University of Thi -Qar Journal for Engineering Sciences
https://doi.org/10.31663/tqujes13.1.469(2023)
Vol 13.1(January2023)
ISSN :2664- 5572 (online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@utq.edu.iq

Improvement Coagulation Process in Removing Turbidity and Total Organic Carbon from Contaminated Water by Mixing Two Coagulants

Suha Mahdi Salih

Chemical and Petrochemical Department, Engineering College, Anbar University, Al-Ramadi, Iraq.Suha.mahdi82@uoanbar.edu.iq

Abstract

Turbidity previously linked with the presence of pathogens has been eradicated by the coagulation process. Coagulation is a chemical treatment procedure that removes solids from water by changing the electrostatic charges of particles suspended in water. The eradication of turbidity and total organic carbon (TOC) has been investigated in this research by adding coagulants such as alum and $FeCl_3$ respectively in concentrations (0, 5, 15, 25, 35, 45mg/L)to water in each jar on a jar measure. And studying the effect of the coagulant concentration on the removal of turbidity and total organic carbon(TOC) .The concentration used (0,5,15,25,35 mg/L)in each jars in the jartest .The speed of flash and slow mixing got initially by testing with three different speeds (flash mixing 400,300,220rpm)and(slow mixing 50,60,70rpm) and then selecting the one that provided the least turbidity and total organic carbon. The same procedure done with three different pH of water (6,7.25,8)to study the effect of pH on coagulation . The findings show that $FeCl_3$ is more successful at removing turbidity and total organic carbon. It has been observed that 220 rpm,50 rpm,6 pH yields the best outcomes. Mixing of two Coagulant alum and $FeCl_3$ was studied to improve coagulation process and reduce the cost of coagulant .Mixing of two coagulants was made with proportions (Alum100%+$Fecl_3$0%, Alum75%+$Fecl_3$25%, Alum50%+$Fecl_3$ 50%, Alum25%+$Fecl_3$75%, Alum0%+$Fecl_3$100%). Best removal of turbidity and TOC at 25 mg/L (75 percent Alum25%+$Fecl_3$75%,).This study proved that Mixing coagulation improves the coagulation process in removing turbidity and total organic carbon .

***Keywords*:** Turbidity, Coagulation, Total organic carbon, Flocculation

1. Introduction

Coagulation is a chemical treatment process that removes solids from water by altering the electrostatic charges of suspended particles. During this method, small, highly charged molecules are put into the water to disrupt the charges on particles, colloids, or oily materials in suspension. Coagulation is a technique for eliminating and dealing with turbidity in water[**1**], [**2**] . The employment of coagulant and flocculation supports such as alum, ferric chloride, and long-chain polymers is one of the most widely used processes for eliminating suspended particles in drinking water [**3**], [**4**], [**5**].If the turbidity of the water is not too high, the natural organic materials (NOM) content decide the coagulant demand[**6**]. Coagulation is a step in the traditional water treatment process. The appearance of a destabilizing colloid in a water stream is the first distinctive characteristic of this phase. Organic and inorganic particles may be presented in these colloids. According to recent research, natural organic materials (NOM), notably the dissolved organic carbon reservoir, have a significant stabilizing impact on inorganic particles in water. When organic goods are spontaneously occurring. O'Melia discovered that the coagulation kinetics of inorganic particulates were determined by the properties and concentration of natural organics rather than the inorganic particles themselves[**7**]. .

Turbidity is the major factor of light scattering or reflection. High turbidity may make disinfection harder and offer a breeding ground for bacteria. Turbidity may be used to determine the amount of gross phosphorus and suspended particles in streams[**8**].Turbidity may be a better substitute for stream flow when estimating suspended-sediment loads[**9**].There for ,Turbidity peaks are thought to be potential pathogen breakthroughs. It is an essential metric for controlling microbial risk in drinking water treatment. The electrostatic characteristics of various microbial surfaces as a function of turbidity as a pathogen indication [**10**], [**11**], [**12**]. The dilution area around the diffusers for a non-stratified water column may be delineated using turbidity as an environmental tracer[**13**]. The adding of particle size analysis, total suspended solids, reactive suspended solids, suspended solids concentration, total dissolved solids, and other water quality indicators can be used to determine turbidity. In addition to these measurements, secondary measurements, such as phytoplankton species, sediment source, composition, sediment transport, and flux, can aid in the classification of turbidity. [**14**] .
Coagulation performance is affected by a number of parameters, including particle size and type, the quantity and structure of dissolved solid normal organic matter (NOM), the chemical and physical properties of the water, the coagulant's form, dosage, and pH.[**15**], [**16**], [**17**]. The

efficacy of coagulation is determined by a number of factors, some of which are related to environmental conditions. Rainfall events can cause rapid changes in the properties of fresh water, including B. increases in turbidity, Natural organic matter(NOM), and microbial burden. [18]. These anomalies can affect standard water treatment (sedimentation, coagulation, and filtration), increasing the need for coagulants.

