Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 57(5) 500-508, 2015

MODELING OF BOD AND COD REMOVAL IN AN AERATION PROCESS TREATING REFINERY WASTEWATER BY ARTIFICIAL NEURAL NETWORK

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Received July 20, 2015, Accepted November 25, 2015

Abstract

In this study, modeling of BOD and COD removal in the aeration process was investigated. Mathematical models are limited to special system with high error. Artificial Neural Network (ANN) is a more powerful tool for modeling of difficult problems than mathematical modeling. Because the mathematical modeling is very complex or impractical in many cases. The ANN model was employed to develop prediction of BOD and COD of inlet and outlet of aeration process. The obtained results showed that the measured and predicted values were in good agreement with low error. Coefficient of correlation (R-square), mean square error (MSE) and absolute average deviation (AAD) as performance factors had acceptable values according to conditions. The ANN model is a general model for extrapolation and interpolation of BOD and COD removal in the continuous processes at various times.

***Keywords**: BOD; COD; aeration process; mathematical modeling; Artificial Neural Network.*

1. Introduction

Refinery wastewater treatment as one of the important processes is considered. Because refineries are high water consumers and large wastewater producers. Refinery wastewater has many hazardous materials which make environmental pollutions. These pollutions are very dangerous for human life and environment.

In areas of limited water resources, water economics may dictate the possible reuse of wastewater effluent. Therefore, wastewater treatment is vital work in the refineries. Various physicochemical and microbiological treatment methods have been used for the treatment of refinery wastewaters. For example, wastewater treatment process includes gravity oil separator, flotation and aeration process to reduce the concentration of suspended solids, BOD and COD [1-7]. These processes have effective role in the BOD and COD removal. Because necessary oxygen value for wastewater treatment to safe materials was provided. Of course, good quality water was required in order to various consumptions. The organic and mineral materials percent are according to environmental standards and regulations. For instance, table 1 shows acceptable ranges for discharge into rivers and agriculture consumptions [8].

Table 1 The data of wastewater materials according to environmental standards and regu-ations (Archive of Kermanshah refinery, 2009)

	pH	OiL mg/L	PO_4 mg/L	NH_3 mg/L	H_2S mg/L	CL_2 mg/L	DO mg/L	COD mg/L	BOD mg/L	Turb mg/L	T.S.S NTU
Acceptable range (Discharge into rivers)	6.5-8.5	10 max	6 max	2.5 max	3 max	1 max	2 min	100 max	50 max	50 max	40 max
Acceptable range (Agriculture consumptions)	6-8.5	10 max	-	-	3 max	0.2 max	2 min	200 max	100 max	50 max	100 max

Wastewater treatment methods must be confirmed by environmental standards in the different cases.

The flotation method for removing suspended solids has been used with considerable success in the mining industry, treatment of surface raw water, thickening of waste activeted sludge and pretreatment of industrial wastewater [9-22]. Flotation is a very effective method of liquid solid separation and has distinct advantage for the removal of low density particles which have a tendency to float. There are different types of flotation processes but dissolved air flotation (DAF) is the most applicable [22]. The DAF technology has been reviewed in the literature [21-22]. In the DAF process suspended solids are removed. Then wastewater flows to the aeration tank. In this stage, biological and chemical pollutions are decreased. Aeration process provides oxygen for biological and chemical reactions to safe materials. At last, BOD and COD are reduced. Final stage of treatment is done by separators and remained solids are removed [23].

Modeling of BOD and COD removal is very important for data prediction of aeration process in the industry at different times. In this study, Artificial Neural Network (ANN) as powerful tool was employed. Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements [24]. Commonly neural networks are adjusted or trained, so that a particular input leads to a specific target output. Such a situation is shown below (Fig. 1). There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target pairs are used, in this supervised learning, to train a network [24].

