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Investigation and modeling of a hybrid activated sludge system for municipal wastewater treatment using multi-layer perceptron neural networks

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ABSTRACT

This study assesses the performance of a hybrid municipal wastewater treatment system. The proposed system attempted to improve the performance of an activated sludge system by using fully immersed vertical rotating biological contactors in the aeration basin of the system. Besides, a multi-layer perceptron neural network (MLPNN) was used to predict pollutants in the effluent. Overall treatment efficiencies of chemical oxygen demand (COD), total suspended solids (TSS), total phosphorus (TP), turbidity, and NH_3 removal were 94%, 95%, 74%, 94%, and 86%, respectively. Via the training procedure of the MLPNN model, an almost perfect match was achieved between predicted values and experimental values. The correlation coefficient (R) was higher than 0.95 for all models predicting COD, TSS, TP, turbidity, and NH_3, and mean squared error was satisfactory. The results were verified and demonstrated the effectiveness of the MLPNN model to predict effluent values. Also, the findings confirmed the effectiveness of the system in municipal wastewater treatment. Consequently, this system is recommended for treating municipal wastewater.

Keywords: Municipal wastewater treatment; Activated sludge process; Rotating biological contactors; Hybrid growth process; Neural networks; Prediction

1. Introduction

Due to the rapid increase in population, the amount of municipal wastewater has dramatically increased in recent years. Therefore, some measures must be taken in order to collect and treat produced wastewater to achieve a non-polluting and healthy environment [1]. Additionally, it is crucial to reuse wastewater in regions that are suffering from water shortage. Overall, conventional wastewater treatment systems cannot be sufficient for the treatment of this amount of produced wastewater; as a result, new technologies and innovations should be used for wastewater treatment [2].

Generally, the activated sludge process is the most used biological method of wastewater treatment, and a bacterial biomass suspension is responsible for removing the pollutants in this process [3]. Different kinds of activated sludge systems have been utilized for various types of wastewaters. Recently, different studies have been performed in order to improve the performance of the activated sludge systems to treat different kinds of wastewaters. As an example, Jung et al. [4] utilized batch activated sludge systems to treat dairy wastewater with high oil and grease contents. In another study, Pala and Tokat [5] applied an activated sludge pilot in order to treat the cotton textile industry wastewater. Tellez et al. [6] utilized a field continuous-flow activated sludge system to remove petroleum hydrocarbons from produced water. Based on the field-scale test results in this study, the activated sludge system can be effectively used for removing total petroleum hydrocarbon from produced water. Also, Aslan et al. [7] used an activated sludge system to remove COD from the edible oil wastewaters. In another study, Côté et al. [8]

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used an immersed membrane activated sludge system to treat municipal wastewater. The findings showed that the immersed membrane activated sludge system resulted in acceptable BOD and COD removal efficiencies.

The performance of suspended growth systems, such as the activated sludge system, can be improved for wastewater treatment by using various types of packing materials in the aeration basin of these systems [9,10]. In other words, packing materials are very suitable to improve overloaded suspended growth wastewater treatment systems by converting unused volumes into attached growth reactors [11]. The usage of biofilm media in the aeration basin of activated sludge systems might increase the performance of these suspended growth systems. As an example, You et al. [12] reported that the combination of rotating biological contactors (RBCs) with an activated sludge system could promote nitrifying activity, which contributed to the nitrification performance. In a study, Zaoyan et al. [13] combined RBCs with the activated sludge system to treat dye wastewater. According to the results, the system could effectively remove the color from the wastewater. In another study, Gebara [14] utilized plastic nets as biofilm media inside the aeration basin of an activated sludge system. Based on the results, the addition of nets could improve BOD_5 removal efficiency for treating synthetic wastewater. Su and Ouyang [15] combined an activated sludge system with fixed biofilms to treat synthetic municipal wastewater with different operating parameters. They reported that the combined system is a successful strategy to upgrade the activated sludge systems. A polyurethane fluidized bed biofilm was combined with an activated sludge system to treat dyeing wastewater by Park and Lee [16]. The system could effectively remove COD from the wastewater in different organic loading rates. Di Trapani et al. [17] investigated the performance of a hybrid activated sludge/biofilm process for wastewater treatment in a cold climate region. The hybrid system showed excellent removal efficiencies in organic pollutants. Also, Zhang et al. [18] combined a pilot-scale continuous activated sludge reactor with fixed carriers to treat high ammonium wastewater. The results indicated that the integrated pilot was successful in nitrogen removal.

