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An Attempt to Find Suitable Parameters for Coagulation-Flocculation Processes for the Treatment of Water

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Abstract

Water turbidity is considered as an important physical parameter of water quality. It is a good indicator for assessing the required treatment for the drinking water. In the present study, a standard jar tests were conducted to obtain the most suitable parameters for the design of coagulation-flocculation process. Results proved that the best rapid mixing time (t_1), slow mixing time (t_2), and settling time (t_3) are 1, 50 and 60 min respectively. The maximum removal efficiencies of turbidity were 99.31, 98.56 and 94.72% at t_1, t_2 and t_3 equal to 5, 50 and 60 min respectively, with pH values ranged from 3.7 to 8.9. The measured values of water turbidity removal perecentage were represented using an artificial neural network (ANN) technique and the results signified that there is a remarkable agreement between experimental and predicted values with coefficient of determination (R^2) and root mean squared error (RMSE) equal to 0.932 and 0.5501 respectively.

Keywords: Coagulation, Fluctuation, Water, Treatment,Turbidity.

1-Introduction:

Due to importance of the subject of water turbidity in the treatment of drinking water, Many researchers studied this subject during the last time which associated with the most suitable design parameters of coagulation – flocculation processes. The previous researchers used the parameter of turbidity in evaluating the treatment efficiency of the drinking water. [1] stated that the most significant inorganic coagulants are aluminum and iron salts. These are the most typically simple salts (such as aluminum salts sulfate or ferric chloride). [2] indicated that the heart of the treatment process for the water treatment plant will be turbidity removal. He used extensive bench-scale studies (jar test) to optimize the design of the turbidity removal process. Also, he studied the process design criteria that include the choice of coagulant, optimum dose and pH, the best coagulation aid and its point of addition, rapid-mix time and energy total flocculation time, optimum energy, and compartmentation, and the design overflow of the setting basin. [3] studied the effective of sequence of alum and weighting agents. Three cases, namely, alum before, with, and after weighting agents were investigated. Al-Marshidi stated that the best sequence is to add alum after the addition of bentonite or porcelains weighting agents. [4] claimed that the coagulation process is a safe and effective method of treating water which improves its quality by reducing levels of organic compounds, dissolved phosphorus, color, and suspended particles.

[5] studied the process of coagulation with alum, which was conducted by standard jar test to optimize coagulation pH and alum dose in removal of turbidity and soluble dissolved organic matter. The natural organic matter removal by alum dose and pH control during coagulation-flocculation process was optimized. Optimum removal of turbidity (98%) and broken up natural carbon (DOC) (70%) which was accomplished for 100 mg/L alum portion at pH 5. Alum portion and pH control of coagulation were observed to be vital components administering broken up natural issue (DOM) evacuation. It was likewise demonstrated that humic substances are preferably more evacuated by alum over the other (DOC) mixes.

[6] obtained that the neutral pH, moderate coagulant dose and a higher load in suspensions of raw water presented the optimum parameters for coagulation–flocculation processes. [7] concluded that the optimal parameters through the traditional method of jar tests were 12 mg/l optimum dose of alum, and the optimum pH value was 7.6., while the final turbidity was within 0-5 NTU.

[8] investigated automatic control of optimal alum dosage in water treatment plant by intelligent controller. During the rainy season and floods it is too difficult to obtain a good quality drinking water because the high turbidity of raw water. The intelligent controller consisted of dosage predictor, inverse model for optimal dosage prediction, and pulse width modulation controller (PWM).

[9] studied the optimal parameters of coagulation- flocculation of water and they are found that the optimal coagulation conditions were as follows: pH=8, alum dosage= 3 mg/L as Al+3 ,G value=172 s-1, and rapid mixing time was 20 s.

The more recent study had been conducted by [10] , and this study was used jar test to get optimal parameters of coagulation- flocculation processes for the water treatment of Shatt – Al- Hilla. The results revealed that the optimal times of rapid mixing, slow mixing time, and settling times were 60 s, 17 min, and 45 min respectively. These results were based on alum dosage in range of (90 – 150) mg/L and the pH value was of 8.

It is worthy to note that the turbidity is considered as a good indicator of the water quality and it is strongly affected by the design parameters of the coagulation- flocculation processes. Therefore, the justifications of the present study are to find the appropriate times of these processes in addition to find the suitable dosage of alum in order to avoid using of large amount of chemicals and this will certainly reduce the cost of the water treatment.

The main aim of the present study is to find the optimum of rapid mixing time, slow mixing time, and settling time that give maximum turbidity removal effeciency, with suitable alum dosage and pH for water that required to be treated.

2-Theoretical Background

In water treatment plants, chemical coagulation is usually accomplished by the addition of trivalent metallic salts such as Al2(SO4)3 (aluminum sulfate) or FeCl3 (ferric chloride). Although the exact method by which coagulation is accomplished cannot be determined. Four mechanisms are thought to occur and they can be included ionic layer compression, adsorption and charge neutralization, entrapment in a flocculent mass, and adsorption and interparticle bridging .[11]

The most important electrical property of the colloidal and suspended particles is their surface charge. This charge makes the particles stay in suspension without conglomerating for extensive stretches of time. Surface water molecule suspensions are thermodynamically temperamental and, given enough time, they will flocculate and settle. In any case, the conglomeration procedure is moderate, and the particles can't be expelled by sedimentation in a sensible measure of time, that is, a short enough time that would permit generation of an adequate measure of water for a network of in excess of a couple of individuals.

A colloidal dispersion in solution does not have a net charge. This is on the grounds that the contrarily charged particles collect positive counter particles on and close to the molecule surface. The adsorbed layer of cations (known as the Helmholtz layer or the Stern layer) is bound to the molecule surface by electrostatic and adsorption powers. It is about 0.5 nanometers (nm) thick. A free diffuse layer shapes past the Helmholtz layer. The twofold layer (Helmholtz in addition to diffuse) has a net negative charge over the mass arrangement, Figure 1 is demonstrated the qualities of the particles.