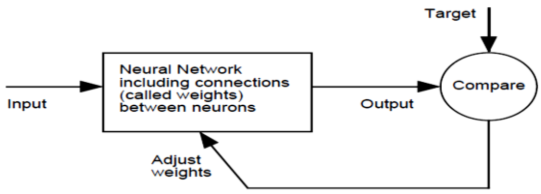


Fig.1. A general schematic of ANN model

Batch training of a network proceeds by making weight and bias changes based on an entire set of input vectors. Incremental training changes the weights and biases of a network as needed after presentation of each individual input vector. Incremental training is sometimes referred to as "on line "or "adaptive "training. Neural networks have been trained to perform complex functions in various fields of application including pattern recognition, identification, classification, speech, vision, control and system model. Today neural networks can be trained to solve problems that are difficult for conventional computers or human beings. The ANN model including a variety of kinds of design and learning techniques which enrich the user choices [25]. In summary, the ANN model structure including, input layer, hidden layer and output layer which are presented in Fig.2.

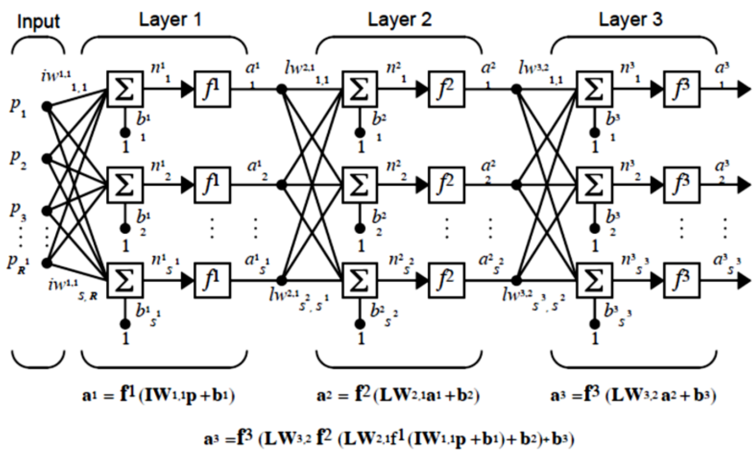


Fig.2. Schematic of artificial neural network (ANN) with 3 layers [24]

The aims of this work are production and development of the model with low error in order to predict BOD and COD in the inlet of aeration process and their removed values in the outlet of aeration process at different times. At last, R-square, MSE and AAD as performance factors had acceptable values according to conditions. The Outlet of aeration process analyses confirmed standard values because these values were below the maximum acceptable limits for disposal.

2. Materials and methods

2.1 Definition of process

In this study, wastewater treatment of Kermanshah refinery was done by flotation, aeration and separation. The aeration process as an effective stage of decreasing BOD and COD was considered. Therefore, modeling of this process play important role in the wastewater treatment of refinery. The schematic view of the processes is shown below.

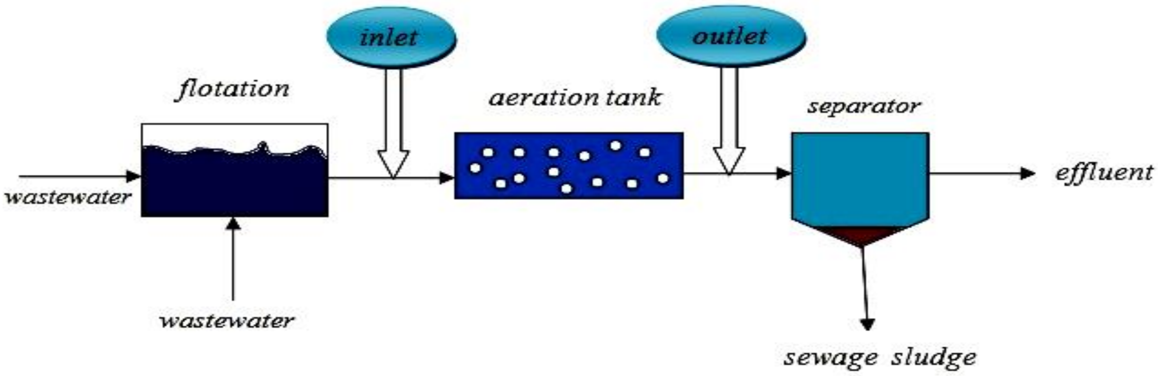


Fig. 3. The processes of wastewater treatment of refinery

A feed-forward neural network was designed using back-propagation training algorithm. The number of neurons in input and output layers depends on the independent and depended variables, respectively. Two output variables (BOD and COD) and eight input variables (pH, Oil, PO_4, NH_3, H_2S, Turbidity, T.S.S and DO) as the most effective input variables were analyzed in the refinery laboratory. Modeling of inlet and outlet of aeration process is presented in next parts.

