

Evaluating the Efficiency of Coagulants Mixture (Alum and Ferric Chloride) in Minimizing the Turbidity and TOC Colloidal in Drinking Water Treatment Units

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Abstract

In this paper jar tests were done on fresh water (river water) taken from AL-Jadriya / Baghdad drinking water treatment plant to examine two coagulant mixtures (alum and ferric chloride) at several percentages (0, 25, 50, 75 and 100%). Ferric chloride has been used to remove turbidity using NTU (Nephelometric Turbidity Units) and total organic carbon (TOC). A 95.4% removal of NTU at 25mg/L dose at 25% coagulant mixture obtained, while for alum alone the result was 94.8% NTU (0.6% difference) and 68.7%, and 62.5% TOC removal for a mixture of 25% and 50% respectively, higher than 56.2% for alum alone and increased the results to a significant difference of 12.5% and 6.3% for TOC removal. This means that using a mixture of coagulants enhances their performance to higher than each one alone.

Key words: Coagulant, Mixture, Alum and Ferric Chloride.

اختبار كفاءة خليط من المخثرات في تقليل العوالق و المحتوى الكربوني العضوي في محطات تصفية مياه الشرب

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وزارة العلوم و التكنولوجيا / دائرة البيئة و المياه / مركز تكنولوجيا معالجة المياه

بغداد - العراق

الخلاصة

أجريت اختبارات الجرة على المياه (ماء النهر) المأخوذة مباشرة من محطة معالجة مياه الشرب في الجادرية- بغداد لاختبار خليط من الشب وكلوريد الحديد مع نسبة وزنية للخلط 0، 25، 50، 75 و 100% لكلوريد الحديد ($FeCl_3$) في إزالة العكورة (NTU) والكربون العضوي الكلي (TOC). تم إزالة 95.4% من العكورة في جرعة 25 ملغ/لتر لخليط 25% بينما الشب لوحده أزال 94.8% (0.6% الفرق) و 68.7% و 62.5% إزالة من الكربون العضوي الكلي لنسبة الخليط 25% و 50% على التوالي أعلى من 56.2% من الشب وحده وهذه دفعت النتائج الى حدود عليا مع الحصول على نتائج الفرق عالية ومشجعة 12.5% و 6.3% للمحتوى الكربون العضوي المعالج و المزال. وهذا بدوره يعني استخدام خليط من المخثرات يحسن من ادائهما منفردين.

الكلمات المفتاحية: مخثر ، خليط ، شب و كلوريد الحديد

Introduction

The interest in drinking water treatment has become very important recently especially for TOC (Total Organic Carbon) or NOM (Natural Organic Matter) content and its removal resulting in the formation of DBPs (Disinfect By Products). There are many ways to minimize the TOC content in drinking water and the simplest way is to increase the coagulant dosage (Enhanced Coagulation). The term "enhanced coagulation" refers to the modification of the coagulation process to achieve greater or maximum natural organic matter (NOM) removal where higher doses of coagulant were used and the pH may be controlled during the coagulation/flocculation steps. The control of pH during coagulation is one of the most important factors controlling NOM removal (Chow *et al.*, 2009) and (Ashery *et al.*, 2012) found that enhanced coagulation could achieve better removal efficiency of NOM if a higher coagulant dose and adjusted pH is used. Generally, removing the TOC and NOM in treatment plants has to provide conditions that allow for effective removal of NOM and turbidity without producing excess sludge (Vaezi *et al.*, 2005). Some utilities find measurement of TOC by UV absorbance (UV_{254}) to be useful in optimizing coagulation (Engelhardt, 2010); (Wang *et al.*, 2000); (Egeberg *et al.*, 2002); (Kim *et al.*, 2005). (Ashery *et al.*, 2010) found that the relationship between organic material concentrations and UV_{254} absorption after regression are linear as described by the equation below:-

$$Y = 60.65(UV_{254}) - 1.84$$

Y = organic material concentrations (mg/L)
(Sulaymon *et al.*, 2009) determined a correlation in his work for Tigris River water

relating TOC to UV_{254} The equation with its standard error of estimation was:

$$TOC(mg / L) = 33 \times UV_{254}(cm^{-1}) + 0.6736 \pm 0.085$$

The above equation was very useful, easy to use, quick and not expensive in measuring and calculating TOC in river or surface water.

