IJCPE
Iraqi Journal of Chemical and Petroleum Engineering

Iraqi Journal of Chemical and Petroleum Engineering
Vol.11 No.3 (September 2010) 15 - 22
ISSN: 1997-4884

University of Baghdad
College of Engineering

# USING ALUMINUM REFUSE AS A COAGULANT IN THE COAGULATION AND FLIOCCULATION PROCESSES

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## ABSTRACT

The present work aims to study the efficiency of using aluminum refuse, which is available locally (after dissolving it in sodium hydroxide), with different coagulants like alum [Al2 (SO4)3.18H2O], Ferric chloride FeCl3 and polyaluminum chloride (PACl) to improve the quality of water. The results showed that using this coagulant in the flocculation process gave high results in the removal of turbidity as well as improving the quality of water by precipitating a great deal of ions causing hardness. From the experimental results of the Jar test, the optimum alum dosages are (25, 50 and 70 ppm), ferric chloride dosages are (15, 40 and 60 ppm) and polyaluminum chloride dosages were (10, 35 and 55 ppm) for initial water turbidity (100, 500 and 1000 NTU) respectively. While, adding sodium aluminate with the coagulants (Alum, FeCl3 and PACl), the optimum dose of 50 ppm was enough for the reduction of turbidity and hardness of water.

## INTRODUCTION

Treatment is provided to remove constituents from raw water which may pose a risk to public health or are undesirable in finished water. Turbidity is a characteristic related to the concentration of suspended solid particles in water and has been adopted as an easy and reasonably accurate measure of overall water quality (1). The coagulation-flocculation process is a major step in the production of potable water, allowing the removal of

colloidal particles (2). The main difficulty is to determine the optimum

Coagulant dosage related to the characteristics of raw water. Excessive coagulant overdosing leads to increased treatment costs and public health concerns, while underdosing leads to a failure to meet the water quality targets and less efficient operation of the water treatment plant (3).

Coagulation is the process of conditioning suspended solids particles to promote their agglomeration and produce larger particles that can be more readily removed in subsequent treatment processes (4). Flocculation is the physical process of agglomerating small particles into larger ones that can be more easily removed from suspension. Flocculation is almost always used in conjunction with, and preceded by coagulation. During the coagulation process the repulsive forces between solids particles are reduced or eliminated (5).

Chemicals commonly used in the coagulation process include aluminum or iron salts and organic polymers. The most common aluminum salts used for coagulation is aluminum sulfate (alum) and ferric chloride (FeCl3). In addition, many types of polyaluminum coagulants are commercially available for water treatment, including polyaluminum chlorides (PACl), aluminum chlorohydrate (ACH) and polyaluminum sulfates (PAS) (6, 7). Unlike alum, these products differ in their basicity and strength, and can contain small amounts of other substances, such as sulfate, silica and calcium. Although these coagulants are used successfully in the field for water and wastewater treatment, their chemistry is not as well known as that of alum. Coagulation mechanisms have not been studied extensively, and comprehensive guidelines on their selection and use do not exist (8). Coagulation by itself does not achieve turbidity reduction; in fact turbidity may increase during the coagulation process due to the presences of insoluble compounds generated through chemical addition. The subsequent processes of flocculation, sedimentation, and filtration are used in conjunction with coagulation to achieve suspended solids and turbidity reduction (9).

Sodium aluminate is an important commercial inorganic chemical. It has been used as an effective source of aluminum hydroxide for many applications. The commercial importance of sodium aluminate is due to the versatility of its technological applications. In water treatment systems it is used as an adjunct to water softening systems, as a coagulant to remove suspended solids and some metals (Cr, Ba, Cu), and for removing dissolved silica (10). In construction technology, sodium aluminate is employed to accelerate the solidification of concrete, mainly when working during frosty periods. It is also used in the paper industry, refractory brick production and alumina production, etc. Furthermore, it is used as an intermediate in the production of zeolites for detergents, molecular sieves, adsorbents and catalysts (11).

The main objective of this research is to study the effect of using aluminum refuse as a coagulant for the agglomeration and sedimentation of suspended solids and hardness removal.