2.2. Inlet of aeration process

The effective variables of inlet of aeration process of ten samples were measured at different times (for one month). The most important inlet data which were related to BOD and COD were pH, Oil, PO_4, NH_3, H_2S, Turbidity and T.S.S. DO was nil in the inlet of process while was significant in the outlet of process because of aeration process.

Generally, using trial and error procedure coupling with aforementioned statistical parameters leads to considering log-sigmoid and linear (pure) (Eqs. 1, 2) as the best transfer functions for the hidden and output layers, respectively.

$$F(x) = \frac{1}{1+\exp(-x)} \quad (1)$$

$$F(x) = x \quad (2)$$

The important point should be mentioned is that, the good ability of the proposed network to accuracy correlate the BOD and COD rises from the nonlinearity, continuity and differentiability nature of above functions. At last, the optimum network architecture must be consisted of three layers (input, hidden and output) which 25 neurons are needed in the hidden layer. Modeling of all cases was done by MATLAB R2008b software. Artificial neural network model with Levenberg-Marquardt algorithm was an appropriate model for this work. Experimental data were randomly divided to three parts, 70% for training, 15% for validation and 15% for testing the network. Therefore, the optimum architecture network with low error is as follows:

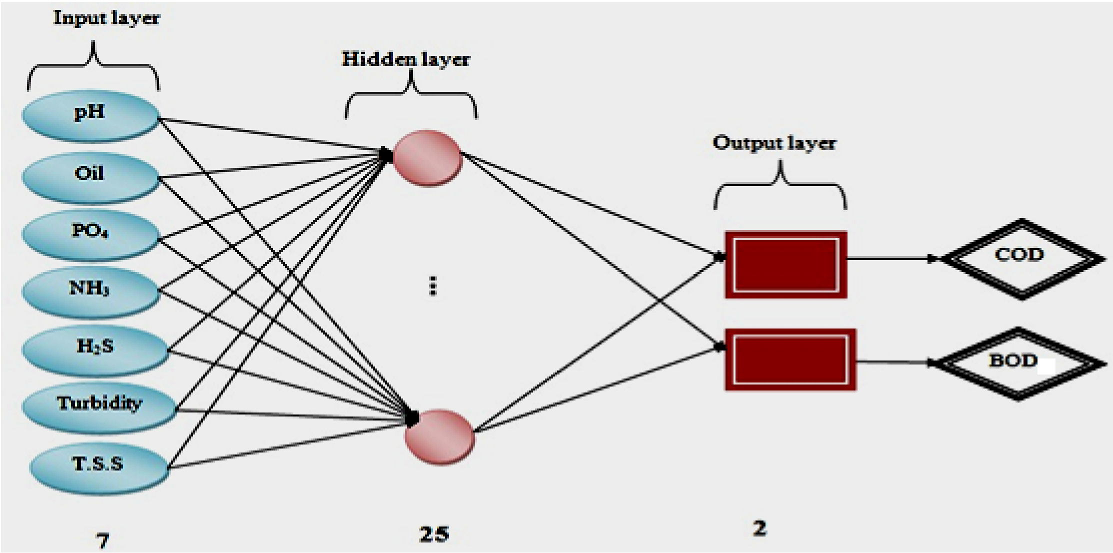


Fig.4 The optimum network architecture of inlet of aeration process (Network structure: structure: 8-27-2).

2.3 Outlet of aeration process

The most important outlet data which were related to BOD and COD were pH, Oil, PO_4, NH_3, H_2S, Turbidity, T.S.S and DO. Transfer functions, software and model (ANN) were according to inlet of aeration process while network structure of 8-27-2 for the optimum architecture network was used. (See Fig.5)