This research attempted to find the effect of coagulant mixtures on the enhance coagulation process by using a mixture of two coagulants ($FeCl_3$ and Alum) without using high dosage, and with no chemical addition to adjust the pH in the drinking water treatment process.

Materials and Methods

All the experiments were done within a three month period (June, July and August 2011) by using fresh Tigris river water taken form Al- Jaderia - Baghdad water treatment plant with the following specification :-

Ambient temperature	(35 – 38 °C)
pH :	(7.2 - 7.7)
NTU:	(46 - 58)
TOC :	(2.5 – 3.2 mg/L)

Two types of commercial coagulants were used Alum $Al_2(SO_4)_3 \cdot 18H_2O$ and Ferric chloride $FeCl_3 \cdot 6H_2O$ (48 wt.%).

Laboratory Equipments

- 1- Spectrophotometer UV absorbance at wavelength 254 nm (UV_{254}) was measured using a spectrophotometer BIOTECH Engineering UV - 9200
- 2- Turbidity Meter Turbi Direct Lovibond Germany
- 3- Jar test Jar test type Wise stir model JT m6 DAIHAN scientific Korea
- 4-pH Meter HAANA HI 8314
- 5-Electronic balance Sartorius BL 210 S

Jars (6 glass beakers 1 liter capacity) were used. Every jar was loaded with 1000 ml of sample with rapid mixing at 300 rpm for 1 minute, slow mixing at 30 rpm for 10 minutes and lastly a settling time of 15 minutes.

The experiments started by examining each coagulant alone to explore their behavior and their efficiency in removal of NTU and TOC. Then a mixture of 0, 25, 50, 75, and 100% of ferric chloride and Alum was used in the experiments (5, 10, 15, 20 and 25 mg/ L.) as shown in Table (1).

Table (1) Percent Mixing Ratio.

Alum%	FeCl ₃ %
100	0
75	25
50	50
25	75
0	100

The TOC was measured by UV₂₅₄ and calculated by the equation used by (Sulaymon *et al*, 2009)

To express the results of NTU and TOC as % removal:

$$\%removal(NTU) = \frac{NTU_{Initial} - NTU_{Reading}}{NTU_{Initial}}$$

x100%

$$\%removal(TOC) = \frac{TOC_{Initial} - TOC_{Reading}}{TOC_{Initial}}$$

x100%

Results and Discussion

The results below in Figure 1A showed that Alum gave better % removal than ferric chloride (94.2%). While fig 1B Showed equal % removal for TOC, (48.1%) for both coagulants but fig 1C Showed the relationship between pH and coagulation dose which shows that FeCl₃ is more acidic than Alum. And fig 1D Shows the relationship between NTU and dose further rine this fig . clearly demonstrates that Alum is better than FeCl₃ at all the doses but it will be to highlight the result at NTU value 5 (according to Iraqi recommended specifications for drinking tap water 1986 and WHO 1984) at doses of 20 & 25 mg L⁻¹ which matched to ≈ 92% and 94% removal NTU and ≈ 29% and 48% removal TOC respectively and noticing the stabilization of NTU value for FeCl₃ at 20 and 25 mg/lit. But for Alum still need more dose to stabilize at NTU value less than 5 which was unnecessary for our goal in this study.