## CHEMICAL REACTIONS

The aluminum refuse used in this study was dissolved in sodium hydroxide solution to produce 0.1M from sodium aluminate according to the following equation:

$$\mathbf{2Al + 2NaOH + 2H_2O \longrightarrow Na_2Al_2O_4 + 3H_2}$$

Sodium aluminate aids in the removal process, reacting with the precipitated hardness to form particles that can be removed more effectively. Sodium aluminate, which is alkaline, releases caustic soda and aluminum hydroxide as it dissolves in water:

$$Na_2Al_2O_4 + 4H_2O \longrightarrow 2Al(OH)_3 + 2NaOH$$

$$Na_2Al_2O_4 + Ca(HCO_3)_2 + 2H_2O \longrightarrow 2Al(OH)_3 + Na_2CO_3 + CaCO_3$$

$$Na_2Al_2O + Mg(HCO_3)_2 + 4H_2O \longrightarrow 2Al(OH)_3 + 2NaHCO_3 + Mg(OH)_2$$

The addition of alum (hydrated aluminum sulfate) to water produces insoluble aluminum hydroxide according to the reaction:

$$Al_2(SO_4)_3.18H_2O + 6H_2O \longrightarrow 2Al(OH)_3 + 6H^+ + 3SO_4^{2-} + 18H_2O$$

The insoluble aluminum hydroxide forms the floc where the colloid particles are agglomerated on. While the addition of ferric chloride to water produces insoluble ferric hydroxide, according to the reaction:

$$FeCl_3 + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+ + 3Cl^-$$

Aluminum and iron coagulants react with bicarbonate alkalinity (HCO3) in acid drainage creating aluminum, ferric hydroxide flocs which attract metals in solution through co-precipitation. Formation of hydroxide flocs with alum and ferric chloride can be represented by the following equations (12):

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 18H_2O$$

$$Al_2(SO_4)_3.18H_2O + 3Mg(HCO_3)_2 \longrightarrow Al(OH)_3 + 3MgSO_4 + 6CO_2 + 18H_2O$$

$$2FeCl_3 + 3Ca(HCO_3)_2 \longrightarrow 2Fe(OH)_3 + 3CaCl_2 + 7CO_2$$

$$2FeCl_3 + 3Mg(HCO_3)_2 \longrightarrow 2Fe(OH)_3 + 3MgCl_2 + 7CO_2$$

## Materials and Methods

**Materials:**

- Preparation of water samples: the addition of quantity of kaolin into the water vessel under manual agitation.
- Coagulants: alum [Al2(SO4)3.18H2O], ferric chloride [FeCl3] and polyaluminum chloride (PACl) were used a long with the aluminum refuse.

**Methods:**

- Jar test apparatus: A conventional unit was used with six beakers, each 1000 ml in capacity.
- HACH Surface Scatter Turbidimeter-5: to measure the turbidity of the samples throughout the experimental work in NTU unit.
- pH meter (type pH 1100/ pH 2100): to measure the pH variation during the chemical reaction.

**Procedure:**

- Two main trails were conducted using three initial turbidity contents: 100, 500 and 1000 NTU.
- The first sets of tests were to find the efficiency of turbidity removal using alum, ferric chloride and PACl as individual coagulants. The second trail was to test sodium aluminate with the above coagulants in the removal of turbidity.
- The experimental work (jar test) was performed as:

  Rapid mixing at 100 rpm for 2 min
  Slow mixing at 25 rpm for 30 min
  Allowing the suspension to settle for 30 min

- Samples were withdrawn from the top inch of each beaker for turbidity and pH measurements.
- All the chemical tests and analysis were done according to Standard method for the examination of water and wastewater (13).

## RESULTS AND DISCUSSION

The effect of different coagulants dosages (Alum, FeCl3 and PACl) on turbidity removal is shown in Figs. 1, 2 and 3 for initial turbidities of 100, 500 and 1000 NTU respectively. These Figs. show that the optimum dose for alum was 25, 50 and 70 ppm for 100, 500 and 1000 NTU turbidity respectively. While, for ferric chloride it was 15, 40 and 60 ppm and for polyaluminum chloride 10, 35 and 55 ppm for 100, 500 and 1000 NTU turbidity respectively.