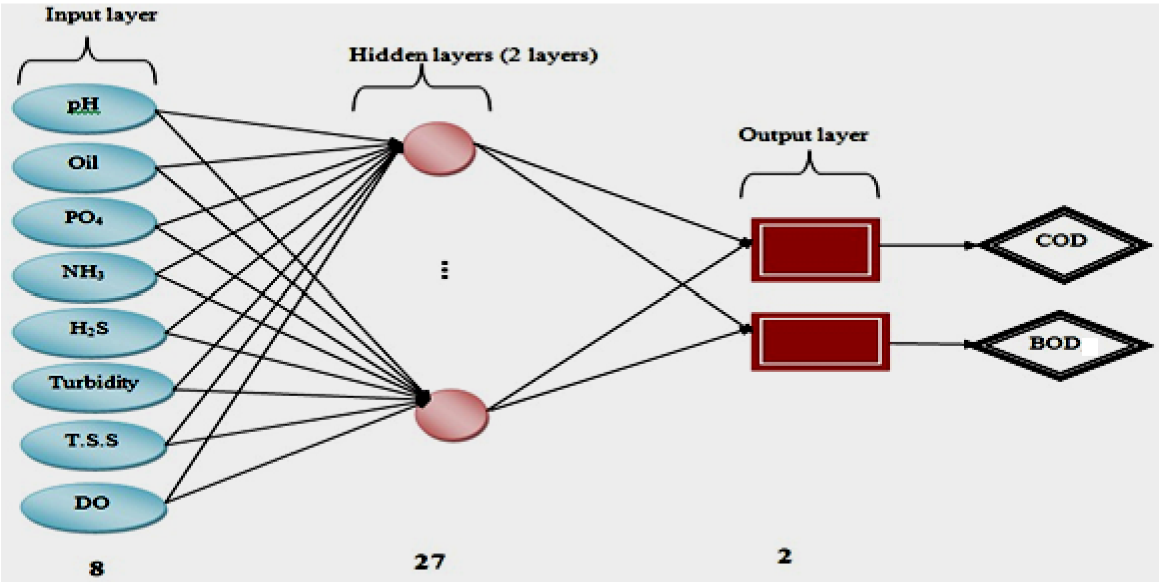


Fig.5 The optimum network architecture of outlet of aeration process (Network structure: 8-27-2)

3. Results and discussion

3.1 Inlet of aeration process

ANN model was used to correlate the BOD and COD of refinery wastewater treatment in the inlet and outlet of aeration process. In this section, inlet of aeration process results is investigated. The optimum architecture network of ANN model was employed for modeling and correlating of BOD and COD. Various arrangements of model structure were tested to achieve in the best model structure. Results of training, validation, testing and all of network are presented in Figs. 6(a-d).

The performance of the constructed ANN in the all of cases was statistically measured by the mean squared error (MSE), coefficient of correlation (R-square), and absolute average deviation (AAD) according to following equations.

$$R-square=\frac{\sum_i^n(y_{exp,i}-y_{model,mean})^2-\sum_i^n(y_{exp,i}-y_{model,i})^2}{\sum_i^n(y_{model,mean}-y_{exp,i})^2} \quad (3)$$

$$MSE=\frac{\sum_i^n(y_{exp,i}-y_{model,i})^2}{n} \quad (4)$$

$$AAD=\frac{1}{n}\sum_i^n\left(\frac{y_{exp,i}-y_{model,i}}{y_{exp,i}}\right)^2 \quad (5)$$

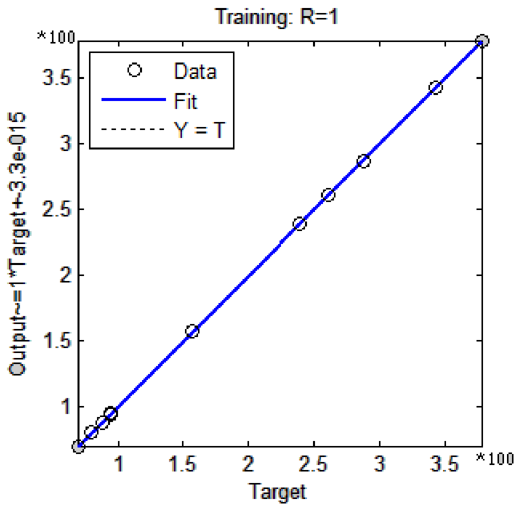
The best results are as follows:

$$\text{R-square}\rightarrow 1 \quad (6)$$

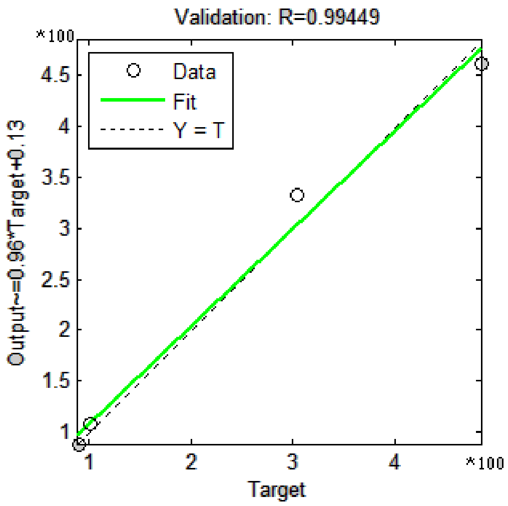
$$\text{MSE}\rightarrow 0 \quad (7)$$

$$\text{AAD}\rightarrow 0 \quad (8)$$

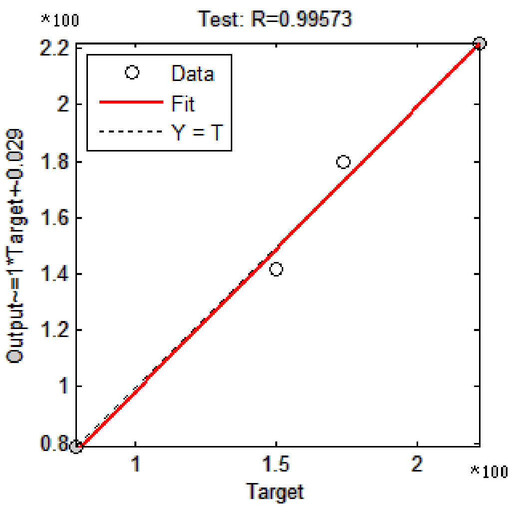
Fig.6 (a), indicates a good correlation for network training with R-square of 1 which is excellent. Part (b) is almost excellent with R-square of 0.99449 for network validation. Part (c) presents a good correlation with R-square of 0.99573 for network test and part (d) shows a good model for all of network with R-square of 0.99761.



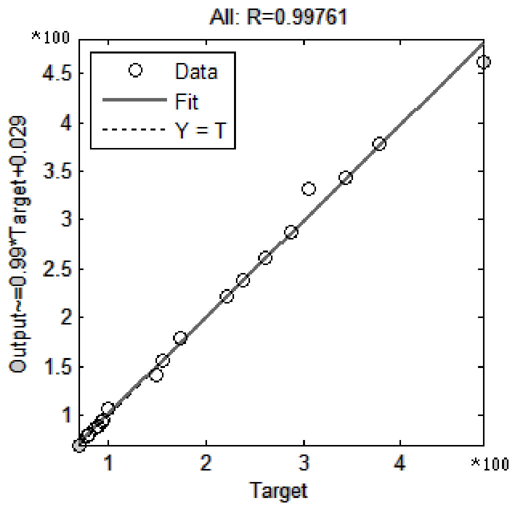
(a)



(b)



(c)



(d)

Fig.6. comparison of output and target results of ANN model in the inlet of aeration process; (a): Training, (b): Validation, (c): Test and (d): All of network

In summary, figures show that modeling of data based on ANN model is in good agreement with R-square condition. Results of 10 samples are shown in table 2. It can be seen that the measured and predicted data have a considerably good correlation, means accurate prediction. In addition, MSE and AAD have acceptable values in the model. The calculated MSE for BOD and COD of inlet of aeration process is 0.00958 and 0.00194, respectively. Also, the AAD of BOD and COD is 9.66E-06 and 0.0064. Therefore, the ANN model was capable to correlate the BOD and COD of refinery wastewater with a greet accuracy. Hence, in some cases the extrapolative and interpolative capability of the proposed network was considerable.

In general, it can be claimed that ANN model can be a promising method to accuracy correlate the BOD and COD of refinery wastewater in the aeration process.