When a charged particle placed in an electric field, it will move to the shaft of inverse charge. This development is called electrophoresis. As the molecule moves, a segment of the water close to the surface moves with it. This development uproots the particle cloud and gives it the shape, the electric potential between the shear plane and the mass arrangement is known as the zeta potential as appeared in Figure (2). [12]

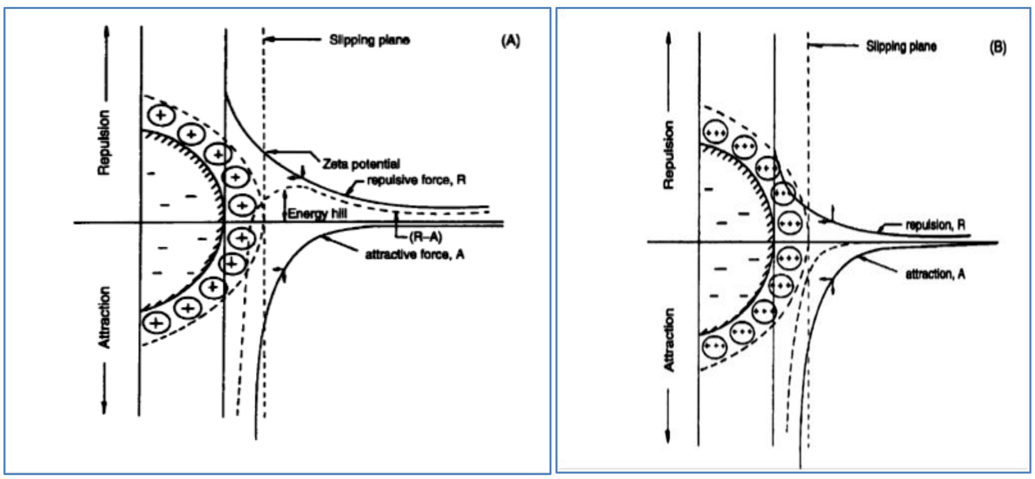

Figure 1: (A) Particle carries net negative charge and van der Waals positive charge; energy barrier prevents coagulation. (B) Addition of trivalent cations reduces energy barrier, and coagulation is possible. [13]

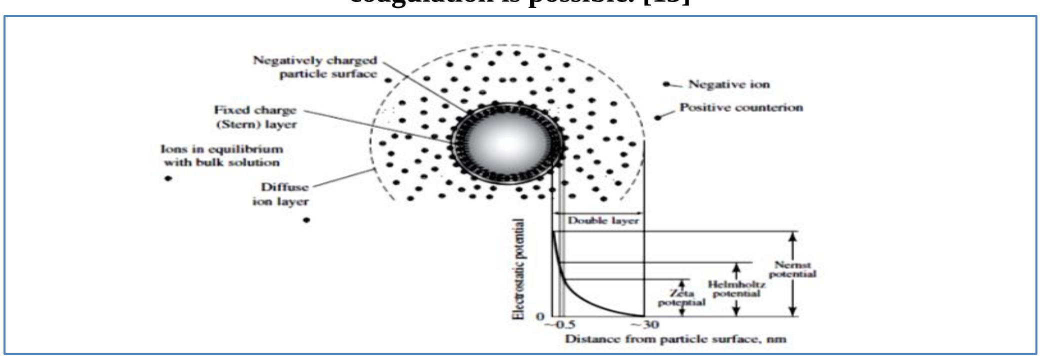

Figure 2: Electrical double layer (zeta potential) [13]

The overreaction of coagulant in water is described by the following equation [14]: -

$$Al_2(SO_4)_3\,.\,18H_2O + 3Ca(HCO_3)_2 \leftrightarrow 2Al(OH)_3 + 3CaSO_4 + 18H_2O + 6CO_3 \ldots\ldots\ldots\ldots(1)$$

Control of pH and alkalinity is an essential aspect of coagulation. The optimum pH for coagulation varies but is generally within the following ranges for turbidity removal:

• Alum: pH 5.5 to 7.5; typical pH 7.0

• Ferric salts: pH 5.0 to 8.5; typical pH 7.5ay be adjusted at one or more points in the treatment, including rapid mixing, pre-filtration, and post-filtration .[15]

3-Experimental Work

The experimental work was achieved to collect the data for evaluating the water turbidity, which has been strongly influenced by the parameters of the processes of coagulation – flocculation-sedimentation that have a direct effect on the overall treatment processes. The goal of the experimental investigations was finding the more suitable parameters of coagulation, flocculation, and sedimentation processes of the drinking water. The adopted variables are included the following points: the initial turbidity of a synthetic turbid water samples, detention times of the coagulation, flocculation , and settling processes, the initial pH of the samples of the synthetic turbid water, and the dosage of the coagulant material which was the alum coagulant. It is necessary to mention that jar test simulates the coagulation-flocculation processes in water treatment plant. The jar test helps operators in measuring the optimal dosage of alum used and thus can be improve the efficiency of the plant in addition to reduce the cost of the treatment, and accordingly, the jar test was adopted in the present study for simulating these processes. The first step of the experimental work was conducted by adjusting the values of the pH of the synthetic turbid water using HCl or NaOH as required. Then, the next step was to fill the jars by water with different dosages of alum which have values of (10, 30, 60, 90, 150, 200, 250) mg/L. All experiments were performed using synthetic turbid water with a constant value of initial turbidity around of 400 NTU .It is well known that one of the jars is usually left as blank or as (control) jar .The beakers stirred rapidly for (1-5 min) with rotating speed of (100 rpm), then were mixed slowly for (20-50 min) with speed of (25 rpm). After that, the produced flocs allowed to settle with different times up to (60 min) as shown in Table (1). It is worthy to note that the selection of the above values of times is adopted based on the recommended times which have presented by [16]. After the end of settling process, then it was possible to determine the optimum dosage of coagulant added and the remaining turbidity. Jar tests were carried out eighteen times for (4 sets) for different values of pH of (3.7-8.9) for synthetic turbid water.