Figs. 4 to 6 show the effect of adding sodium aluminate to alum, FeCl3 and PACl on turbidity removal for the same initial turbidity concentration. In these experiments, the optimum dose for the three coagulants decreased by 50% when adding 20 – 50 ppm sodium aluminate to the tested water samples. As shown in these figures the final turbidity increased when adding more than 50 ppm of sodium aluminate. This may be explained by:

Particulates can be destabilized by adsorption of oppositely charged ions or polymer. Most particulates in natural waters are negatively charged (clays, humic acids, bacteria) in the neutral pH range (pH 6 to 8); consequently, hydrolyzed metal salts and polyaluminum chloride can be used to destabilize particles through charge neutralization. When the proper amount of coagulant has adsorbed, the charge is neutralized and the particle will flocculate. When too much coagulant has been added, the particles will attain a positive charge and become stable once again. For coagulant dosages up to optimum value, the electrophoretic mobility becomes more positive and the amount adsorbed increases. Higher dosage causes charge reversal, particle stability, and a higher residual turbidity (14). At the optimum dosage of coagulant, the particle charge is just neutralized and the collision efficiency reaches a maximum value.

Calcium carbonate hardness is a general term that indicates the total quantity of divalent salts present and does not specifically identify whether calcium, magnesium and/or some other divalent salt is causing water hardness. Figs. 7, 8 and 9 illustrate the effect of the coagulants on hardness variation for different turbidities in the water samples.

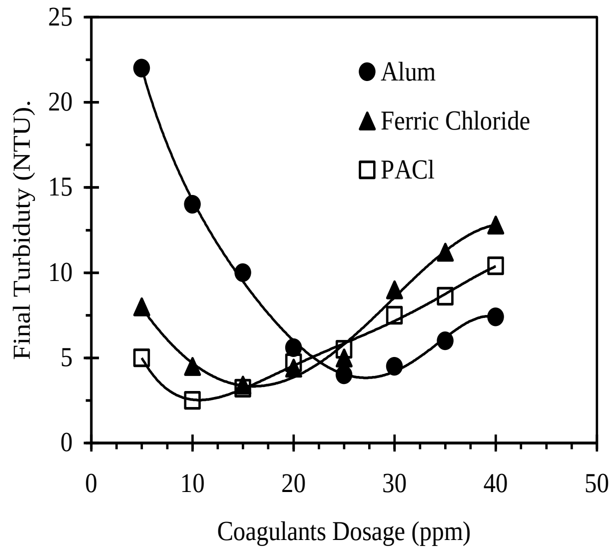


Fig. 1 Effect of Coagulants Dosage on Turbidity Removal (Initial Turbidity = 100 NTU)

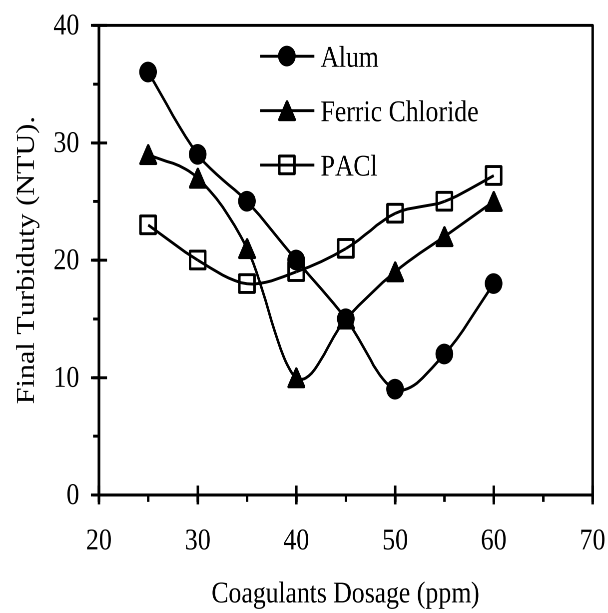


Fig. 2 Effect of Coagulants Dosage on Turbidity Removal (Initial Turbidity = 500 NTU)