This study attempts to investigate the performance of an activated sludge system with fully immersed vertical RBCs in the aeration basin of the system. In other words, the attached growth and suspended growth biological wastewater treatment were integrated into the aeration basin of our system. Despite the positive effect of biofilm media for improving the effectiveness of biological wastewater treatment systems, the detachment of biomass from biofilm media is a critical issue in these attached growth wastewater treatment systems [19]. High rotational speed in RBCs may bring about biofilm detachment, which has an adverse influence on the biomass concentration in these systems [20]. Because of this, the rotational speed of 5 rpm (rotations per minute) was selected for the rotating disks in our integrated wastewater treatment system. Based on our knowledge, this system for the treatment of municipal wastewater has not been previously studied or reported in the literature.

On the whole, even though mathematical solutions can quickly solve each problem with hardware available at the moment, some problems require too high computational capacities. As such, different algorithms, including ant colony optimization algorithms, genetic algorithms, neural networks algorithms, and so on, have been developed to solve this issue. In recent years, artificial neural networks (ANNs) have been employed in diverse scientific areas, such as water resources and environmental engineering [21,22]. Besides, neural networks have been efficiently applied for controlling and monitoring water and wastewater treatment systems [23–25]. Neural networks fundamentally compute relationships among input values and output values via some internal calculations. Hence, a multi-layer perceptron neural network (MLPNN) was used to predict wastewater characteristics at the effluent of the wastewater treatment system in our study.

2. Materials and methods

2.1. Synthetic municipal wastewater characteristics

The pilot plant was located in K.N. Toosi University Laboratory. In this study, the synthetic wastewater was prepared from tap water by adding several compounds. It was chiefly formed of a source of carbon (saccharose; $C_{12}H_{22}O_{11}$), a source of nitrogen (ammonium chloride: NH_4Cl), a source of phosphorous (disodium phosphate: Na_2HPO_4 and monopotassium phosphate: KH_2PO_4), bentonite as a source of total suspended solids (TSS) and turbidity, and other nutrient solutions to simulate the desirable level of organic strength. Table 1 shows the minimum, the average, and the maximum values of synthetic municipal wastewater characteristics.

2.2. Pilot plant

The wastewater treatment system was composed of a feeding tank, an aeration basin, which consisted of four fully immersed vertical rotating biodisks, and a settling tank (Fig. 1). The feeding tank was 2 m above the ground level so as to establish a continuous flow. The RBCs were made of Plexiglass acrylic sheets. A layer of polyurethane foam (PUF) was attached to both sides of each biodisk in order to facilitate both organic matter biodegradation and

Table 1
Synthetic municipal wastewater characteristics

Parameters	COD (mg/L)	BOD_5 (mg/L)	TDS (mg/L)	TSS (mg/L)	NH_3 (mg/L)	Turbidity (NTU)	pH	TP (mg/L)
Min.	335	141	274	220	19	255	6.9	26.8
Avg.	872.5	386	444.5	427	57.5	504.9	7.45	20
Max.	1,410	631	615	634	84	754.8	8	13.2

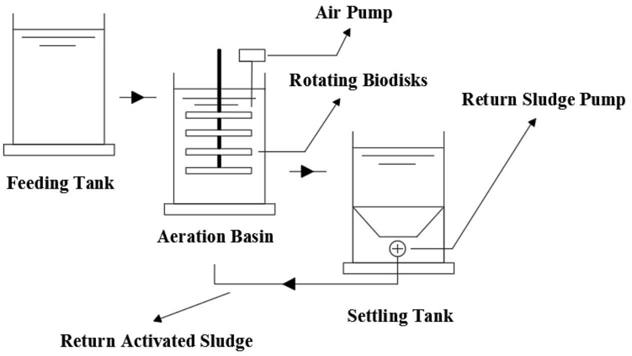


Fig. 1. Configuration of the pilot plant and the process used in this study.

microorganisms' growth. The PUF serves as a suitable media owing to having a high specific surface area and porosity [26]. The characteristics of RBCs used in this study are given in Table 2. The disks were installed in the aeration basin with a volume of 50 L. The biodisks were connected through a stainless steel shaft, and an induction motor was employed for rotating the shaft and disks. Fig. 2 shows the RBCs before and after usage in the wastewater treatment system. An air compressor supplied airflow to the aeration basin via diffusers placed in it to provide oxygen and also ensure mixing in the aeration reactor. Two aquarium heaters were applied to maintain the temperature at 30°C. Eventually, the 12-L Plexiglass settling tank had a trapezoidal shape part because this can facilitate suspended solids and sludge settleability. In order to return settled sludge to the aeration basin, a pump with a specific flow was installed at the bottom of the settling tank.