Table (1): Summary of experimental work conducted in the present study.

Set No.	Jar Test Parameters, pH (3.7-8.9)			Purpose
	$T_{coag.}$ (min.)	$T_{flocc.}$ (min.)	$T_{sette.}$ (min.)	
First Set (A)	1	20	30	To select the optimal rapid mixing time with pH < 7
	2	20	30	
	3	20	30	
	4	20	30	
	5	20	30	
First Set (B)	1	20	30	To select the optimal rapid mixing time with pH >7
	2	20	30	
	3	20	30	
	4	20	30	
	5	20	30	
Second Set	1	20	30	To select the optimal slow mixing time

	1	30	30	
	1	40	30	
	1	50	30	
Third Set	1	20	30	To select the optimal settling time
	1	20	40	
	1	20	50	
	1	20	60	

The experimental work has been conducted at the sanitary laboratory of department of Environmental Engineering Department / College of Engineering / University of Babylon.

4-Results and Discussion

First Set (A) in Table (1) displays the time adopted in (coagulation, flocculation and sedimentation) process in jar tests, with range of pH (3.7-5.9). Figure (3) shows the relationship between alum dosage and turbidity removal efficiency, with different values of t1 (1-5) min and constant of (t2= 20 min, and t3 =30 min). It can be noticed that increasing of dosage will increase the turbidity removal efficiency at specified time t1, also, maximum turbidity removal 99.31% achieved at maximum time t1=5 min with dosage concentration of alum 100 mg/L and vice versa.

The analysis of alum in water indicates the formation of positive ions Al (OH)+ 2 & Al (OH)+, These elements interact with Colloid molecules by equating electronic charges. It means, exchange between the decaying aluminum elements takes place in the water and negative ions, so that the colloidal molecules which have charges on the surface decrease or even completely equal. Aluminum decomposition in water, lead to aluminum hydroxide (OH)3 and it is sediment because a large surface area, it also attaches and restricts colloids, so it becomes practical separating the solid - the liquid is easier and this method of flocculation.

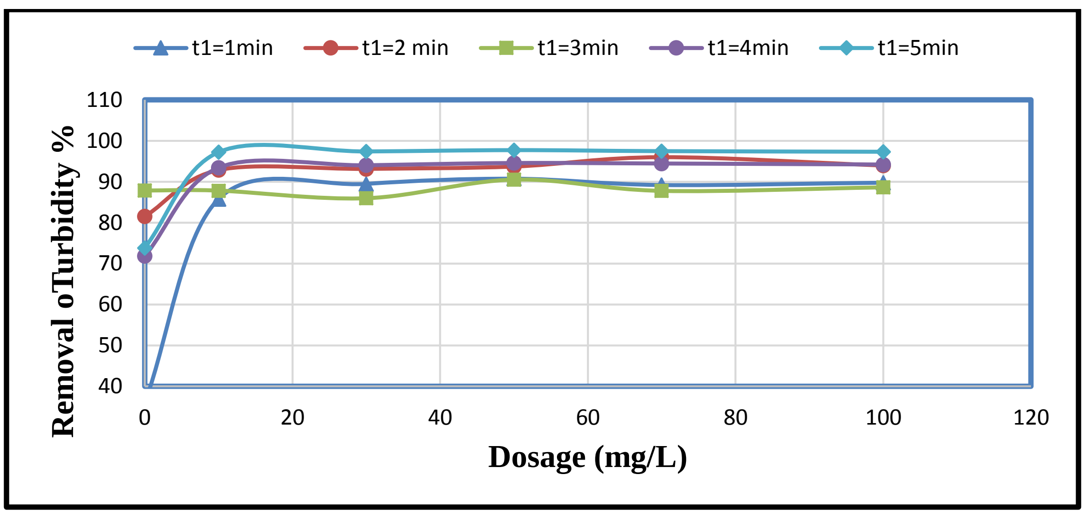

Figure (3): Effect of alum concentration of turbidity removal efficiency with variety of t_1 (set. A).

Figure (4) shows that turbidity removal efficiency was decrease with increasing of pH, at pH = 3.74, the maximum of turbidity removal efficiency was 99.81% at t1=5min but at t1=1min with the same pH, it was 89.75%.

It may be because according the following equations:

$$\mathbf{Al_2(SO_4)_3 . 18H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 18H_2O + 6CO_2} \dots\dots\dots\dots(\mathbf{2})$$

It can be noticed that the reaction came towards right at high values of pH and vice versa when it came in left side.