In recent years, researchers have focused on this specific topic and proposed an alternative strategy to enhance coagulation performance during precipitation, such as minimizing turbidity by increasing alkalinity. [19], [20], using ion exchange for NOM regulation [21], and defining a turbidity-based index to identify rainy periods that disrupt care [22]. The jar test is Typically employed to identify coagulation and flocculation processes. During the coagulation phase, the neutralization or reduction of the charge on the suspended particles, or the charge corresponding to the zeta potential on the minuscule particles in the water, causes them to indiscriminately repel each other, maintaining the separation of the small colloidal particles as they float. The flocculation/coagulation process neutralizes or reduces the negative charge of the particles. The van der Waals attraction is then utilized to promote the initial aggregation of finely suspended matter and colloidal particles, thereby producing microflow. Flocculation employs polymers with long chain lengths, such as flocculants, to mechanically combine or aggregate microfluidic particles into expansive aggregates. Standard coagulation/flocculation unit method [23] is divided into three phases:

1) Rapid or Rapid Mixing: After adding the necessary chemicals (coagulants/flocculants and, if necessary, pH adjusters), the effluent is vigorously mixed.

2) Slow blending (coagulation and flocculation): at this stage, effluent undergoes minimal coagulation and flocculation. Stir to form broad granules and rapidly separate.

3) Sedimentation: The flocculation-produced particles must settle and then be discarded.

Traditionally, the coagulation mechanism is used to eliminate turbidity, which is frequently caused by the presence of microorganisms. Today, however, it is frequently adapted or altered to decrease total organic carbon (TOC) [24]. Thus, enhanced coagulation has been described as the progression from hazy to hazy plus natural organic matter (NOM) elimination in conventional coagulation. In addition to total organic carbon and alkalinity, other conditions, such as the form and concentration of coagulant and the purity of organic matter, must be considered. [25], [26], [27], [28], [29][30]. Selecting the most effective coagulant(s), increasing coagulant dosages, and adjusting pH are all parts of enhanced coagulation [31], [32], [33].

Traditional inorganic coagulants have numerous disadvantages, including high chemical costs and possible health hazards [34]. Since these metals are believed to be harmful to humans and other living organisms, the level of Aluminum or Iron that occurs in drinking water despite increased coagulation is of grave concern, as they can cause Alzheimer's disease, osteoporosis, anemia, and anorexia Aluminum[35], [36].

Numerous researchers have studied Coagulation and fluctuation process [37], [38].The previous studies investigated the effectiveness of aluminum sulfate (alum)and $Fecl_3$ in coagulation each one a lonely and comparing between them in efficiency of removal of turbidity and total organic carbon but the current study in addition to use each coagulant (aluminum sulfate (alum)and $Fecl_3$)a lonely .Both coagulants (aluminum sulfate (alum)and $Fecl_3$)together is used to improve the coagulation in removing turbidity and total organic carbon because mixing the coagulant increase the ionic compound that leading to adhere with organic pollutant in the water .The effect of rapid and slow mixing ,pH of water is studied by making a lot of experiments to determine the optimum speed of mixing and adjust pH of the water to understand the mechanism of coagulation and fluctuation process to be able to enhance this technology in water treatment.

2. METHODOLOGY

2.1 Chemicals and equipments

2.1.1Chemicals

1. Contaminated Water Properties listed in Table .1

Table 1 Contaminated Water Properties

Turbidity	Total Organic Carbon	pH
102NTU	2.8326 mg/L	7.25

.

2.Coagulants

a. alum(aluminum sulfate, $Al_2(So_4)_{3.}n\ H_2o$).

b. $FeCl_3$

2.1.2 Equipments

1. jar tester
2. Turbidirect, Lori bond
3. Multi N/C(3100), analytik jena(company)

2.2 Experimental Procedure

1.The alum(aluminum sulfate, $Al_2(So_4)_3.n\ H_2o$) (1gm) and $FeCl_3$ (1gm) powder were weighed and dissolved in the 1-liter water separately.

2.The various test jars (wise stir® jar tester) were filled with water (102NTU, 2.8326 mg/L TOC). A coagulant such as alum was added in each jar as listed in **Table .2** and mixed at 400rpm for 1min. The speed was slowed to 70rpm in 10 min followed by a slow down to 0 rpm in 15 min. The alum was allowed to sediment at the bottom of the jar. Supernatant turbidity was measured by (Turbidirect, Lori bond) and TOC was measured by (Multi N/C(3100), analytik jena(company).

Table 2 Concentration of Coagulants add in Jars

Sequence of Jars					
Jar 1	Jar 2	Jar 3	Jar 4	Jar 5	Jar 6

Concentration of Coagulant mg/L	0	5	15	25	35	45

3.A similar procedure was repeated for $FeCl_3$. However, the initial speed was 300,220 rpm for 1 min, followed by 60,50 rpm in 10 min. Again supernatant turbidity and TOC were measured.

4.Mixing the two coagulants (alum and $Fecl_3$) and making the treatment mentioned in the above procedure. the concentration of the mixture of the two coagulants are as **Table .2** mg/L respectively and the Coagulants percentage of the mixture listed in **Table .3** and repeated the experiment with every concentration at this percentage repeating all the procedures above with water of PH 6, 7.25, and 8.5 to study the pH effect.