2.3. Operating conditions

After placing rotating contactors in the aeration basin, half of the effective volume of the aeration basin was filled with return activated sludge of the aeration basin unit of Ekbatan municipal wastewater treatment plant. pH, mixed liquor suspended solids (MLSS), and mixed liquor volatile suspended solids (MLVSS) for return activated sludge were 7.4; 9,050 mg/L; and 7,200 mg/L, respectively. The remaining volume was filled with synthetic municipal wastewater. In order to provide organics and nutrients required for the growth of microorganisms, activated sludge and synthetic municipal wastewater were daily added to the aeration basin. This process had been performed 30 times before we started pilot testing. pH typically impacts on the treatability of wastewater in biological wastewater treatment processes [27]. Because of this, pH was measured and was between 6.6 and 8.4. We observed that after 8 h aeration in the aeration basin, the COD removal rate decreases due to the decline in the concentration of MLVSS. This decline can be attributed to the decrease in the food to microorganism ratio and the death of microorganisms in the aeration basin of the activated sludge system, which commonly increase COD concentration. In addition, based on the inlet wastewater flow rate and the dimensions of the settling tank of the activated sludge system, settling time in the activated sludge system was 2.5 h. As a result, 10.5 h optimum was chosen for the whole integrated municipal wastewater treatment system as the optimum hydraulic retention time. The settling tank was added to the system after the adaptation phase. Afterwards, synthetic municipal wastewater with approximately 100 mL/min flow rate was discharged into the aeration basin. The return activated sludge pump returned settled activated sludge from the settling tank to the aeration basin at 20% of the influent synthetic wastewater flow rate. During the aeration phase, the biodisks were rotated at 5 rpm. Finally, wastewater samples were collected to measure the wastewater characteristics before and after the treatment process.

Table 2
Characteristics of rotating biological contactors used in this study

Parameter	Value
Number of disks	4
Diameter of disks (cm)	25
Spacing between disks (cm)	5
Surface material	PUF
Thickness of disks (cm)	4.5
Total surface area of disks (m^2)	0.4
Porosity of disks (%)	85
Disk submergence (%)	100

Fig. 2. Rotating biological contactors before the biofilm formation (a) and after biofilm formation in the aeration basin (b).

2.4. Analytical method

In this study, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total phosphorus (TP), MLSS, MLVSS, TSS, ammonia (NH_3), total dissolved solids (TDS), temperature, turbidity, and pH were measured. A spectrophotometer (Loviband Laboratory Spectrophotometer) was used to measure NH_3 and COD at the university laboratory.

TDS was measured by AZ8371, and turbidity was measured by PC CHECKIT Loviband. The pH and the temperature were measured by a digital pH meter. TSS, MLSS, MLVSS, and BOD_5 were measured according to standard methods [28].

2.5. NN-based model development

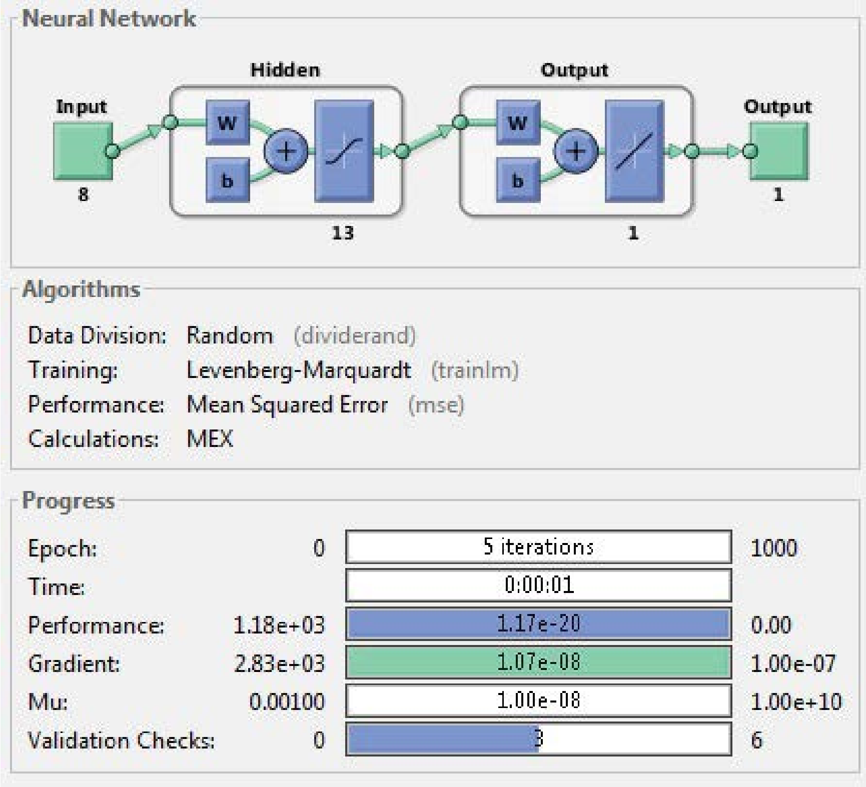
Overall, ANNs are inspired by the animals' brain performance [29]. Neural networks generally consist of tons of artificial neurons, and the networks' functions are determined by connections among these neurons [30]. To put it another way, neural networks try to define a relationship among inputs and outputs without a specific rule, and this is the most advantage of ANNs [31]. As a single layer cannot efficiently detect the relationships among a large number of inputs and outputs, a multi-layer perceptron (MLP) is commonly used for creating the neural network models [32]. In this study, we used an MLPNN with three layers, including an input layer, a hidden layer with 13 neurons, and an output layer.