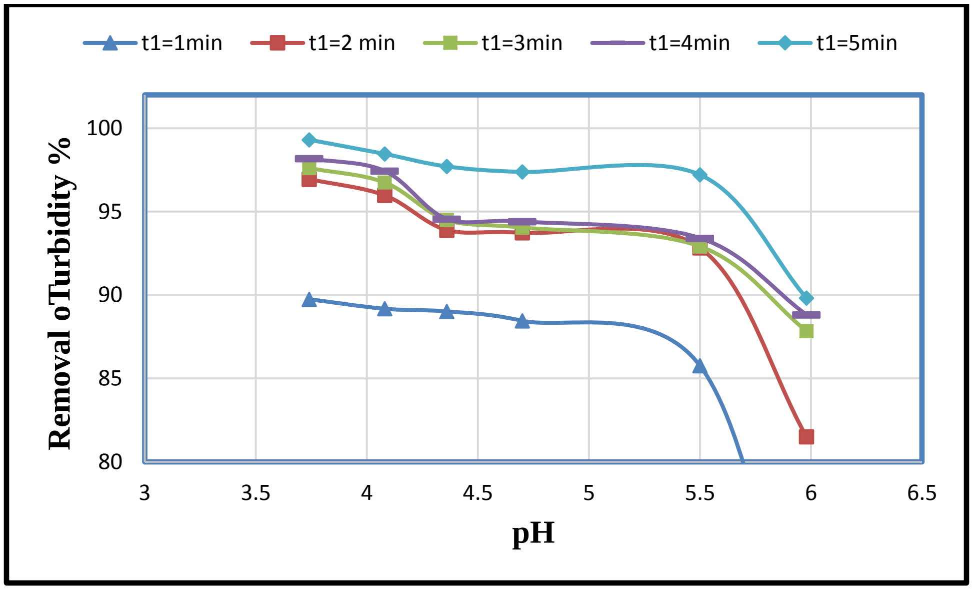

Figure (4): Effect of pH changes on turbidity removal efficiency with variety of t_1 (set A).

First Set (B) in Table (1) displays the time adopted in (coagulation, flocculation and sedimentation) process in jar tests, with range of pH (7.2-8.9). Figure (5) shows the relationship between alum dosage and turbidity removal efficiency, with different values of t1 (1-5) min and constant of (t2= 20 min, and t3 =30 min). It can be noticed that increasing of dosage will increase the turbidity removal efficiency at specified time t1, also, maximum turbidity removal 99.1% achieved at maximum time t1=5 min with dosage concentration of alum 100 mg/L and vice versa.

Figure (6) elucidated that turbidity removal efficiency was decrease with increasing of pH, at pH = 7.2, the maximum of turbidity removal efficiency was 99.9% at t1=5min but at t1=1min with the same pH, it was 99.12%.

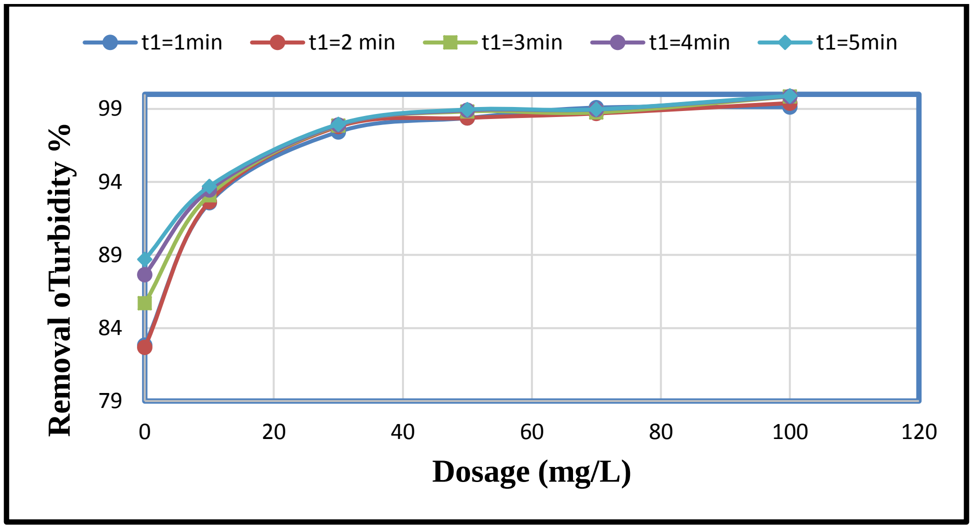

Figure (5): Effect of alum concentration of turbidity removal efficiency with variety of t_1 (set B).

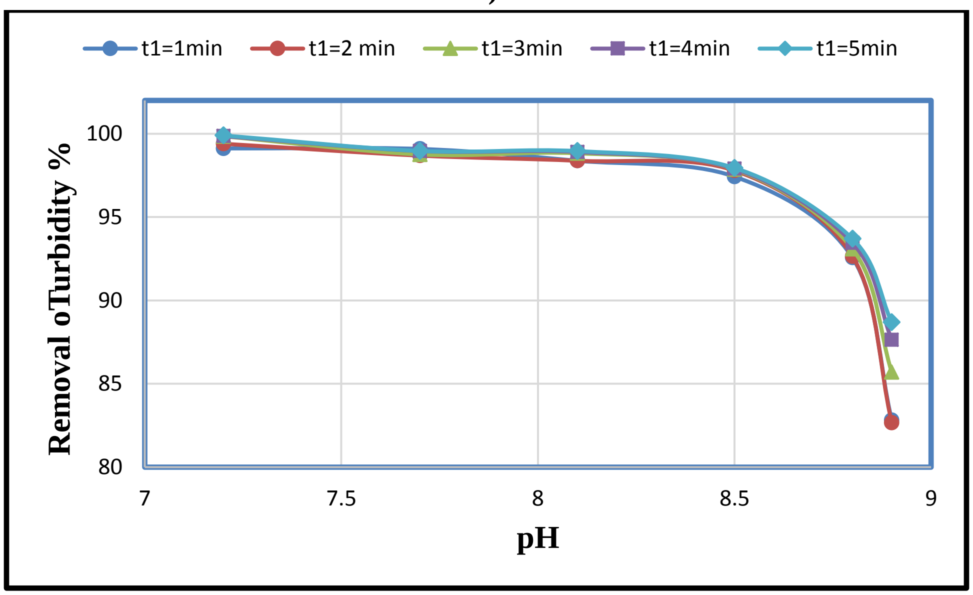

Figure (6): Effect of pH changes on turbidity removal efficiency with variety of t_1 (set B).