Table 3 Percentage of Coagulants

Coagulant	
A=$Fecl_3$	B=Alum (Sulfate Alminium)
0%	0%
0%	100%
25%	75%
50%	50%
75%	25%
100%	0%

3.RESULTS AND DISCUSSION

The standard method used in removal the turbidity and total organic carbon from the polluted water is the coagulation and fluctuation process by using jartest equipment. Many researchers used the same technique [37], [38].

3.1 Coagulants Used in The Current Study.

1.Alum ($Al_2(SO_4)_3.18H_2O$).

This study examined the effect of combining coagulation (Alum and $FeCl_3$) on the removal of turbidity and total organic carbon (TOC). Alum a trivalent salt, has a greater capacity for coagulation than the majority of electrolytes. After a series of hydrolytic reactions, the Al^{3+} trivalent ion dissociates into aqua metal complexes and numerous mononuclear species are produced (hydroxo-alum in this case). This mononuclear ion has a positive charge, allowing it to bind to negatively charged clay or silica particles in the solution, causing them to coagulate. [**39**], [**40**].Previous studies are similar to current study in utilizing Alum in Coagulation [**41**], [**42**].

2.$Fecl_3$

Fe^{2+} mononuclear ions are produced by $FeCl_3$ coagulant neutralize negative charge of impurities in the water . In the present study $FeCl_3$ eliminated turbidity and total organic carbon(TOC) more effectively than alum as shown in **Figs.1.(a) and (b), 2.(a) and (b), 3.(a) and (b).** Numerous authors reported comparable results[**2**], [**24**], [**43**], [**44**], [**45**] . Since $FeCl_3$ has a higher active metal content and a higher molecular weight of Fe, $FeCl_3$ has a far larger total usable surface than alum[**42**], [**46**], [**47**].

3.2 Effect of flash mixing speed on turbidity removal and total organic carbon contained.

Flash mixing make coagulant disperse in the water lead to neutralize negative charge with positive charge.In the present investigation, experiments were conducted at different flash mixing rates (400, 300, and 220 rpm) to examine the impact of flash mixing producing the least turbidity. 220 revolutions per minute effectively eradicate turbidity and total organic carbon(TOC). **Fig 1.(a) and (b)** below shows that the removal of turbidity and total organic carbon (TOC) decreased as the speed of flash mixing increased because in extreme fast speed mixing make particles repel each other instead of neutralizing that prevents making flocs in slow mixing[**48**] .

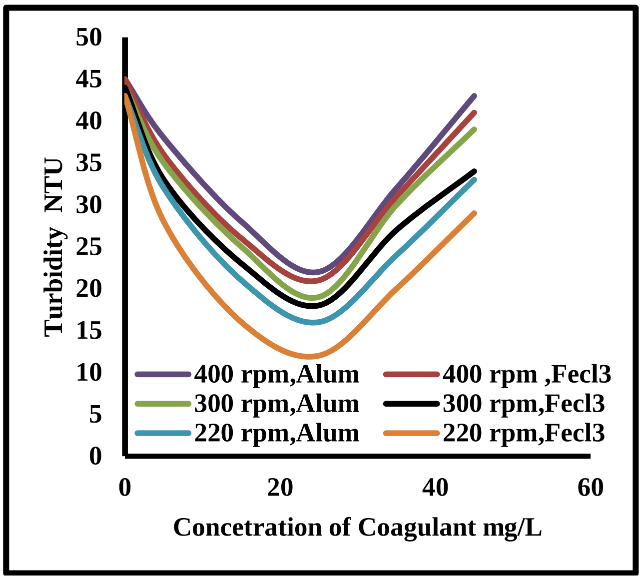
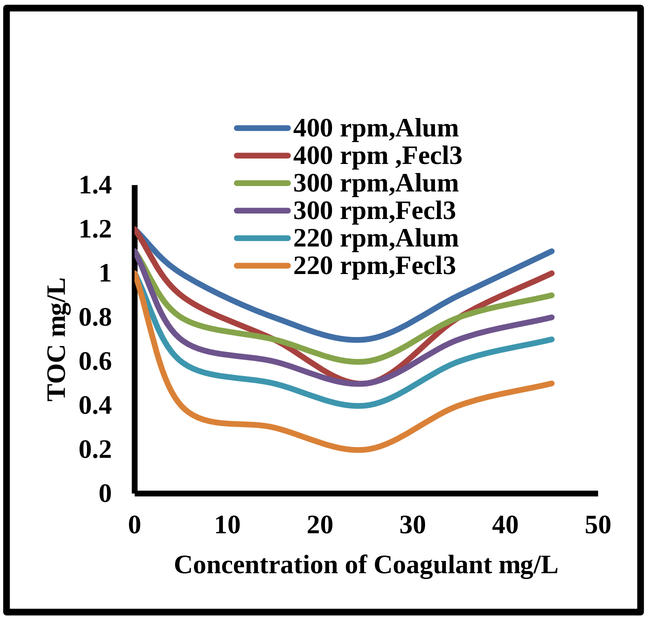


Fig.1 Effect of alum and $FeCl_3$ at different flash mixing speed.(a)On turbidity



(b) On total organic carbon

3.3 Effect of slow mixing speed on turbidity removal and total organic carbon contained

slow mixing makes positive and negative charges of impurities and coagulants that formed in rapid mixing stage attract each other with enough time 10 min to from floc that sediment in the third stage to settle and then remove it from the water. **Figs 2.(a) and (b)** shows that as slow mixing increases the removal of turbidity and total organic carbon decreases because powerful slow speed prevents making flocs and breaking them and settle in the jars that lead to fail the removal[49] Due to decreased floc shearing during initial floc formation, a slower mixture speed can improve turbidity removal at lower concentrations [50] .The optimal rate for sluggish blending in the current study was determined to be 50 rpm.