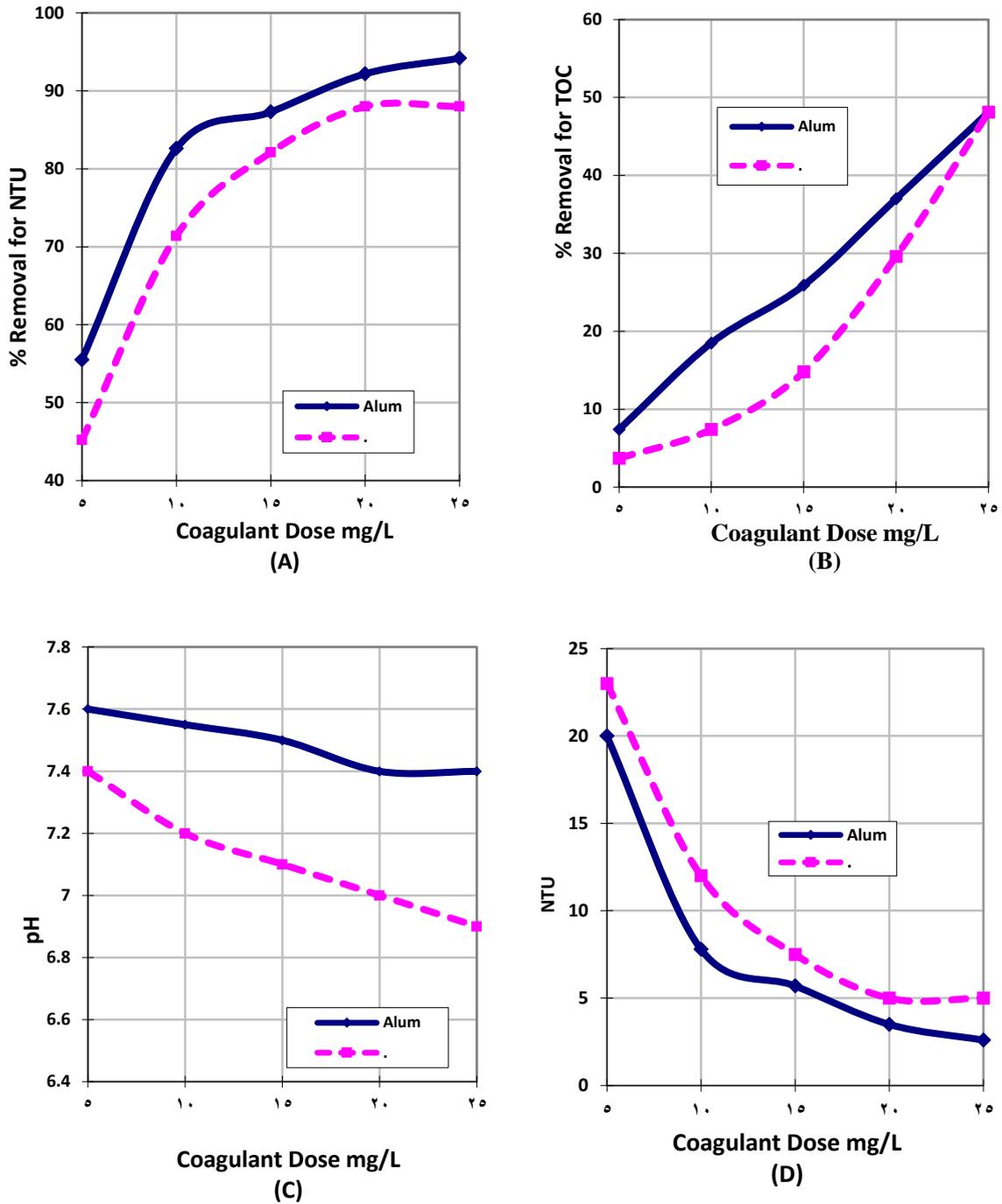


Fig. (1) The Test Results for each Coagulant Alone without Mixing of Alum and FeCl₃, (A) Relation between % Removal for NTU and Dose mg/L, (B) Relation between % Removal for TOC and Dose mg/L, (C)

Relation between pH and Dose mg/L, (D) Relation between NTU and Dose mg/L.

In above and subsequent figures there are two horizontal lines appearing in the figures the upper one refers to 0% FeCl₃ (100% Alum) and the lower one refer to 100% FeCl₃ (0% Alum) and the values in between show the deviation in % removal for NTU and TOC according to its individual % mixing in the chemical dose used (25,50 and 75%).

From Figure 2 (A) and (B) the coagulant mixture at 25, 50 and 75 % indicates that the more active coag-ulant was Alum and it was clear for NTU % removal and also for TOC % removal although it was not as high (0- 7%) the % removal for TOC at 100% FeCl₃ was not detected (very small) because the small coagulant dose and FeCl₃ is more acidic than Alum and is used in neutralization of the alkalinity in treated water. For 2C the solution goes more acidic because of ferric chloride but still in the alkaline pH region from 7.0 to 7.2 that may explain the depression in FeCl₃ action.