Second Set in Table (1-3) displays the time adopted in (coagulation, flocculation and sedimentation) process in jar tests, with range of pH (4.5-7.25). Figure (7) shows the relationship between alum dosage and turbidity removal efficiency, with different values of t2 (20-50) min and constant of (t1= 1 min, and t3 =30 min). It can be noticed that increasing of dosage will increase the turbidity removal efficiency at specified time t2, also, maximum turbidity removal 98.56% achieved at maximum time t2=50 min with dosage concentration of alum 100 mg/l and vies versa.

While Figure (8) explained turbidity removal efficiency was decrease with increasing of pH with variety of t2 , it achieve maximum removal at high value of t2 at a specific value of pH. At pH = 4.55, the maximum of turbidity removal efficiency was 98.56% with t2=50 min but at t2=20 min with the same pH, it was 89.75%.

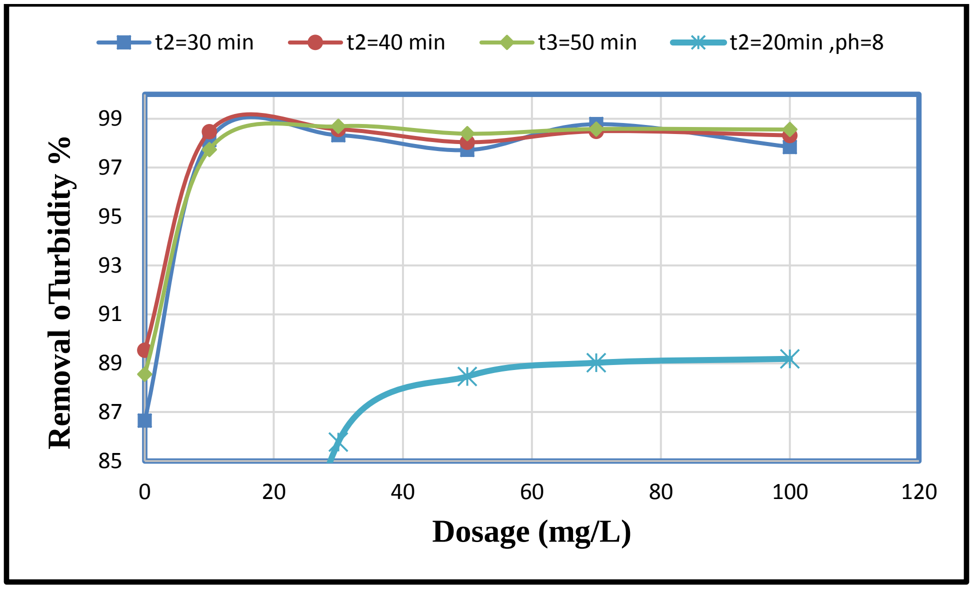

Figure (7): Effect of alum concentration of turbidity removal efficiency with variety of t_2.

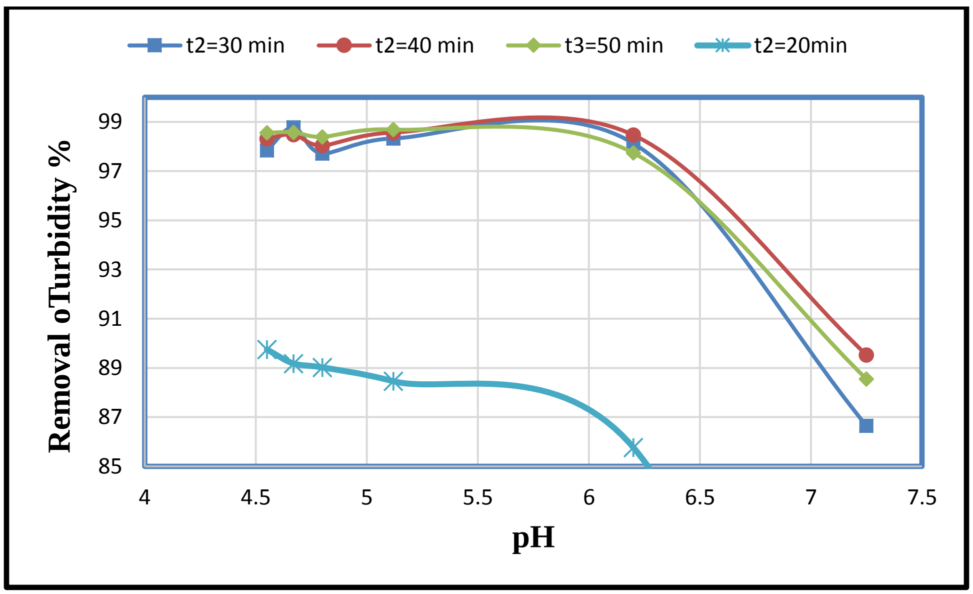

Figure (8): Effect of pH changes on turbidity removal efficiency with variety of t_2.

Third Set which is in Table (1) displays that the time adopted in coagulation, flocculation and sedimentation process in jar tests, with range of pH 4.25-7.0. Figure (9) shows the relationship between alum dosage and turbidity removal efficiency, with different values of t3 (30-60 min) and constant of t1 and t2 (t1= 1 min, and t2 =20 min). It can be noticed that increasing of dosage will increase the turbidity removal efficiency at specified time t3, also, maximum turbidity removal 94.72% achieved at maximum time t3=60 min with dosage concentration of alum 100 mg/L and vice versa.