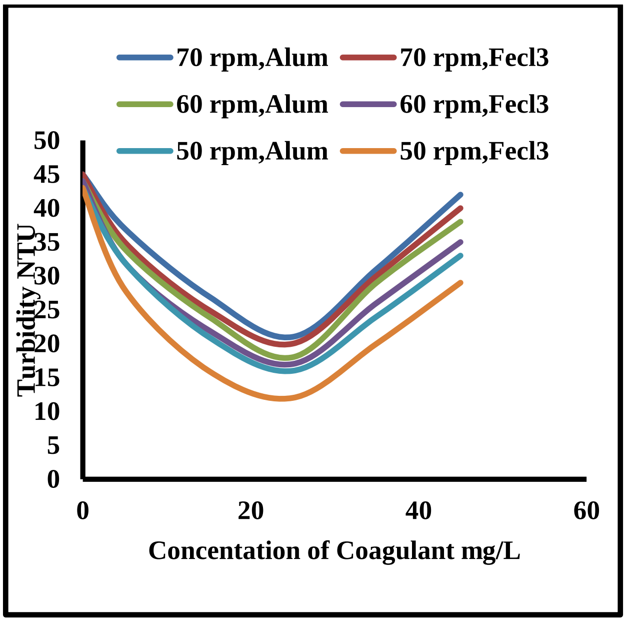


Fig.2 Effect of alum and $FeCl_3$ at different slow mixing speed (a)On turbidity.

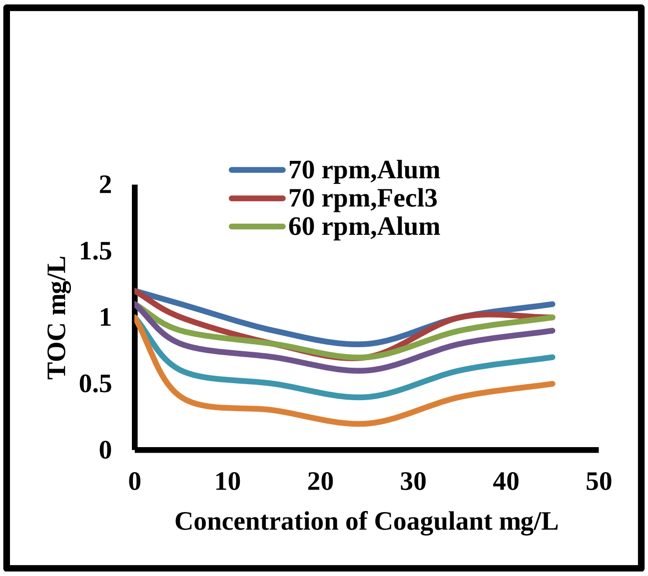


Fig. b On total organic carbon.

3.4 Effect of pH on turbidity removal and total organic carbon .

pH regulation is one of the most significant aspects of coagulation. The optimal pH for removing natural organic materials (NOM) varies with the type of water[51]. It affects the surface charge of colloids, and the pH at which coagulation occurs is the most important factor in assuring effective coagulation [52] [53] .In the current study as the pH of the water decreased, turbidity and total organic carbon (TOC) also decreased. As shown in **Figs 3.(a) and (b)**due to the fact that the coagulation powers of both coagulants (alum and ferric chloride) increased as pH decreased. The explanation of this result is the pH of water is crucial to the coagulation process. Since acidic coagulants consume alkalinity from water, the pH must be decreased to increase coagulation and prevent the addition of a heavy coagulant [**51**].The optimal removal of turbidity and total organic carbon TOC in the present study in water with a pH of 6 at the flocculation mixing speeds of 50 rpm (10 min), flash mixing speeds of 220 rpm (1 min), and sedimentation time of 15 min. Similar results have been published by prior authors [**15**], [**54**] [**55**]. Another study has done by[**56**] gave opposite results and explained the discrepancy between his study and the current study that the suspension predominantly employed a sweep-coagulation mechanism.Therefore, disparities in suspension properties, specifically particle size. the volume of solids in the travertine suspension used is also greater than the particle size in the current increased coagulating power and, can be explained Since all travertine and selective granules are negatively charged although the higher pH [**57**] .Another study conflicts with current study conclusion [**58**] , [**59**]