Fig. 3 demonstrates the architecture of the MLPNN used in the study for the prediction of effluent wastewater characteristics. Eight parameters, including influent COD, BOD_5, TP, NH_3, TSS, TDS, turbidity, and pH, were used as the inputs of the MLPNN to predict effluent COD, TSS, TP, turbidity, and NH_3. Table 3 demonstrates the characteristics of input and output variables in the MLPNN modeling process. By means of a random data division, the data set was divided into three sets, 80% (10 readings) for training, 10% (1 reading) for validation, and 10% (1 reading) for testing of the MLPNN model. In this study, the Levenberg–Marquardt algorithm was used for training the MLPNN model, and the performance of the MLPNN model in predicting effluent COD, TSS, TP, turbidity, and NH_3 was measured employing correlation coefficient (*R*) and mean squared error (MSE). Influent and effluent values of wastewaters characteristics used in the MLPNN model are available as supplementary information in Table S1.

3. Results and discussion

3.1. COD removal efficiency

The average COD concentration in the influent of the raw synthetic municipal wastewater was about 724 mg/L, which decreased to the average concentration of 44 mg/L in the effluent (lower than the standard limit of 60 mg/L by U.S. EPA) [33]. The standard deviation for raw wastewater and effluent after the hybrid wastewater treatment system was 390.1 and 12.1, respectively. The average COD removal efficiency was approximately 94% at the end of the wastewater treatment system. Based on the results, our hybrid growth (attached/suspended growth) wastewater treatment system is effective in COD removal from municipal wastewater. Our hybrid activated sludge system displayed higher COD removal efficiency than some other activated sludge systems. As an example, Schwede et al. [34] used a microalgae-based activated sludge process for municipal wastewater treatment on a pilot scale.



Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MEX

Epoch: 0 5 iterations 1000
Time: 0:00:01
Performance: 1.18e+03 1.17e-20 0.00
Gradient: 2.83e+03 1.07e-08 1.00e-07
Mu: 0.00100 1.00e-08 1.00e+10
Validation Checks: 0 3 6

Fig. 3. Architecture of the MLPNN used in the study for the prediction of effluent COD, TSS, TP, turbidity, and NH_3.

Table 3
Characteristics of input and output variables in the MLPNN modeling process

Input variable	Value	Output variable	Value
Influent conc.		Effluent conc.	
COD (mg/L)	335–1,410	COD (mg/L)	25–64
BOD_5 (mg/L)	141–631	BOD_5 (mg/L)	11–31
TDS (mg/L)	274–615	TDS (mg/L)	206–449
TSS (mg/L)	220–634	TSS (mg/L)	18–45
NH_3 (mg/L)	19–84	NH_3 (mg/L)	1.9–12
TP (mg/L)	13.2–26.8	TP (mg/L)	3.6–7
Turbidity (NTU)	255–754.8	Turbidity (NTU)	19.2–40
pH	6.9–8	pH	6.5–8.1

According to the findings, the average COD removal in our system is higher than that system with COD removal between 75% and 90%. In another study, Sperling et al. [35] combined an activated sludge system with an up-flow anaerobic sludge blanket (UASB) reactor to treat municipal wastewater. COD removal efficiency in that combined system changed from 85% to 93%, which is lower than the average COD removal in our hybrid system. Also, our hybrid activated sludge system showed higher COD removal efficiency as compared with a conventional activated sludge system utilized by Guven et al. [36]. In addition, the microorganisms in our hybrid growth system have a higher ability to remove organic carbon than other single growth wastewater treatment processes. As an example, sequencing batch reactors (SBRs) are suspended growth biological wastewater treatment systems, and in a study, Jin et al. [37] used two parallel SBRs for removing organic matters in municipal wastewater; COD removal in the best condition was approximately 70%, which is lower than COD removal in our system. Also, the COD removal efficiency of our system is higher than another pilot-scale SBR [38]. In another study, Sarti et al. [39] used anaerobic pilot-scale SBRs for domestic sewage treatment with the COD removal efficiency of less than 60%. Our hybrid system displayed higher COD removal efficiency as compared with that study. Moreover, our system showed higher COD removal efficiency than some other attached growth systems. For example, Wang et al. [40] employed a moving bed biofilm reactor (MBBR) to treat municipal wastewater. The COD removal efficiency was between 57% and 77%, which is lower than COD removal efficiency in our system. Besides, Yang et al. [41] applied membranes in an SBR system in a study. The COD removal efficiency in that system was analogous to our system, but they confronted membrane fouling problem, which is a severe obstacle in these kinds of wastewater treatment systems [42].