Table 2 Statistical results of COD and BOD in the inlet of aeration process

	COD(mg/L)					BOD(mg/L)				
Run	Target	Output (modeL)	Error	MSE	AAD	Target	Output (modeL)	Error	MSE	AAD
1	241	240.92	0.08	0.00194	0.0064	97.7	97.777	-0.077	0.00958	9.66E-06
2	293	292.95	0.05			81	81.124	-0.124		
3	231	230.94	0.06			77	76.96	0.04		
4	288	288.0102	-0.0102			89.9	90.01	-0.11		
5	268	268.041	-0.041			133.3	133.124	0.176		
6	286	286.0124	-0.0124			71.5	71.555	-0.055		
7	327	327.0267	-0.0267			96.6	96.5634	0.0366		
8	205	205.01	-0.01			149.9	150.0123	-0.1123		
9	196	196.049	-0.049			95.5	95.5576	-0.0576		
10	341	341.0412	-0.0412			78.8	78.8976	-0.0976		

3.2 Outlet of aeration process

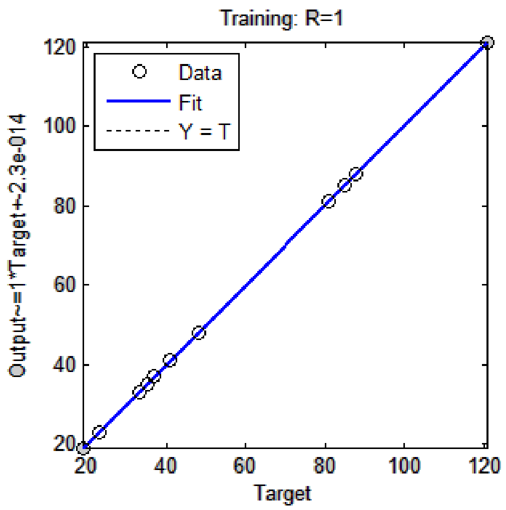
Outlet of aeration process according to inlet of aeration process was studied by the ANN model of MATLAB R2008b software. A good structure network with low error for modeling of BOD and COD was used. Results of training, validation, testing and all of network are introduced in the Figs. 7(a-d). These figures show that modeling of data based on ANN model is appropriate with R-square condition. R-square of training, validation, test and all is 1, 0.9986, 1, and 0.99932, respectively.

Performance of 10 samples is given in table 3. It shows that the measured and predicted data have a low error and suitable agreement. Also, MSE and AAD of BOD and COD of outlet of aeration process are introduced. The calculated MSE for BOD and COD of outlet of aeration process is 0.03883 and 0.06465, respectively. Also, the AAD of BOD and COD is 5.60E-05 and 4.90E-05. The results of Output of aeration process are acceptable for refinery wastewater treatment. The ANN model of output process similar to inlet of process is general and powerful.

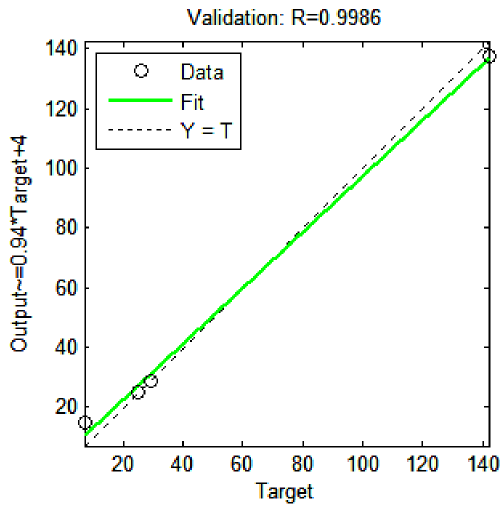
Table 3 Statistical results of BOD and COD in the outlet of aeration process

	COD(mg/l)					BOD(mg/l)				
Run	Target	Output (model)	Error	MSE	AAD	Target	Output (model)	Error	MSE	AAD
1	81	81.123	-0.123	0.06465	4.90E-05	41	41.233	-0.233	0.03883	5.60E-05
2	85	85.1345	-0.1345			35	35.1145	-0.1145		
3	48	48.0445	-0.0445			33	33.1165	-0.1165		
4	121	121.2771	-0.2771			37	37.2227	-0.2227		
5	7	7.143	-0.143			25	25.3382	-0.3382		
6	207	207.0232	-0.0232			21	20.92	0.08		
7	89	89.399	-0.399			18	17.8634	0.1366		
8	142	142.154	-0.154			29	29.19442	-0.1944		
9	88	88.376	-0.376			19	19.1321	-0.1321		
10	85	85.435	-0.435			23	23.2513	-0.2513		