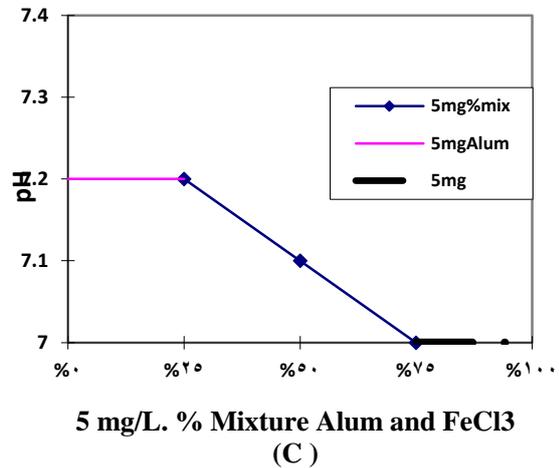
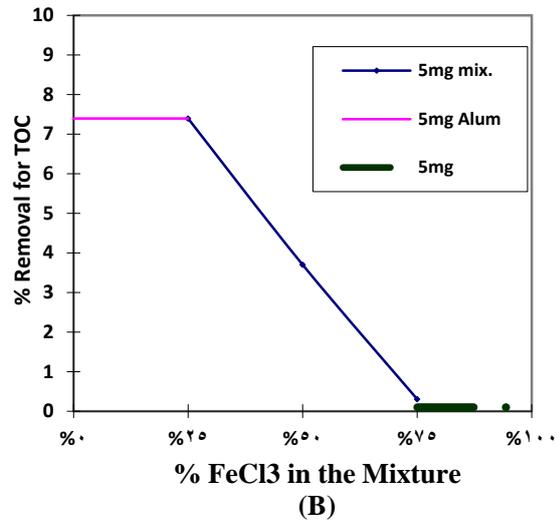
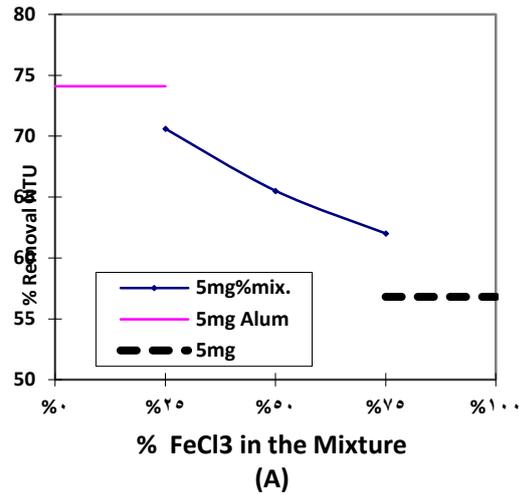


Figure (2) 5mg/L Mixture of Alum and Ferric Chloride, (A) % Removal NTU (B) %Removal TOC , (C) pH Scale for Coagulant Mixture.

While the results which was shown in Figure 3 A and B ,for 10 mg/L mixture have higher % removal but it still showed the same behavior as 5mg/L for both NTU and TOC % removal which means that the colloidal material and the organic material need more coagulant dose and this improved ferric chloride performance but it was still less than that of alum , and in Figure 3 C .

the results went to less pH values towards FeCl₃ (which depends on initial pH value for the sample)because of acidic nature of ferric chloride while the water sample is still in the alkaline region moving the pH from 3.7 to 7.5 noting the pH value depending on the fresh water sample in the day it was taken from AL-Jaderiya drinking water treatment station.

the curve's in Figure 4 look like a mix between the upper and lower lines for Alum 100% and ferric chloride 100%, Still it can be seen the same behavior but with an increase in NTU % and TOC % removal due to the increased dose and the pH of the solution lowered because the acidic nature of the coagulant consumes the alkalinity of the water samples depending on the initial pH value for fresh water samples .At this dose the high % NTU removal with small deviations between upper line 0% FeCl₃ and 25%FeCl₃ was 92.4% and 90.4% respectively (about 2%). Also for TOC % removal 37% and 35.1% respectively (about 2.1%) noting that at 25% FeCl₃ mixture the TOC removal at 10mg/L 15.6% and in the 15mg/L dose get double 35.1% removal, because more coagulant is available to remove organic contaminates .