3.2. TSS removal efficiency

The average TSS concentration in the influent of the raw synthetic wastewater was about 393 mg/L, which decreased to the average concentration of 22 mg/L in the effluent. The standard deviation for raw wastewater and effluent after the hybrid wastewater treatment system was 124.9 and 9.3, respectively. The average TSS removal efficiency was approximately 95% at the end of the wastewater treatment system. The results showed that the system is successful in TSS removal from municipal wastewater. TSS removal efficiency in our system was higher than some other wastewater treatment systems. For example, TSS removal in our integrated system was higher than TSS removal in a conventional activated sludge municipal wastewater treatment system, which was used by Gonzalez et al. [43]. Besides, our hybrid activated sludge system showed higher TSS removal efficiency as compared with an activated sludge system utilized by Hannah et al. [44]. Our hybrid system also performed better, in the removal of TSS from municipal wastewater, than a system in which an activated sludge system was combined with a dissolved air flotation unit for the municipal wastewater treatment, and achieved an average removal efficiency of 78% in the best condition [45]. In a study, Torres and Foresti [46] used a combined anaerobic–aerobic system composed of an UASB reactor followed by an SBR to treat domestic sewage in tropical regions. The overall TSS removal in that system was 84%; therefore, TSS removal in our wastewater treatment system was higher than their wastewater treatment system. In another research, Guida et al. [47] used the coagulation process in municipal wastewater treatment to meet the Italian water quality discharge limits in diverse conditions. 92% TSS removal efficiency in our system was higher than TSS removal efficiency in that research in most of the circumstances.

3.3. TP removal efficiency

The average TP concentration in the influent of the raw synthetic municipal wastewater was about 19.2 mg/L, which decreased to the average concentration of 5 mg/L in the effluent (lower than the standard limit of 6 mg/L by U.S. EPA) [33]. The standard deviation for raw wastewater and effluent after the hybrid wastewater treatment system was 4.6 and 1.1, respectively. The average TP removal efficiency was approximately 74% at the end of the wastewater treatment system. According to the results, our hybrid growth (attached/suspended growth) wastewater treatment system is effective in TP removal from municipal wastewater. Our hybrid wastewater treatment system showed higher TP removal efficiencies than some other systems. As an example, Seo et al. [48] used an altered activated sludge system for domestic wastewater treatment. 74% TP removal efficiency in our hybrid system was higher than 23% TP removal in their system. In a study, Singh and Kazmi [49] utilized a single-stage aerobic integrated fixed-film activated sludge reactor to treat municipal wastewater. TP removal in that integrated system was about 50%, which is lower than 74% TP removal in our hybrid system. In another study, Wang and Chen [50] investigated the performance of a full-scale activated sludge municipal wastewater treatment plant. TP removal efficiency of our hybrid system is higher than that activated sludge system. Moreover, the TP removal efficiency of our hybrid wastewater treatment system was higher than a single growth wastewater treatment system (a conventional SBR) with removal efficiencies from 20% to

70% [51]. Also, in a study, Lin and Cheng [52] combined an attached growth system (an SBR system) with chemical coagulation for municipal wastewater treatment. TP removal efficiency in their combined system was lower than our hybrid system. In another study, Zinatizadeh and Ghaytooli [53] employed an MBBR, which is an attached growth process for treating wastewater. TP removal in our hybrid system was higher than their attached growth biological wastewater treatment system.

3.4. Turbidity removal efficiency

The average turbidity concentration in the influent of the raw synthetic wastewater was about 470 NTU, which decreased to the average concentration of 30 NTU in the effluent. The standard deviation for raw wastewater and effluent after the hybrid wastewater treatment system was 145.9 and 8.5, respectively. The average turbidity removal efficiency was approximately 94% at the end of the wastewater treatment system. The results indicated that the system is efficient in turbidity removal from municipal wastewater in comparison with some other wastewater treatment systems. As an example, Moussaoui et al. [54] applied an activated sludge reactor to treat synthetic urban wastewater. Our hybrid system showed higher turbidity removal efficiency as compared with that system. Also, our hybrid activated sludge system indicated higher turbidity removal efficiency than an activated sludge system, which was used by Shivaranjani and Thomas [55]. In a study, Li et al. [56] used a sequencing batch biofilm reactor with biological filtration for wastewater treatment, and the average turbidity removal in their wastewater treatment system was 85%, which was lower than the average turbidity removal in our system. In another study, Ahmed et al. [57] investigated the performance of an anaerobic SBR for primary settled wastewater treatment at different temperatures and reaction times. The best average turbidity removal in that system was roughly 80%, which indicates that the average turbidity removal in our system is promising. The findings also showed that turbidity removal in our system is higher than an electro-coagulation treatment process [58].