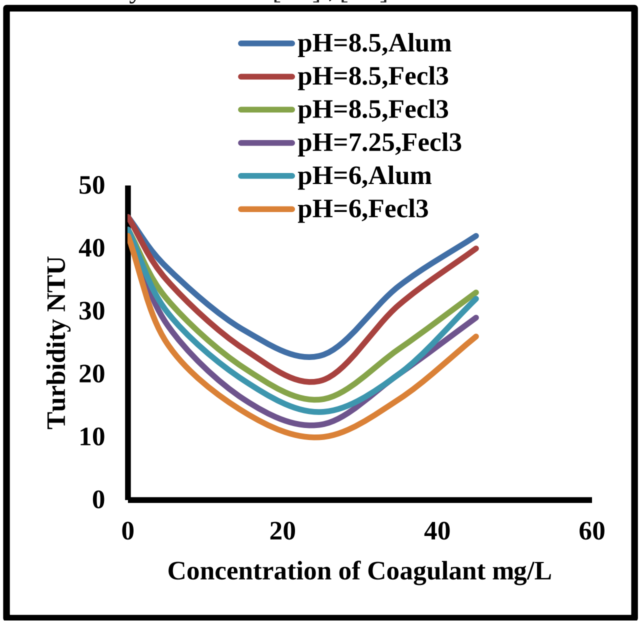


Fig.3Effect of pH on alum and $FeCl_3$ coagulation (a)On turbidity .

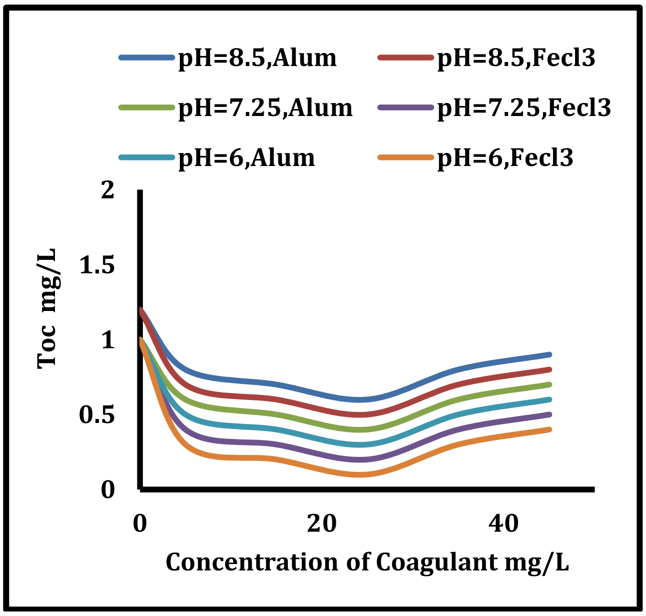


Fig . b On total organic carbon .

3.5 Effect of coagulant concentration on turbidity and total organic carbon removal.

Different concentrations of coagulant (0,5,15,25,35 mg/L) were put in each jar in the jartest to show the increasing of coagulant dosage effect . It is shown in **Fig 1.(a) and (b),Fig 2.(a)and (b) ,Fig 3.(a) and (b)** as coagulant concentration increasing the removal of turbidity and total organic carbon increased until reach 25 mg/L begiun to decrease the removal [**41**], [**47**].

3.6 Comparison between Alum and $Fecl_3$

The turbidity and total organic carbon of water decreased as coagulant concentrations increased. As more coagulants failed to eliminate turbidity and TOC, the turbidity and TOC of water at high coagulant concentrations increased. Since charge neutralization is dominant at low doses and the sweep-flocculation process becomes dominant at very high doses, as shown in **Fig 1.(a) and (b),Fig 2.(a)and (b) ,Fig 3.(a) and (b)** an excess amount may have a negative effect on coagulation due to colloidal particle destabilization and charge reversal formation [**58**] ,[**59**]. Numerous authors reported comparable results[**2**], [**39**], [**40**], [**42**], [**43**] . Since $FeCl_3$ has a higher active metal content and a higher molecular weight of Fe, $FeCl_3$ has a far larger total usable surface than alum[**40**], [**43**].

3.7 Effect of alum and $FeCl_3$ mixture on turbidity and total organic carbon removal

$FeCl_3$ is more effective than alum, so adding a percentage of $FeCl_3$ to alum increased its efficacy. The purpose of this research is to increase the efficiency of alum by adding a percentage of $FeCl_3$ rather than using $FeCl_3$ alone, as shown in **Fig. 4 (a) and (b).** Since $FeCl_3$ is more expensive than alum, the blending reduces the cost. Best removal of turbidity and TOC at 25 mg/L (75 percent

$FeCl_3$ and 25 percent Alum). The previous study agreed with this result [**38**].