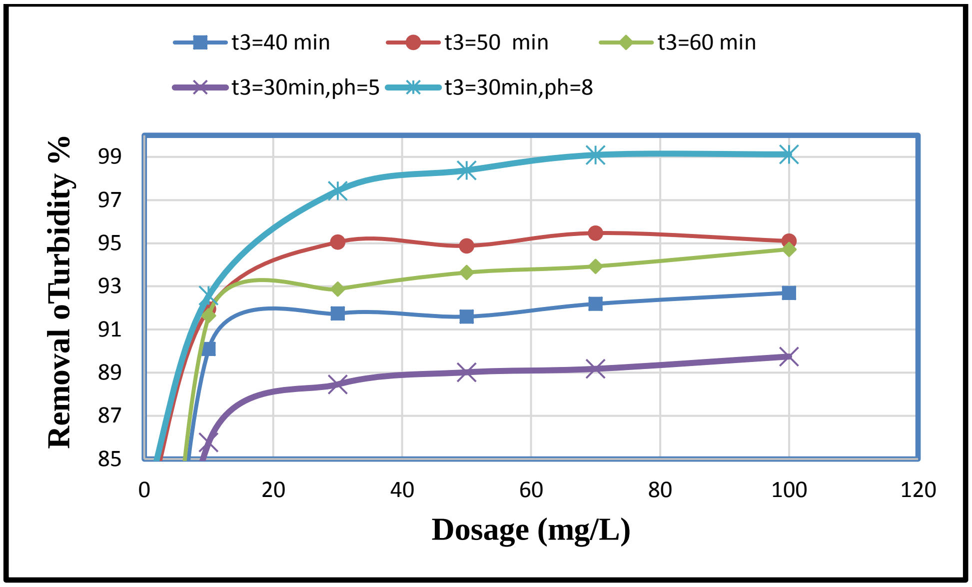

Figure (9): effect of alum concentration of Turbidity removal efficiency with variety of t_3.

Figure (10) certified that the turbidity removal efficiency was decrease with increasing of pH with variety of t3 and achieve maximum removal at high value of t3 at a specific value of pH. At pH = 4.25, the maximum of turbidity removal efficiency was 98.72% with t3=60 min but at t3=30 min with the same pH, it was 89.75%.

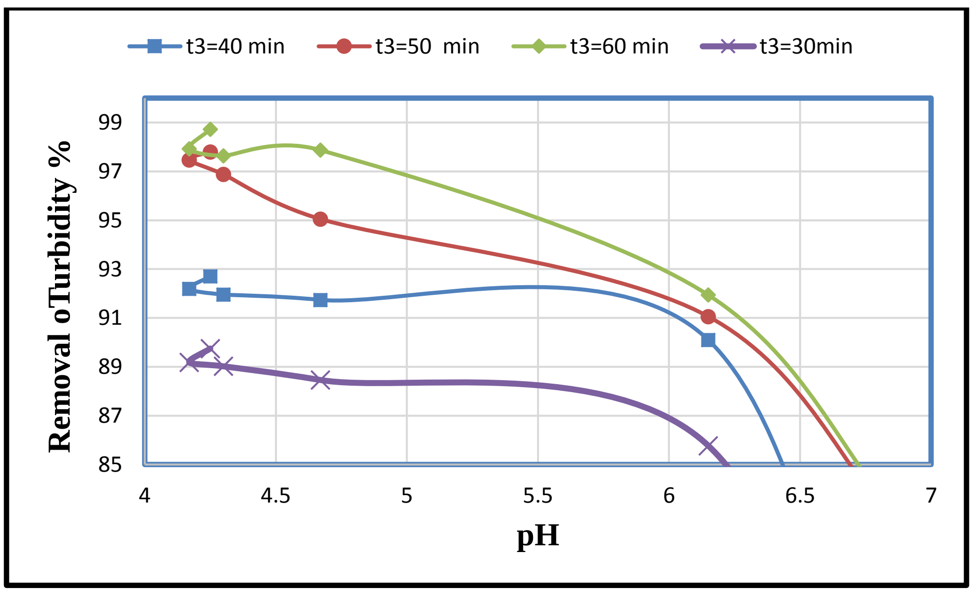

Figure (10): effect of pH changes on Turbidity removal efficiency with variety of t_3.

5. Artificial Neural Network Modeling

The artificial neural network model for estimating the turbidity removal efficiency was developed using the software "MATLAB 2014 version 9.3", which allows the modeling of the problem with different network architecture, and use back propagation algorithm for adjusting the weights of the model. The activation function of hidden layer used was hyperbolic tangent while activation function of output layer was identity. The pH, alum concentration dosage, rapid mixing time (t1), slow mixing time (t2) and settle time (t3) are adopted as input variables for present problem, while the removal efficiency of turbidity can be considered the target parameter.

This model architecture and normalized are important for input parameters, which indicate that alum concentration dosage, recorded 100% importance among all parameters but less importance was 48.8 %, recorded at rapid mixing time (t1), are shown in Figure (11) and Figure (12), respectively. 108 running have done to predict that model, depending on trial and error the training percent was 68.5%, testing 18.5% and validation 13%.