3.5. NH_3 removal efficiency

The average NH_3 concentration in the influent of the raw synthetic wastewater was about 46.8 mg/L, which decreased to the average concentration of 6.5 mg/L in the effluent. The standard deviation for raw wastewater and effluent after the hybrid wastewater treatment system was 20.2 and 3.4, respectively. The average NH_3 removal efficiency was approximately 86% at the end of the wastewater treatment system. According to the findings, the system is effective in NH_3 removal from municipal wastewater. NH_3 removal in our hybrid system was higher than some other activated sludge municipal wastewater treatment systems. For example, in a study by Wu et al. [59], using a cyclic activated sludge technology (CAST) system for municipal wastewater treatment, the maximum NH_3 removal efficiency was 83%. In another study, Wang et al. [60] evaluated a CAST system for municipal wastewater treatment. The 86% NH_3 removal efficiency of our hybrid system is higher than approximately the 55% NH_3 removal efficiency of that system. Besides, NH_3 removal in our hybrid system was higher than some other biological wastewater treatment systems. In a study, Wei et al. [61] applied a modified submerged membrane bioreactor to treat municipal wastewater. The maximum NH_3 removal in that system was 58.2%, which is lower than NH_3 in our system. Valipour et al. [62] also employed a compacted aerobic attached growth fix-film unit for domestic wastewater. NH_3 removal in our hybrid system was higher than that biological attached growth wastewater treatment system. In another study, Moore et al. [63] employed biological aerated filters in wastewater treatment. NH_3 removal in our hybrid system was higher than that system.

3.6. NN-based prediction of effluent characteristics

After testing several network architectures with neurons at the hidden layer to predict the effluent COD, TSS, TP, NH_3, and turbidity in this study, a three-layer MLPNN was chosen for the network. While using more hidden neurons might be practical for improving the performance of the network, employing a large number of neurons might bring about overfitting, and this usually undermines the generalization capacity of the neural networks [64]. Consequently, an MLPNN with 3 layers and 13 neurons in the hidden layer brought about higher accuracies for the most of effluent characteristics and tested architectures in this study, and the training procedure of the MLPNN model was promising for the prediction of effluent COD, TSS, TP, NH_3, and turbidity. Fig. 4 demonstrates the results of the prediction for the five effluent characteristics using the MLPNN algorithm. In other words, Fig. 4 shows the accuracy of the MLPNN model in the 12 cycles of raw synthetic wastewater treatment with various characteristics in this study. The results indicated that there is a perfect match between predicted values and experimental values for the effluent COD, TSS, TP, NH_3, and turbidity. Besides, the results confirmed the high generalization capability of the MLPNN algorithm.

Fig. 5 shows the regression lines for the MLPNN model predicting effluent COD, TSS, TP, turbidity, and NH_3 based on all data sets. In this research, the results verify the high correlation of predicted values with experimental values. MSE and R values for each of the measured parameters are given in Table 4. According to the results of our modeling for the prediction of effluent characteristics, the MLPNN model displays higher accuracies in comparison with some previously developed models [65,66]. The optimal architecture of the MLPNN model was found to be successful as the error based on all data sets was promising for the effluent COD, TSS, TP, turbidity, and NH_3 in this study.

4. Conclusion

This study examined the novel application of an integrated system for the treatment of municipal wastewater. The hybrid system was composed of an activated sludge system, which was coupled with fully immersed vertical RBCs with a rotational speed of 5 rpm. The RBCs were used in order to make a trade-off between the attached growth