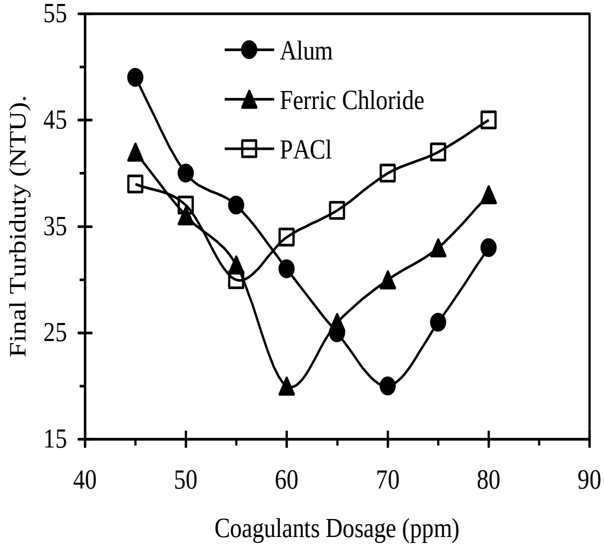


Fig. 3 Effect of Coagulants Dosage on Turbidity Removal (Initial Turbidity = 1000 NTU)

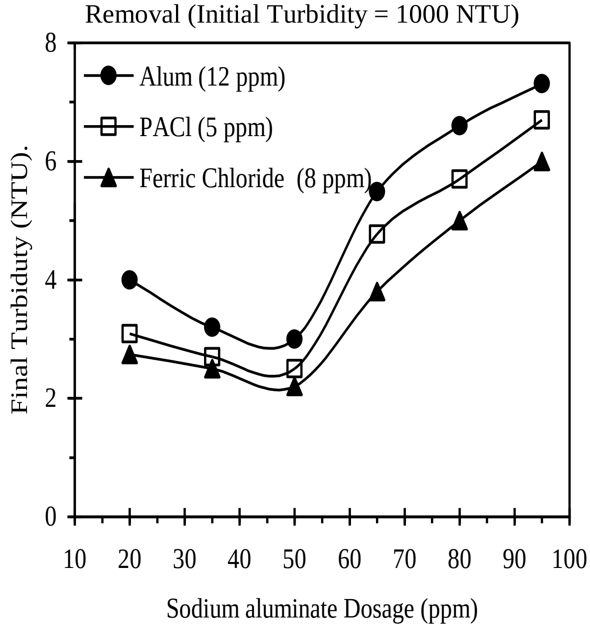


Fig. 4 Effect of Sodium Aluminate Dosage on Turbidity Removal for Different Coagulants (Water Turbidity = 100 NTU, pH = 7.6, Hardness as CaCO3 = 56 mg/l)

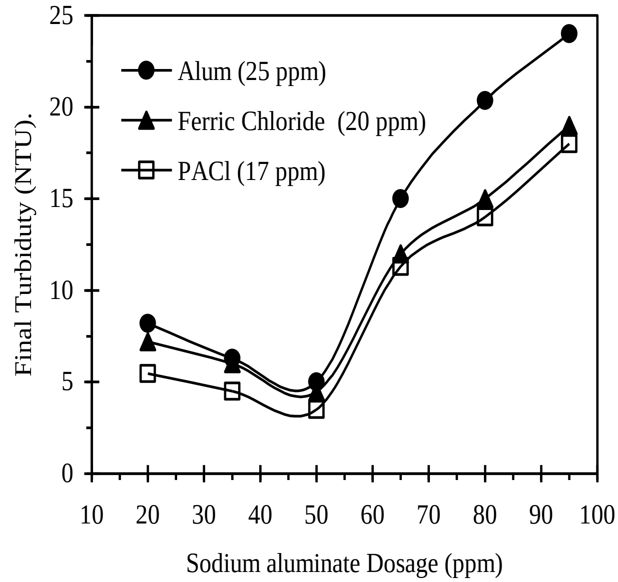


Fig. 5 Effect of Sodium Aluminate Dosage on Turbidity Removal for Different Coagulants (Water Turbidity = 500 NTU, pH = 8, Hardness as CaCO3 = 83 mg/l)