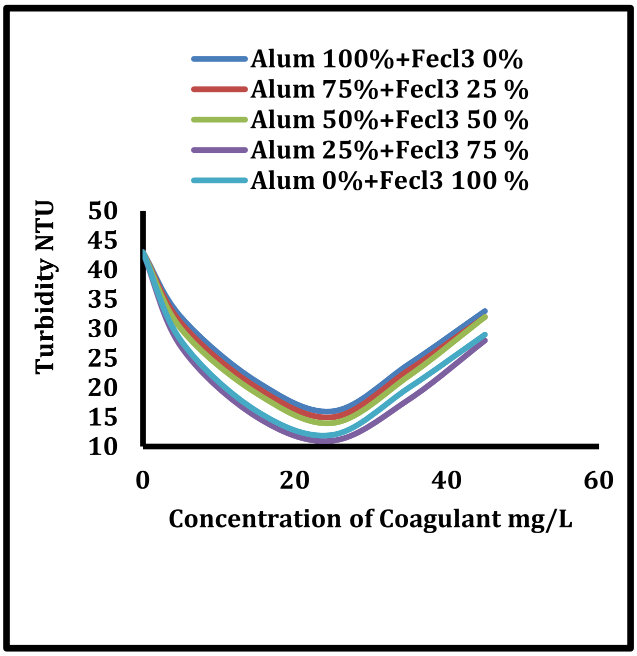


Fig. 4 a Effect of the mixture of alum and $FeCl_3$ on turbidity removal

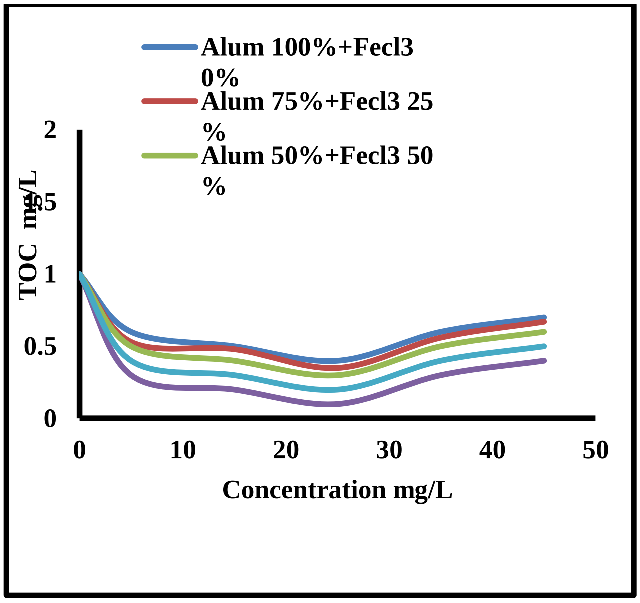


Fig. 4 b. Effect of the mixture of alum and $FeCl_3$ on turbidity removal..

CONCLUSION

The conclusion of the study is that combining coagulants improves the efficacy of removing turbidity and TOC. In addition, the optimal conditions for rapid blending coagulation were determined through a series of experiments. The three fastest velocities are 220, 300, and 400 revolutions per minute. It has been determined that the top three sluggish combining velocities are (50, 60, and 70 rpm), with 50 rpm producing the finest results. Concerning slow mixing speed, it was discovered that reducing slow mixing speed increases the efficacy of removing turbidity. Finally, the optimal water pH was determined using three distinct values (6, 7.25, and 8), and 6 pH yielded the finest results. In conclusion, the results indicate that $FeCl_3$ was more effective than alum at removing turbidity and total organic carbon (TOC).

References

[**1**]Eikebrokk, B.,. Coagulation-direct filtration of soft, low alkalinity humic waters. *Water Science and Technology*,1999 ,*40*,.55..

[**2**]Volk, C., Bell, K., Ibrahim, E., Verges, D., Amy, G. and LeChevallier, M.. Impact of enhanced and optimized coagulation on removal of organic matter and its biodegradable fraction in drinking water. *Water research*, 2000, *34*,.3247.

[**3**]Baruth, E.E. Water Treatment Plant Design: American Water Works Association American Society of Civil Engineers. ., 2005

[**4**]Edzwald, J.K. and Van Benschoten, J.E. October. Aluminum coagulation of natural organic matter. In *Chemical Water and Wastewater Treatment: Proceedings of the 4th Gothenburg Symposium.1990 October 1–3, Madrid, Spain* (. 341). Berlin, Heidelberg: Springer Berlin Heidelberg.

[**5**]Gregor, J.E., Nokes, C.J. and Fenton, E.. Optimising natural organic matter removal from low turbidity waters by controlled pH adjustment of aluminium coagulation. *Water Research*. 1997, *31*,.2949.

[**6**]Ratnaweera, H., Gjessing, E. and Oug, E. Influence of physical-chemical characteristics of natural organic matter (NOM) on coagulation properties: an analysis of eight Norwegian water sources. *Water science and technology* , 1999, *40*,89.

[**7**]O'melia, C.R. Particle—particle interactions in aquatic systems. *Colloids and surfaces* . 1989,*39*,.255.

[**8**]Grayson, R.B., Finlayson, B.L., Gippel, C.J. and Hart, B.T. The potential of field turbidity measurements for the computation of total phosphorus and suspended solids loads. *Journal of environmental management*. 1996, *47*,257..

[**9**]Christensen, V.G., Rasmussen, P.P. and Ziegler, A.C. Comparison of estimated sediment loads using continuous turbidity measurements and regression analysis. In *Proceedings of Turbidity and other sediment surrogates workshop*. 2002, April 3.

[10]Drozd, C. and Schwartzbrod, J. Hydrophobic and electrostatic cell surface properties of Cryptosporidium parvum. *Applied and Environmental Microbiology*. 1996,*62*,1227.