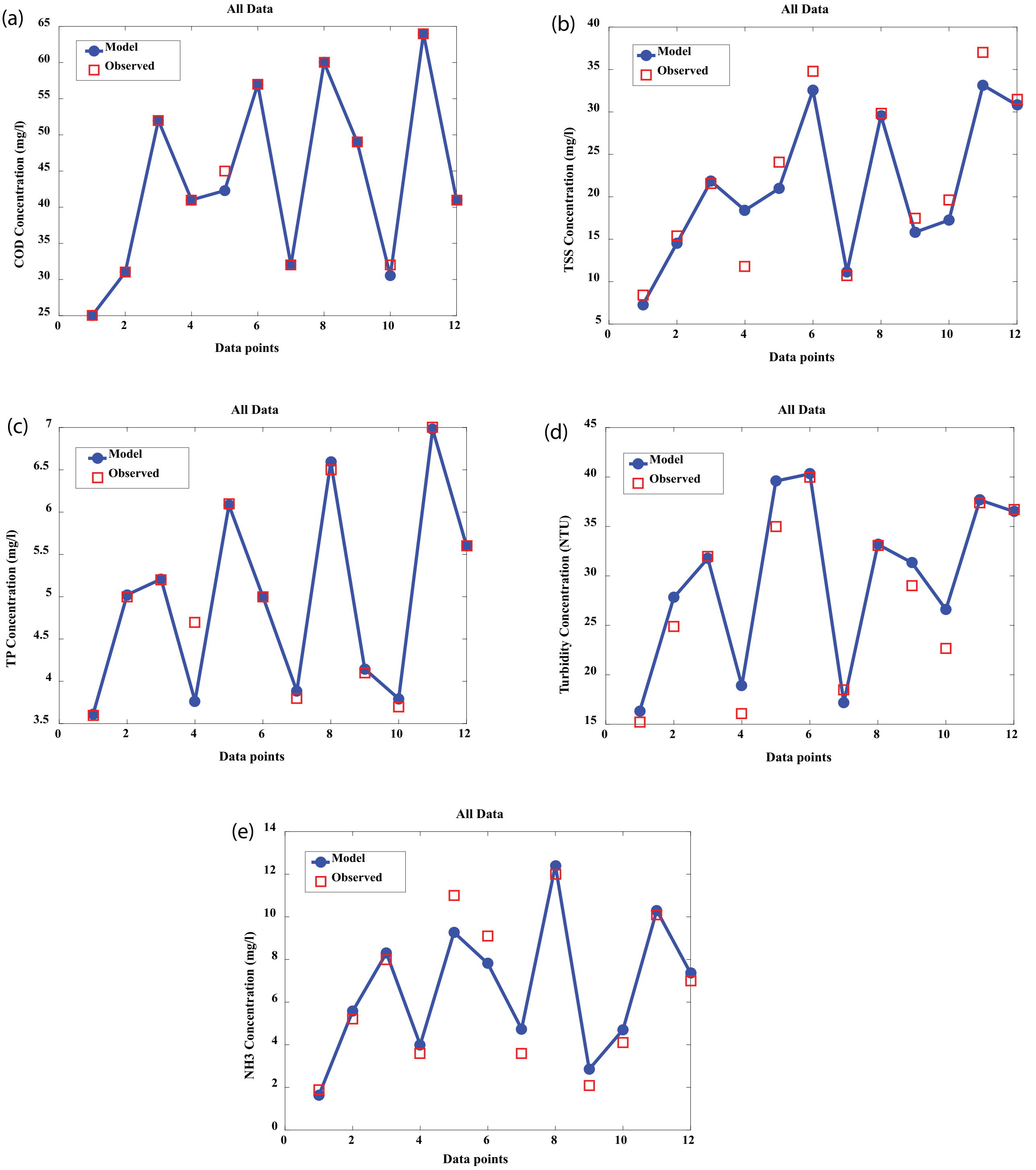


Fig. 4. Prediction of (a) effluent COD, (b) effluent TSS, (c) effluent TP, (d) effluent turbidity, and (e) effluent NH_3 using MLPNN model.