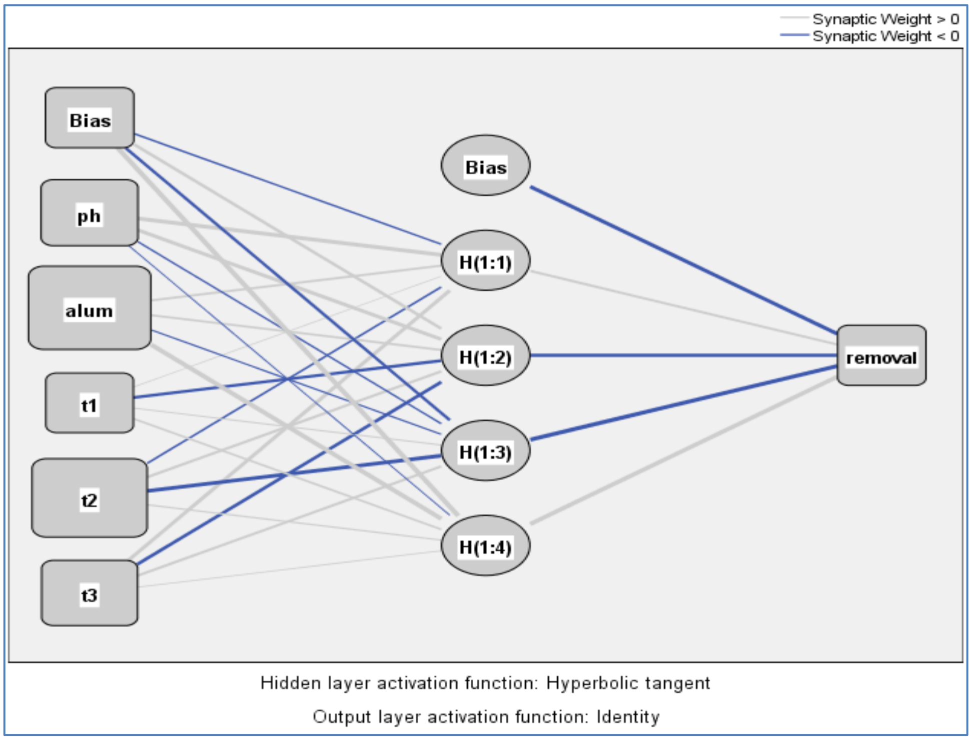

Figure (11): The ANN model architecture for turbidity removal efficiency.

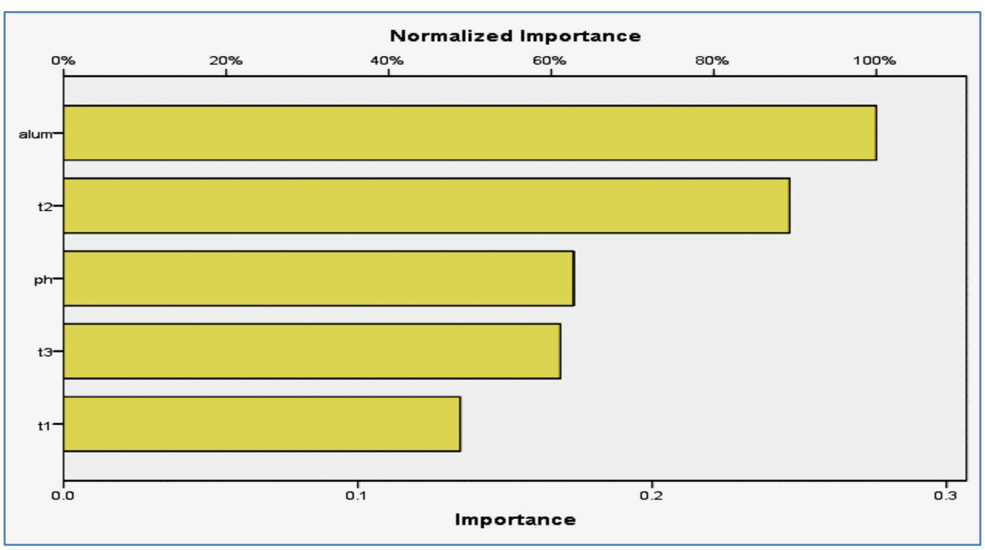

Figure (12): Normalize importance for input parameters of model

In order to check the models validity for tested estimated, Fig. (13) shows the comparison between these values and the measured values tested. It is clear that the model gives good estimation for the output variables, which considered as a strong correlation with R^2 = 0.932, RMSE=0.5501.

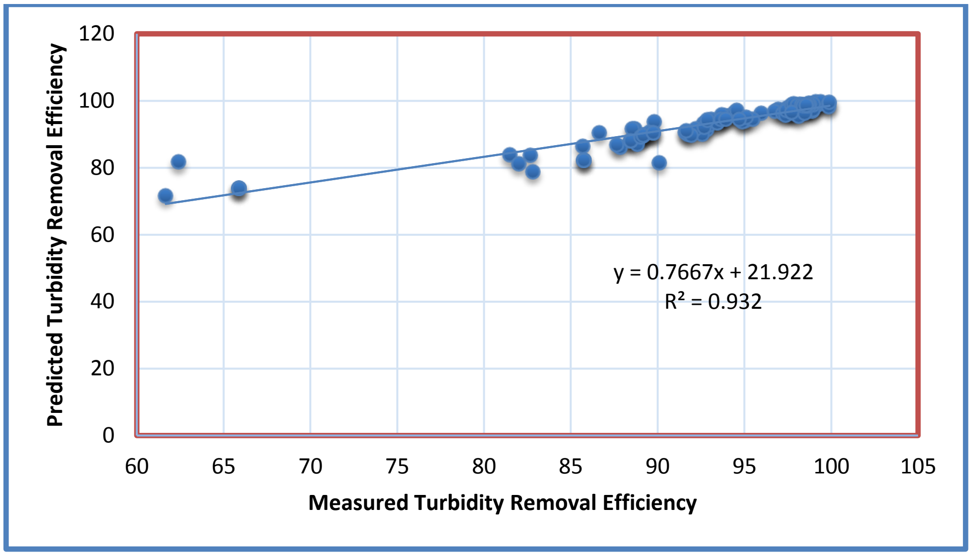

Figure (13): Comparison between estimated and measured values of turbidity removal efficiencies.