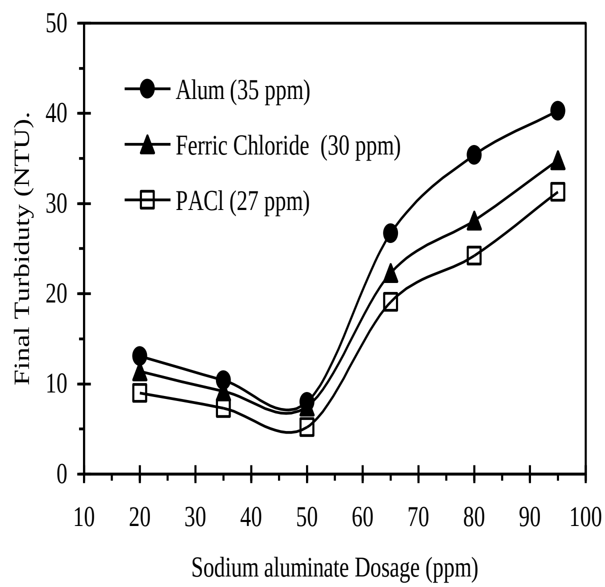


Fig. 6 Effect of Sodium Aluminate Dosage on Turbidity Removal for Different Coagulants (Water Turbidity = 1000 NTU, pH = 8.3, Hardness as CaCO3 = 120 mg/l)

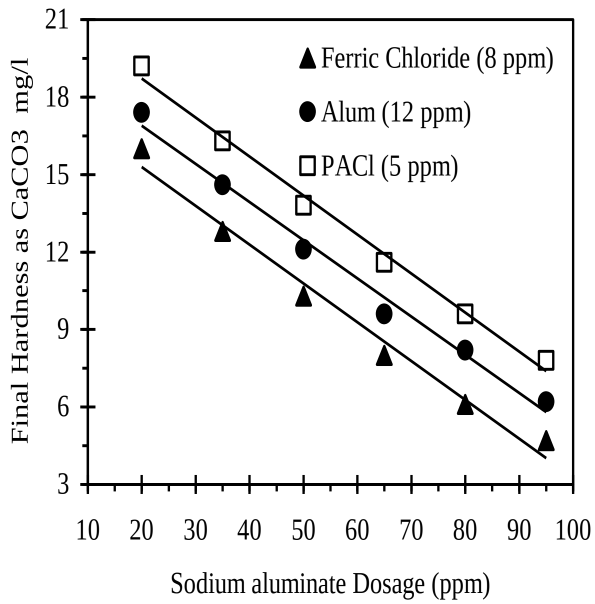


Fig. 7 Effect of Sodium Aluminate Dosage on Hardness for Different Coagulants (Water Turbidity = 100 NTU, pH = 7.6, Hardness as CaCO3 = 56 mg/l)

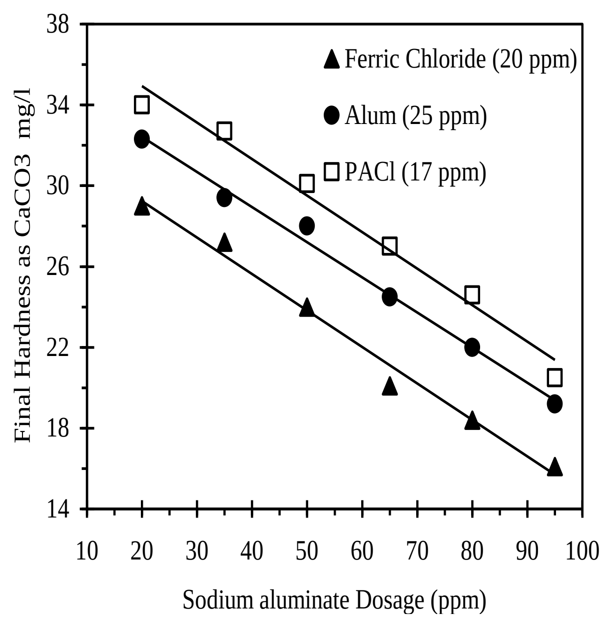


Fig. 8 Effect of Sodium Aluminate Dosage on Hardness for Different Coagulants (Water Turbidity = 500 NTU, pH = 8, Hardness as CaCO3 = 83 mg/l)