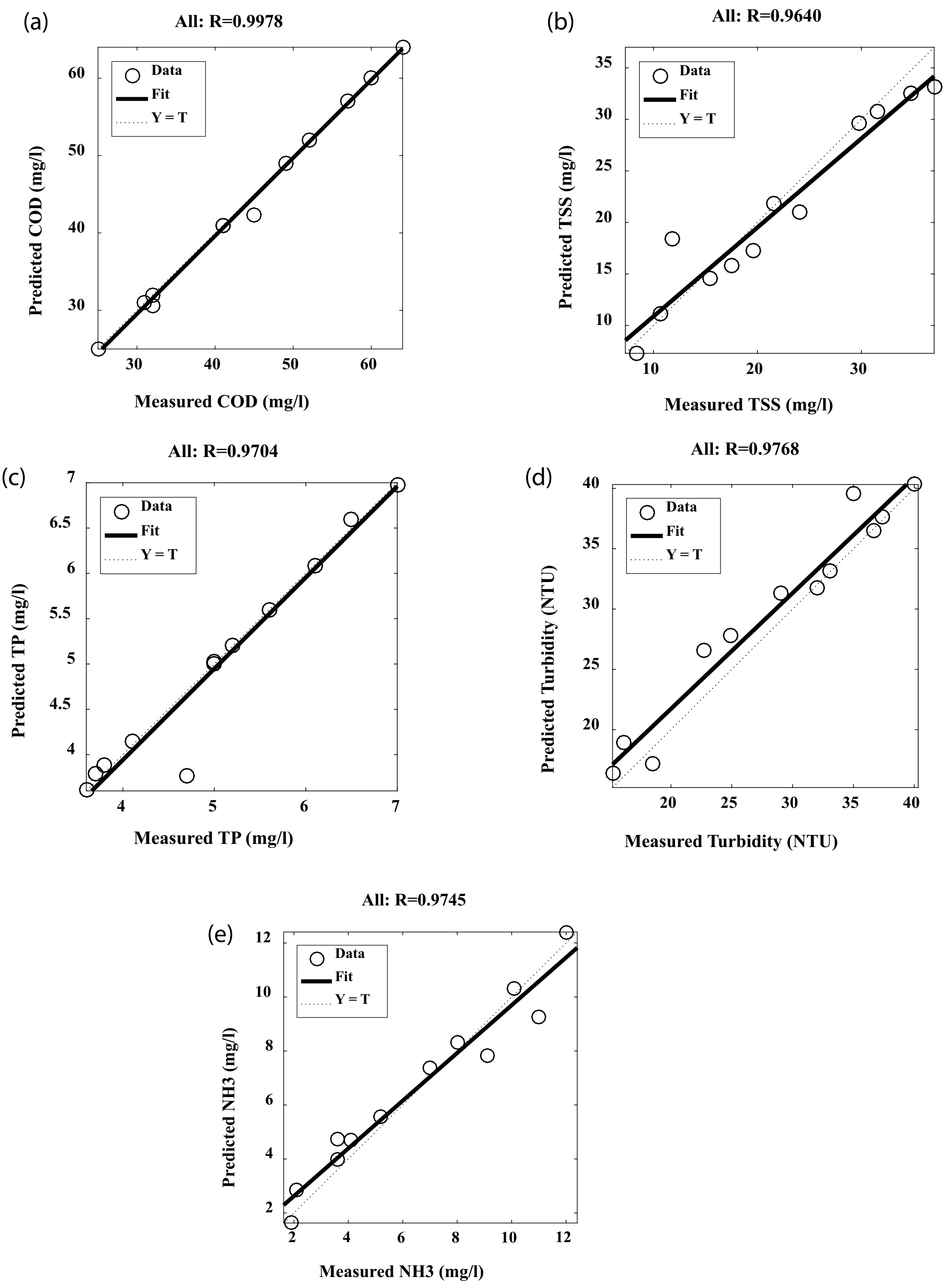


Fig. 5. Regression plots for the MLPNN models predicting (a) effluent COD, (b) effluent TSS, (c) effluent TP, (d) effluent turbidity, and (e) effluent NH_3.

Table 4
R and MSE values for measured parameters

Parameters	*R*	MSE
COD	0.9978	0.791
TSS	0.9640	7.023
TP	0.9704	0.007
Turbidity	0.9768	5.121
NH_3	0.9745	0.639

and suspended growth in the aeration basin of the activated sludge system in this study. With a hydraulic retention time of 10.5 h, the removal efficiency of COD, TSS, TP, turbidity, and NH_3 was 94%, 95%, 74%, 94%, and 86%, respectively. According to the findings, the integrated system obtained a successful result in municipal wastewater treatment. Additionally, an MLPNN model was used for the prediction of wastewater characteristics. The results verified that the MLPNN model is a practical tool to predict characteristics of the effluent wastewater.

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Supplementary information

Table S1
Influent and effluent values of wastewaters characteristics used in the MLPNN model

Influent								
Parameter	COD (mg/L)	TP (mg/L)	NH_3 (mg/L)	pH	TDS (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	Turbidity (NTU)
1	335	15.4	31	7.4	287	141	220	255
2	420	13.2	32	8	329	195	297.2	356.6
3	743	17	60	7	384	340	387	464.4
4	435	16.4	26.4	7.7	296	202	310	370
5	1,240	24.4	67	6.9	550	559	479	574.8
6	902	22.7	44	7.2	400	404	487	484.4
7	375	14.6	40	7.8	309	161	257	305.7
8	1,364	25.7	84	7.3	596	617	566.7	674
9	450	16.8	29.7	7.6	394	214	345.9	416.7
10	390	15	19	7.9	274	167	280.3	336.4
11	1,410	26.8	77	7	615	631	634	754.8
12	850	21.8	52	7.1	420	394	450.1	540.1
Effluent								
1	25	3.6	1.9	8.1	214	11	8.4	15.2
2	31	5	5.2	7.9	247	14	15.4	24.9
3	52	5.2	8	7.2	290	24	21.6	32
4	41	4.7	3.6	7.9	223	19	11.8	16.1
5	45	6.1	11	6.5	411	21	24.1	35
6	57	5	9.1	7.5	301	26	34.8	40
7	32	3.8	3.6	7.7	233	13	10.7	18.5
8	60	6.5	12	7	449	28	29.8	33.1
9	49	4.1	2.1	7.7	294	22	17.5	29
10	32	3.7	4.1	7.8	206	15	19.6	22.7
11	64	7	10.1	6.6	440	31	37	37.4
12	41	5.6	7	7.3	308	18	31.5	36.7