6. Conclusions

1. The concentrations of the experimental doses were measured at 10-100 mg / L. The highest removal rates for the highest concentration were included in all test categories.
2. The pH changes in the experiments of the first set which was changed from the acidic values to the alkalinity values made an increase in the rate of removal of the turbidity at a specific rapid mixing time (t_1) with the concentration of alum be used.
3. Maximum turbidity removal efficiency achieved at t_1 equal to 5 min with constant values of (t_2 and t_3), it was 99.9% with 100 mg/l of alum dosage , and with pH value of (7.2).
4. Maximum turbidity removal efficiency achieved at t_2 equal to 50 min with constant values of (t_1 and t_3), it was 98.56% with 100 mg/l of alum dosage, and with pH value of (4.55)
5. Maximum turbidity removal efficiency achieved at t_3 equal to 60 min with constant values of (t_1 and t_2), it was 94.72%. with 100 mg/l of alum dosage, and with pH value of (4.25).
6. After application (ANN) technique to make a model to predicte of turbidity removal efficiency, it gives a good correlation between estimated and predicted values of output target with R^2 = 0.932 and RMSE=0.5501.

Acknowledgements:

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6- References:

[1] Dentel, S. K.," Coagulation control in water treatment" Critical reviews in environmental control. Vol.21, No. 1, CRC Press, Inc., France. 1991.

[2] Silbert, M. (Kurita Handbook of water treatment, 2nd English edition.) Kurita Waters Industries Ltd, Tokyo .1999.

[3] Marshidi, S.A.T., "Study into the ability of improving the performance of locally produced alum). MSc. Thesis, College of Engineering, University of Technology, Iraq. 2000.

[4] Braul, L.and Leade ,A.,"Chemical for on Farm Coagulation ", Internet: http:// www.quantumltux.com / water. 2004.

[5] Gone Droh Lancine, Kamagate Bamary, Ligban Raymound, Seidal Jean- Luc, Batiot Christelle, and Biemi Jean," Coagulation-Flocculation Treatment of a Tropical Surface Water with Alum for Dissolved Organic Matter (DOM) Removal: Influence of Alum Dose and pH Adjustment", J.Int.,Environmental Application & Science, vol.3 (4):247-257, 2008.

[6] Giani Apostol, Redha Kouachi, Inol Constantinescu,"Optimization of Coagulation – Flocculation Process with Aluminum Sulfate Based on Response Surface Methodology" , U.P.B. Sci. Bull. Series B, Vol. 73, Iss.2, 2011.

[7] M. Zainal- Abidden, A. Aris, F. Yusof, Z. Abdul-Majid, A. Selamat and S.I.Omar, " Optimization the Coagulation Process in Drinking Water Treatment Plant – Comparison Between Traditional and Statistical Experimental Design Jar Tests", Water Science & Technology, 65.3,2012.

[8] Satheesh Kumar J., Poongodi P., Balakumaran P., (Artificial Intelligence Based Alum Dosage Control in Water Treatment Plant). International Journal of Engineering and Technology (IJET), Volume 5, Sep. 2013.

[9] S.R.Ramhal, M.S.Sibiya,"Optimization of Coagulation-Flocculation parameters using a Photometric Dispersion Analyzer",Drink.Water Eng.Sci.,7,73-82,2014.

[10] Marwa J. Darwish, "Optimal Parameters of Coagulation – Flocculation – Sedimentation Processes for Water Treatment of Shatt- Al- Hilla", Higher Diploma Thesis, Civil Eng. Department, College of Engineering, University of Babylon, Iraq, 2018.

[11] Howard s. Peavy, Donald R. Rowe, and George Tchobanoglous, "Environmental Engineering", McGraw- Hill Book Co., Singapore,1985.

[12] Mackenzie L. Davis, Ph.D., P.E., BCEE,(Water And Wastewater Engineering) , The McGraw-Hill Companies, Inc, 2010.

[13] Weiner, Matthews, "Environmental Engineering", 4th edition. Copyright Q, Elsevier Science (USA). All rights reserved. Printed in the United States of America. 2003.

[14] E. W. Steel, Terence J. McGhee,(Water Supply and Sewerage), fifth edition. McGraw-Hill, Texas, USA, 1979.

[15] AWWA, ASOCE, "Water Treatment Plant Design" fourth edition. McGraw-Hill, NY, USA, 2005.

[16] Syed R. Qasim, Edward M. Motley, and Guang Zhu, "Water Works Engineering- Planning, Design & Operation", Prentice- Hall, Inc., USA, 2000.

محاولة لايجاد محددات مناسبة لعمليات التخثر-التلبد لمعالجة المياه

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الخلاصة:

تعتبر عكورة المياه من المحددات الفيزيائية المهمة لقياس نوعية المياه كونها مؤشر جيد لتحديد المعالجة المطلوبة لمياه الشرب.في الدراسة الحالية ،فحوصات الجرة القياسية ستجرى للحصول على افضل المحددات لتصميم عمليات التخثير– التلبيد.اثبتت النتائج بأن افضل زمن للخلط السريع ,(t_1) ولزمن الخلط البطيئ ,(t_2) ولزمن الترسيب (t_3) كان 60, 50 ,1 على التوالي اذ ان اعلى كفاءة ازالة للعكورة كانت %(94.72 , 98.56 ,99.31) لزمن خلط سريع مقداره ٥ دقائق وزمن خلط بطيئ مقداره ٥٠ دقيقة وزمن ترسيب مقداره ٦٠ دقيقة لقيم حامضية تتراوح (8.9 - 3.7). تم تمثيل القيم المقاسة لنسب ازالة العكورة بأستخدام تقنية الشبكات العصبية الصناعية ...اذ اوضحت النتائج تقارب جيد بين القيم المقاسة والقيم المخمنة بقيمة معامل تحديد (R^2) وقيمة معدل الخطأ 0.5501 , 0.932 على التوالي.

الكلمات الدالة: التخثير، التلبيد، الماء، المعالجة، العكورة.