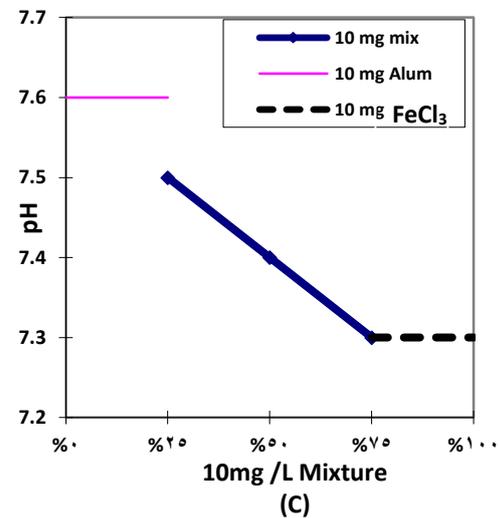
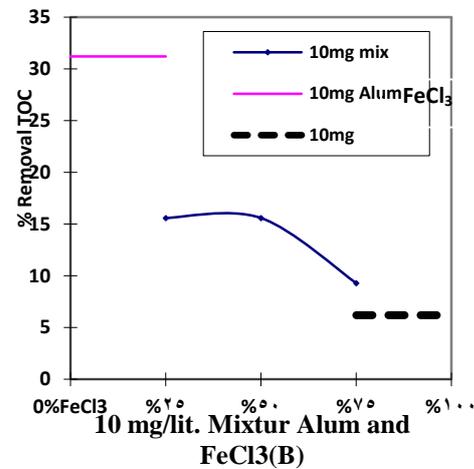
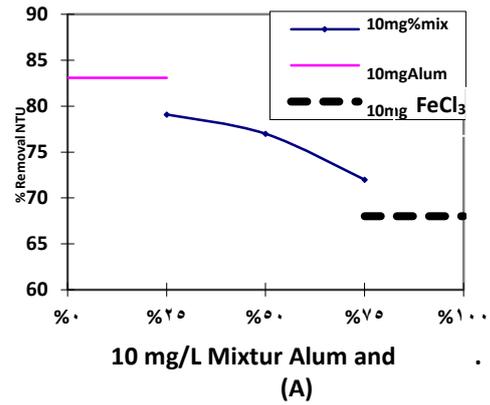


Figure (3) 10 mg/L Mixture for Alum and Ferric Chloride, (A) % Removal for NTU (B) %Removal for TOC (C) pH Scale.

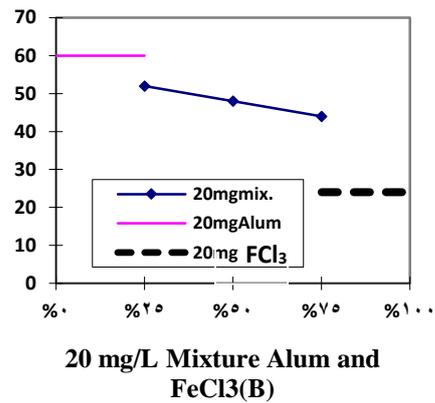
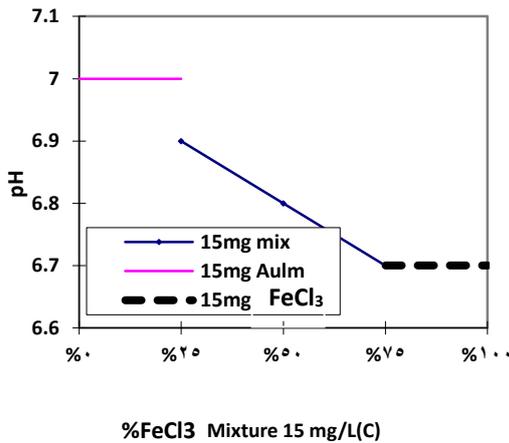
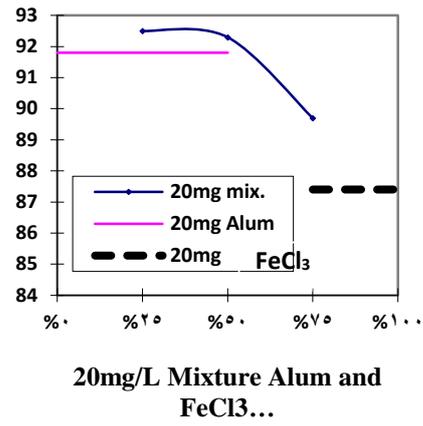
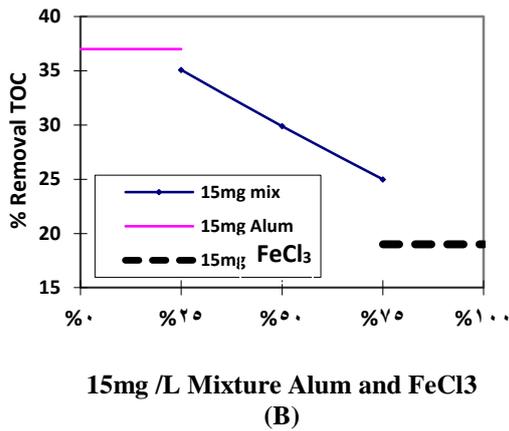