[11]Brush, C.F., Walter, M.F., Anguish, L.J. and Ghiorse, W.C. Influence of pretreatment and experimental conditions on electrophoretic mobility and hydrophobicity of Cryptosporidium parvum oocysts. *Applied and Environmental Microbiology* . 1998,*64*,4439. .

[12]Butkus, M.A., Bays, J.T. and Labare, M.P. Influence of surface characteristics on the stability of Cryptosporidium parvum oocysts. *Applied and Environmental Microbiolog*. 2003, *69*,3819.

[13]Pecly, J.O.G. and Roldão, J.S.F. Using the effluent turbidity as an environmental tracer: application to a domestic sewage outfall and comparison with dye tracer data. International Symposium on Outfall Systems, Mar del Plata, Argentina,2011.

[14]Paul, S. Turbidity: Description, impact on water quality, sources, measures-a general overview. *Descr. Impact Water Qual Sources, Meas*. 2008, *3*, 2 .

[15]Ersoy, B., Tosun, I., Günay, A. and Dikmen, S. Turbidity removal from wastewaters of natural stone processing by coagulation/flocculation methods. *CLEAN–Soil, Air, Water,* .2009, *37*,225

[16]Shammas, N.K. Coagulation and flocculation. In *Physicochemical treatment processes* (103). Totowa, NJ: Humana Press.. 2005.

[17]Dempsey, B.A. and Ganho, R.M. O Melia CR: The coagulation of humic substances by means of aluminum salts. *Journal American Water Works Association*. 1984,*76*, 141.

[18]Amirtharajah, A. and O'melia, C.R.. Coagulation processes: destabilization, mixing, and flocculation. *MCGRAW-HILL, INC.,(USA).* 1990, *1194*,

[19]Ching, H.W., Elimelech, M. and Hering, J.G. Dynamics of coagulation of clay particles with aluminum sulfate. *Journal of Environmental Engineering*, 1994,*120*,.169.

[20]Hurst, A.M., Edwards, M.J., Chipps, M., Jefferson, B. and Parsons, S.A. The impact of rainstorm events on coagulation and clarifier performance in potable water treatment. *Science of the total environment*.2004, *321*(1), 219.

[21]Tseng, T., Segal, B.D. and Edwards, M. Increasing alkalinity to reduce turbidity. *Journal-American Water Works Association*.2000, *92*, 44.

[22]Fearing, D.A., Banks, J., Guyetand, S., Eroles, C.M., Jefferson, B., Wilson, D., Hillis, P., Campbell, A.T. and Parsons, S.A. Combination of ferric and MIEX® for the treatment of a humic rich water. *Water Research* .2004, *38*,2551.

[23] Ebeling, J.M., Sibrell, P.L., Ogden, S.R. and Summerfelt, S.T. Evaluation of chemical coagulation–flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluentdischarge. *Aquacultural Engineering*.2003, *29*1,.23.

[24]Rizzo, L., Belgiorno, V. and Casale, R Simultaneous compliance of TOC and turbidity related to pathogen breakthrough and THMs control by enhanced coagulation. *Global NEST Journal*, 2005. *7*, 145

[25]Singer, P.C. and Harrington, G.W. November. Coagulation of DBP precursors: theoretical and practical considerations. In *Proc. Water Quality Technol. Conf., American Water Works Assoc., Denver, Colo,*1993 (1).

[26]Kavanaugh, M.C. Modified coagulation for improved removal of trihalomethane precursors. *Journal-American Water Works Association*.1978, *70*,.613.

[27]Randtke, S.J. Organic contaminant removal by coagulation and related process combinations. *Journal-American Water Works Association*.1988, *80*,40.

[28]Amy, G.L., Collins, M.R., Kuo, C.J., Chowdhury, Z.K. and Bales, R.C. Effects of humic substances on particle formation, growth and removal during coagulation. 1989.

[29]Cheng, R.C., Krasner, S.W., Green, J.F. and Wattier, K.L., 1995. Enhanced coagulation: a preliminary evaluation. *Journal-American Water Works Association*.1995, *87*,91.

[30]AWWA Research Foundation and Dennett, K.E. *Humic substance removal and minimization of trihalomethanes by ferric chloride coagulation*. American Water Works Association. 1995.

[31]Strasser, A., Hale, B. and Koval, E.J. Denver Water's System Specific Study for the Stage 2 Disinfectants and Disinfection Byproducts Rule. In *Impacts of Global Climate Change* .2005 ,1

[32]Krasner, S.W. and Amy, G. Jar-test evaluations of enhanced coagulation. *Journal-American Water Works Association*.1995, *87*,93..

[33]Vrijenhoek, E.M., Childress, A.E., Elimelech, M., Tanaka, T.S. and Beuhler, M.D. Removing particles and THM precursors by enhanced coagulation. *Journal-American Water Works Association*.1998, *90*,139.

[34]Cheng, W.P. and Chi, F.H. A study of coagulation mechanisms of polyferric sulfate reacting with humic acid

using a fluorescence-quenching method. *Water research*.2002, *36*,.4583.

[35]Van Leeuwen, J., Daly, R. and Holmes, M. Modeling the treatment of drinking water to maximize dissolved organic matter removal and minimize disinfection by-product formation. *Desalination*.2005, *176*(1-3),.81

[36]Jekel, M.R.. Removal of Al in coagulation and acidic raw water. *Water Supply*. 1991, *26*,,.9.