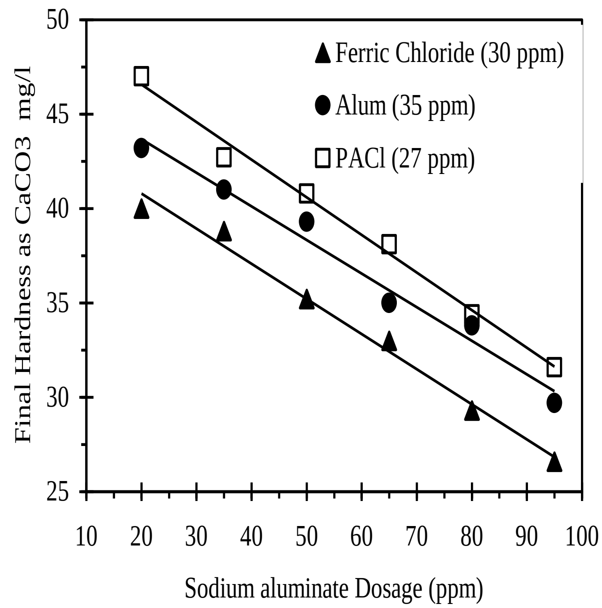


Fig. 9 Effect of Sodium Aluminate Dosage on Hardness for Different Coagulants (Water Turbidity = 1000 NTU, pH = 8.3, Hardness as CaCO3 = 120 mg/l)

## CONCLUSION

1. Adding sodium aluminate with other coagulants such as alum, ferric chloride and PACl in water treatment had a significant effect, which is summarized as:

2. The optimum dose of the coagulants decreased by 50% and high turbidity removal was obtained.

3. The hardness of the tested water decreased to low concentrations.

4. This addition speeds up the coagulation processes which may decrease the treatment time.

5. Reduced amounts of coagulant dose may reduce the cost of the treatment process.

NOMENCLATURE

| Symbol | Definition |
|---|---|
| A | aluminum |
| Cl | chloride |
| P | poly |
| PACl | polyaluminum chloride |

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## الخلاصة

يهدف البحث الى دراسة كفاءة استخدام نفايات الالمنيوم، المتوفرة محلياً (بعد اذابتها في محلول هيدروكسيد الصوديوم)، مع مخثرات مختلفة مثل الشب $[Al_2(SO_4)_3.18H_2O]$، كلوريد الحديديك $FeCl_3$ و بولي المنيوم كلوريد (PACl) لتحسين نوعية الماء. النتائج اوضحت بأن استعمال هذا المخثر في عملية التلبيد اعطى نتائج عالية الى ازالة العكورة بالاضافة الى تحسين نوعية الماء بترسيب الكثير من الايونات التي تسبب عسرة الماء. لقد وجد من النتائج العملية لفحص الجرة، ان الجرعة الامثل للشب هي ( 25، 50 و 70 جزء بالمليون)، الجرعة الامثل لكلوريد الحديد هي ( 15، 40 و 60 جزء بالمليون) والجرعة الامثل لبولي المنيوم كلوريد هي ( 10، 35 و 55 جزء بالمليون) لعكورة الماء ( 100، 500 و1000 وحدة كدرة) على التوالي. بينما، عند اضافة الومينات الصوديوم مع المخثرات (الشب، كلوريد الحديد و بولي المنيوم كلوريد) كانت افضل جرعة 50 جزء بالمليون لتقليل العكورة وعسرة للماء.