Figure (4) 15 mg/L. Mixture Alum and FeCl₃, (A) % Removal NTU. (B) % Removal TOC. (C) pH Scale for 15mg/L Mixture.

Moreover Figure 5 A showed the effect of the mixing of two coagulants at 25% (25% FeCl₃, 75% Alum) on the % removal of NTU was 92.5% and 50% (50% FeCl₃ and 50% Alum) on the % removal of NTU was 92.3% they worked together to push the % removal of NTU in advance to a higher value than Alum alone 91.8% (about 1% more) while in the same figure 5B % removal of TOC is slightly more than 48% (primary measuring) get 52% this is still less than Alum alone (60%) TOC removal in this water sample test, in Figure 5 C the mixture goes more acidic.

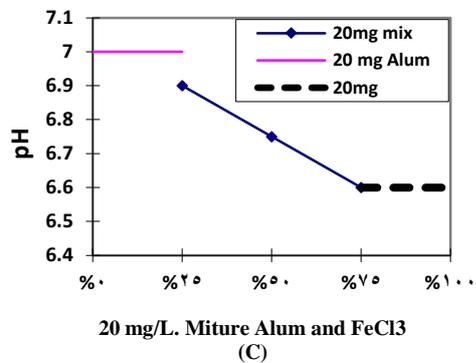
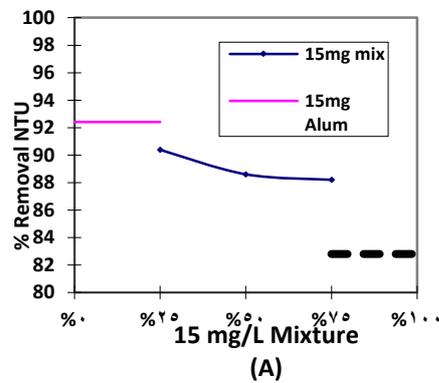
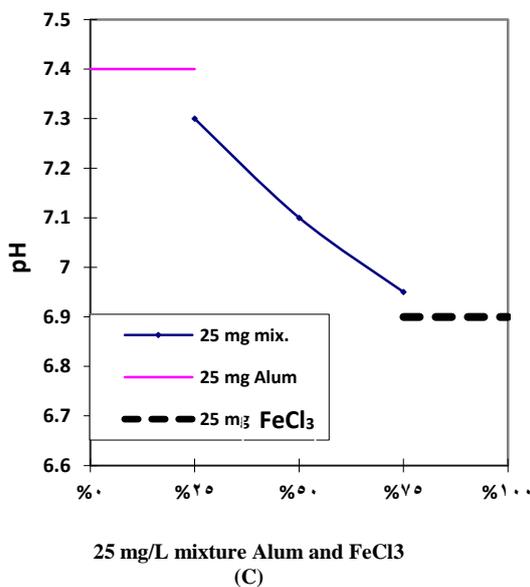
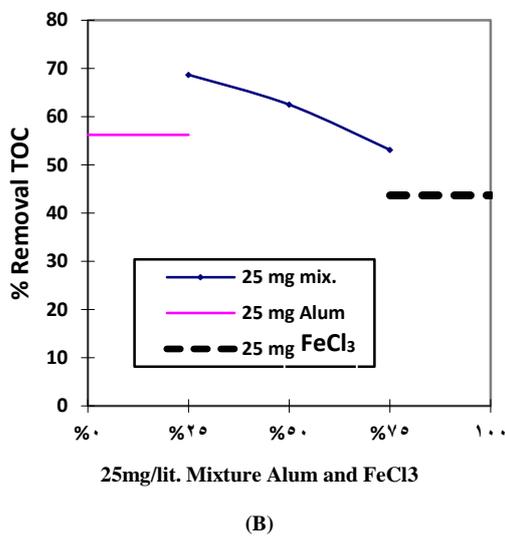
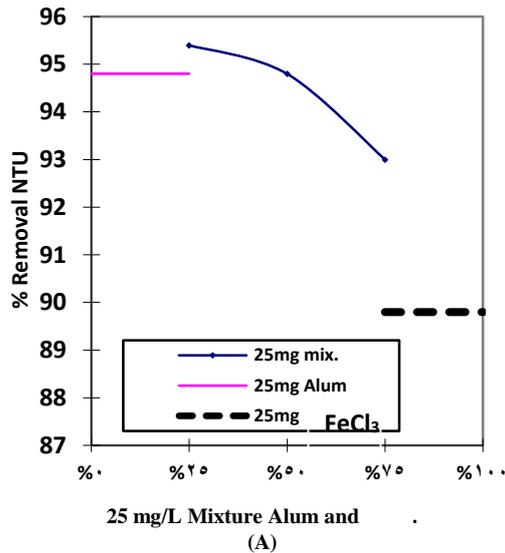


