability to reduce the levels of nitrogen-containing organic compounds in the effluent of municipal and industrial wastewater. In this process, the amount of the required oxygen is less than the other activated sludge modifications. According to the results of the present study, after upgrading from the CAS to the MLE process, the concentration of the ammonium compounds in the treated municipal wastewater at TMWTP improved by more than 86% (Table 4). In other words, the mean concentration of the ammonium compounds in the treated wastewater at TMWTP was 60.61±1.56 mg/l before system upgrading, while after upgrading the treatment plant to the MLE process, this value was determined to be 8.02±4.42 mg/l (Table 5). Although the implementation of the MLE process could improve the concentration of the ammonium compounds in the effluent, the obtained value could not reach the standard level. The findings of the current research indicated a significant difference between the mean concentrations of the ammonium compounds in the effluent with the Iranian maximum permissible limits ($P<0.05$) (Table 7). It is also notable that the mentioned effluent before or after upgrading was not appropriate for discharge into the local river.

Comparable results have been reported by Hafez *et al.*, who employed the MLE process at the hydraulic retention time of 5.5 hours in order to evaluate the capacity of the system to reduce the levels of nitrogen compounds in the effluent of a wastewater treatment plant. According to the final findings, the nitrification rates in the MLE process at the temperature of 20 °C were 55% better than in the CAS system.[1]

According to the results of the present study, the mean concentration of nitrate before and after upgrading in the treated wastewater at TMWTP was 29.09±4.88 and 29.51±7.84 mg/l, respectively (Table 6). In other words, the mean concentration of nitrate in the effluent of the treatment plant was highly similar before and after upgrading, and no significant difference was observed in this regard. However, it must be noted that the mean concentration of the ammonium compounds was not similar before and after upgrading at the end of the treatment, and a significant difference was denoted in this regard. In fact, the mean concentration of the ammonium compounds in the treated wastewater at TMWTP improved by more than 86% after the system upgrading (Table 4). Therefore, it could be concluded that a significant portion of the removed ammonium was converted into nitrate during the nitrification process, while a large portion was also converted into nitrogen gas during the denitrification process. Finally, it seems that the amount of nitrate remained relatively constant and was significantly lower than the current standards in Iran (Table 7).

Several studies have been focused on the mentioned issue.[1,2,3,7,16-18] For instance, Liu and Wang applied periodic aeration to the MLE process in order to improve denitrification performance. According to the obtained results, periodic aeration could significantly improve the removal of total nitrogen, thereby causing the nitrate concentration to decrease to approximately 7 mg/l in the municipal wastewater effluent.[2]

Effect of the MLE upgrading on TSS

High concentrations of suspended solids in effluent wastewater could cause numerous environmental damages.[18] The findings of the current research demonstrated a significant difference between the effluent TSS and Iranian standards for wastewater disposal into rivers ($P<0.05$) (Table 7). In fact, the amount of TSS in the effluent remained within the standard range after upgrading, while it differed with the standard values before the upgrade.

Effect of the MLE upgrading on phosphorus

Before and after upgrading, the mean concentration of phosphorus in the treated wastewater at TMWTP was 3.08±1.36 and 0.90±0.63 mg/l, respectively (Table 6). Although the upgrading of TMWTP resulted in the reduction of phosphorus concentration in the effluent by 70%, the concentration of this compound in the effluent was within the standard range before and after upgrading (Table 7). A similar pilot study was carried out regarding the MLE process and its ability to reduce the concentration of phosphorus in wastewater effluent in a treatment plant, and the obtained results indicated that the mean concentration of the effluent phosphorus was 0.5 mg/l.[2]

Effect of the MLE upgrading on DO

Before and after upgrading, the mean concentration of DO in the treated wastewater at TMWTP was 0.62±0.18 and 1.13±0.26 mg/l, respectively (Table 6). The DO concentration in effluent wastewater is affected by several factors, such as operational parameters, wastewater temperature, adjustment of the time of nitrification and denitrification, and treatment capacity.[10] Therefore, further investigations are required to assess the correlation between DO concentration and denitrification efficiency.

Conclusion

The MLE process is a customizable process that could be used as a treatment option for the removal of pollutants from wastewater. Our findings indicated a significant reduction in the concentrations of NH_4-N, PO_4-P, TSS, COD, and BOD_5 in the effluents of the MLE process. Given the importance of environmental protection, it is recommended that researchers shift to the measurement of the main parameters of wastewater treatment system (e.g., solid retention time, sludge volume index, mixed liquor suspended solid, sludge recycling, and other aeration parameters) in different conditions with variable pH and temperatures in order to optimize the methods and tools for the improvement of the system efficiency in the MLE process.

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