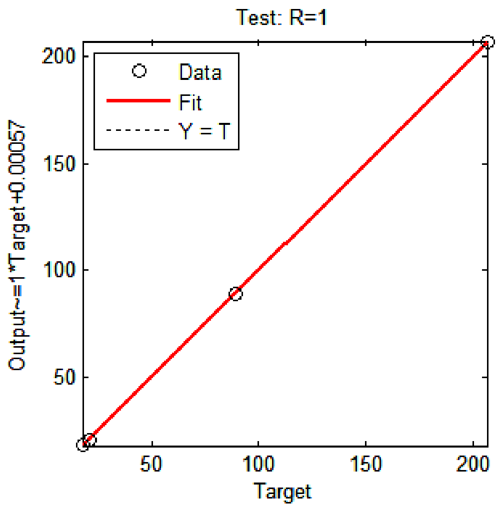
Obviously, comparison of inlet and outlet of aeration process shows that the aeration process has an effective role in the BOD and COD removal. Therefore, it makes to standard values for various consumptions and recovery.



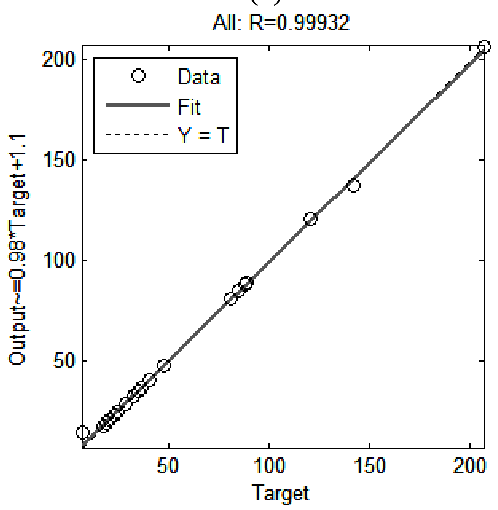
(a)



(b)



(c)



(d)

Fig.7. comparison of output and target results of ANN model in the outlet of aeration process; (a): Training, (b): Validation, (c): Test and (d): All of network

4. Conclusions

The ANN model is a powerful tool for modeling of complex problems. It is fast, easy structure and practical compared with mathematical modeling. The optimum network for inlet of aeration process was 7-25-2. The R-square of training, validation, test and all of network was 1, 0.99449, 0.99573 and 0.99761 respectively. The calculated MSE for BOD and COD of inlet of aeration process of 0.00958 and 0.00194 was respectively obtained. Also, the AAD of BOD and COD was 9.66E-06 and 0.0064. The optimum network of 8-27-2 for outlet of aeration process was employed. The R-square of training, validation, test and all of network was 1, 0.9986, 1 and 0.99932 respectively. The calculated MSE for BOD and COD of outlet of aeration process of 0.03883 and 0.06465 was respectively obtained. Also, the AAD of BOD and COD was 5.60E-05 and 4.90E-05. The results show a good agreement between the measured and predicted data. The ANN model is a general model for interpolation and extrapolation of BOD and COD removal in the refinery wastewater treatment.

Performance factors including; R-square, MSE and AAD have acceptable values according to conditions. The Outlet of aeration process confirmed the standard values because these values were below the maximum acceptable limits for disposal. Finally, the flotation and aeration processes play important roles in the BOD and COD removal of refinery wastewater.

Nomenclatures

AAD	*Absolute average deviation*	*R*	*number of elements in input vector*
ANN	*Artificial neural network*	*R-square*	*Coefficient of correlation*
b	*bias*	*S*	*number of neurons in layer*
BOD	*Biological oxygen demand (mg/L)*	*T.S.S*	*Total suspended solids (NTU)*
COD	*Chemical oxygen demand (mg/L)*	*Turb*	*Turbidity (mg/L)*
DAF	*Dissolved air flotation*	*W*	*weight matrix*
DO	*Dissolved oxygen (mg/L)*	$y_{exp,i}$	*experimental value of i*
MSE	*Mean square error*	$y_{model,mean}$	*mean of model values*
n	*number of samples*	$y_{model,i}$	*model value of i*

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