Figure (5) 20 mg/L. Mixture Alum and FeCl₃, (A) % Removal NTU, (B) % Removal TOC, (C) pH Scale with 20mg/L Mixture Alum and FeCl₃.



Finally Figure 6 A and B showed clearly that at mixture 25% (25% FeCl₃, 75% Alum) pushes the % removal in advance for both NTU and TOC for NTU % removal 95.4% while for Alum alone 94.8% (0.6% difference) but the most interesting observation is that % TOC removal reaches 68.7%.and 62.5% for mixture 25% and 50% respectively while it was 56.2% for Alum alone and that made a reasonable high difference of 12.5% and 6.3% for TOC removal.

Figure (6) 25 mg/liter Mixture Alum and FeCl₃. (A) % Removal for NTU, (B)% Removal for TOC. (C) pH Scale.

Most researchers pointed out that FeCl₃ is better than Alum in removing NTU and TOC from surface water and related that with the low pH and hardness content. Coagulation pH is dependent on the coagulant type and treated water sample, lowering the pH value for water sample enhances the removal of TOC and DOC, and UV₂₅₄ absorbance. Coagulation pH appeared to be a determining factor for maximum NOM removal and better removal was obtained at pH < 7 than at the initial pH of the water (Mesdaghinia *et al.* 2006).

In this work the pH range 7.2 -7.7 for initial water samples so far from acidic environment for optimum removal for FeCl₃ coagulant. The positive effect on coagulation using Alum with a small addition of FeCl₃ need more understanding of their chemistry in water, the low turbidity surface water contains mainly two types of particles:-

- 1- Inorganics like clay, iron oxides, silicates, calcites, aluminum oxides and many other minerals.
- 2- Organic material produced by decaying vegetation (humic and fulvic acid), organic soils, and biological activity and some of them particulate or soluble or semi soluble.

It seems to be at high dosage 25mg/L the mixture moves the water to a more or near acidic region because of ferric chloride (FeCl₃) and both coagulants worked together

in removing NTU and TOC. However ferric chloride proved to be consistently more effective than alum in removing NOM in water as determined by (Zehra *et al.*, 2009), and that let Alum complete the removal of the remaining colloidal matter.

Conclusions

Using the mixture of coagulants could be a successful choice for enhanced coagulation in minimizing or removal the TOC and NOM in drinking water which done on two coagulants Alum and Ferric chloride belonging to the same nature (metallic) of compounds. This could be very useful in the existing water treatment plant and done without using any extra equipment to get better quality of drinking water from the drinking water treatment plants.

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