[37]Abdulmajeed, B.A. and Oleiwi, H.B. Evaluation of alum/lime coagulant for the removal of turbidity from al-ahdab iraqi oilfields produced water. *Journal of Engineering of Baghdad university*.2015 , *21*(7),.145.

[38]Ahad, M.Y.A. and Ibrahim, S.J. Use of non-Conventional Material to Remove Cu+ 2 ions from Aqueous Solutions using Chemical Coagulation. *Journal of Engineering of Baghdad university g*.2015, *21*,20.

[39]Sadoon, Z.A. and M-Ridha, M.J. Removal of reactive dyes by electro coagulation process from aqueous solution. *Journal of Engineering*.2020, *26*,.14.

[40]Alwared, A.I. and Faraj, N.S. Coagulation-flotation process for removing oil from wastewater using sawdust+ Bentonite. *Journal of Engineering of Baghdad university* .2015, *21*,.62.

[41]Casey, T.J. and Casey, T.J. *Unit treatment processes in water and wastewater engineering*.1997 166 Chichester: Wiley.

[42]Reynolds, T.D., 1982. Unit operations and processes in environmental engineering. In *Unit operations and processes in environmental engineering*. PWS Publishers

[43]Koohestanian, A., Hosseini, M. and Abbasian, Z. The separation method for removing of colloidal particles from raw water. *American-Eurasian J. Agric. & Environ. Sci*.2008, *4*,.266..

[44]Krasner, S.W., McGuire, M.J., Jacangelo, J.G., Patania, N.L., Reagan, K.M. and Aieta, E.M. The occurrence of disinfection by-products in US drinking water. *Journal-American Water*

Works Association.1989, *81*(8), 41.

[45]Crozes, G., White, P. and Marshall, M. Enhanced coagulation: its effect on NOM removal and chemical costs. *Journal-American Water Works Association*.1995, *87*,78.

[46]Metcalf, L., Eddy, H.P. and Tchobanoglous, G., 1991. *Wastewater engineering: treatment, disposal, and reuse* 4,. New York: McGraw-Hill.

[47]Mesdaghinia, A., Rafiee, M.T. and Mahvi, F.V.A. Evaluation of ferric chloride and alum efficiencies in enhanced coagulation for TOC removal and related residual metal concentrations. *Journal of Environmental Health Science & Engineering*.2005, *2*, 189.

[48]Ahmed, S.B., Ayoub, G.M., Al-Hindi, M. and Azizi, F., The Effect of Fast Mixing Conditions on the Coagulation-Flocculation of Highly Turbid Suspensions Using Magnesium Hydroxide Coagulant.2020.

[49]Zhang, Z., Dan, L.I.U., Dandan, H.U., Duo, L.I., Xiaojing, R.E.N., Cheng, Y. and Zhaokun, L.U.A.N. Effects of slow-mixing on the coagulation performance of polyaluminum chloride (PACI). *Chinese Journal of Chemical Engineering*.2013, *21*,.318.

[50]Sharp, E.L., Parsons, S.A. and Jefferson, B. Seasonal variations in natural organic matter and its impact on coagulation in water treatment. *Science of the Total Environment*.2006, *363*(1-3),.183

[51]Yang, Z.L., Gao, B.Y., Yue, Q.Y. and Wang, Y. Effect of pH on the coagulation performance of Al-based coagulants and residual aluminum speciation during the treatment of humic acid–kaolin synthetic water. *Journal of Hazardous Materials* .2010, *178*,596

[52]Montgomery, J.M. Water treatment: principles and design. In *Water treatment: Principles and design*. John Wiley & Sons. 1985.

[53]Yan, M., Wang, D., Yu, J., Ni, J., Edwards, M. and Qu, J. Enhanced coagulation with polyaluminum chlorides: role of pH/alkalinity and speciation. *Chemosphere*.2008, *71*,1665

[54]Semmens, M.J. and Field, T.K., 1980. Coagulation: experiences in organics removal. *Journal-American Water Works Association*, *72*(8), 476

[55]Ching, H.W., Tanaka, T.S. and Elimelech, M. Dynamics of coagulation of kaolin particles with ferric chloride. *Water research*.1994, *28*,559.

[56]Ozkan, A. and Yekeler, M.E.F.T.U.N.İ. Coagulation and flocculation characteristics of celestite with different inorganic salts and polymers. *Chemical Engineering and Processing: Process Intensification*.2004, *43*,873.

[57]Kim, S.H., Moon, B.H. and Lee, H.I. Effects of pH and dosage on pollutant removal and floc structure during coagulation. *Microchemical Journal*.2001, *68*,197.

[58]Al-Malack, M.H., Abuzaid, N.S. and El-Mubarak, A.H. Coagulation of polymeric wastewater discharged by a chemical factory. *Water Research*1999, *33*, 521.

.

[**59**] Van Leeuwen, J., Chow, C., Fabris, R., Drikas, M. and Spark K. Enhanced coagulation for dissolved organic carbon removal in conventional treatment with alum. In *Proceedings of the 18th Federal Convention*, 1999, April .11.