



## Removal of Turbidity, Organic Matter, Coliform and Heterotrophic Bacteria by Coagulants Poly Aluminium Chloride from Karoon River Water in Iran

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This study was conducted with the aim of investigating turbidity, coliform bacteria, heterotrophic bacteria removal efficiency with poly aluminum chloride from drinking water. The study was carried out at water treatment plant, in order to determine the optimum conditions of poly aluminum chloride performance in turbidity, coliform bacteria and heterotrophic bacteria removal. All the tests were performed based on variables such as coagulant dose (3, 5, 8, 10, 15, 20, 30, 40, 50 mg/L), pH (5.5, 6, 6.5, 7, 7.5, 8) and turbidity between 33-100 NTU. The residual turbidity and microbial parameters of samples were measured and coagulant performance in turbidity and microbial parameter removal were determined. The results showed that the most optimal conditions for turbidity removal and microbial parameters efficiency by poly aluminum chloride were pH = 8, flash mixing = 120 rpm and the optimal doses of poly aluminum chloride were obtained as 10 and 30 ppm. The turbidity, total coliform, fecal coliform and heterotrophic bacteria removal efficiency under optimum condition of poly aluminum chloride application for dose 10 ppm were, respectively, 96.59, 90, 82.75, 84.17 % while turbidity, total coliform, fecal coliform and heterotrophic bacteria removal efficiency under optimum condition of poly aluminum chloride dose of 30 ppm was 99, 94.65, 88.94, 90.47 %, respectively.

**Key Words:** Water treatment, Coagulation, Poly aluminum chloride, Turbidity, Coliform.

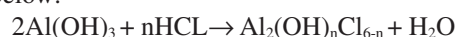
### INTRODUCTION

Coagulants have been long used in water treatment systems. Egyptians used alum as a coagulant almost 2000 years ago. In 1767, the British began to use alum to treat polluted water. In 1884, new orleans company using perchlorates as coagulant patented the first coagulation process. One year later, Rutgers University published results of the first researches on alum indicating that coagulation process as a prerequisite complements filtration<sup>1</sup>.

Different coagulants are used during coagulation process. A coagulant is used to destabilize particles and make them adhere to one another. The main objective is to increase the density of adhered particles and accelerate their deposition<sup>1</sup>. Usually, metal salts such as aluminum sulfate (alum), ferric sulfate, ferrous sulfate, ferric chloride and poly aluminum chloride are used as coagulants while compounds such as sodium aluminates, bentonites, sodium silicates (active sillies) and variety of cationic, anionic and nonionic poly electrolytes are used as additional coagulants during water treatment procedure to remove turbidity<sup>1,2</sup>.

In recent years, extensive researches have been conducted on coagulation process and various coagulants in literature. Poly-aluminum chloride (PAC) with formula  $Al_2(OH)_nCl_{6-n}$  is a pre-polymerized coagulant which has been used extensively in recent years in such that it has becomes one of the most common coagulants in different water and wastewater treatment plants in countries such as US, Canada, China, Italy, France and Britain<sup>3</sup>.

Poly aluminum chloride or hydrated aluminum chloride is a mineral macromolecule whose monomers are consisted of a dual-core complex aluminum<sup>4</sup>. This compound forms multi-core complex in wet environment and this unique characteristic helps poly aluminum chloride work efficiently during coagulation process. Poly aluminum chloride has a polymer structure with general formula  $(Al_3(OH)_{b-x}Cl_x \cdot YH_2O)_z$ , which is a product of aluminum hydroxide reaction with choleric acid as below:



Z varies from 12 to 18, but for proper formulation it is equal to 15 in 95 % of chemical combinations<sup>5</sup>. Aluminum has a polymer structure in poly aluminum chloride molecules.

However, in some of its variations, sulfate and mineral salts such as sodium, potassium, calcium, chloride, *etc.*, are found which is unlike aluminum sulfate where a small portion appears as monomer. In a poly aluminum chloride molecule, a large portion of aluminum appears in form of large oligomer polymers of Al cations with +7 ions as  $[Al_{13}(OH)_{24}O_4(H_2O)]^6$ .

The advantages of poly aluminum chloride leading to the increase of effective use in water and wastewater treatment plants are: wide pH ranges, less sensitive to temperature<sup>2,7</sup>, decrease in the coagulant dose and less produced sludge during treatment process<sup>8</sup>.

Advantages of poly aluminum chloride can be summarized as follows. It flocculates rapidly, thus it needs less time to react and deposit. By using a constant dose of coagulants, lower pH results from less poly aluminum chloride used in comparison to other coagulants, especially when water is excessively turbid, pH of treated water should be adjusted in a short time.

The aim of the present study is to determine the optimum conditions for poly aluminum chloride to remove turbidity, total coliform bacteria and heterotrophic bacteria from treated water of Ahwaz Water Treatment Plant, Iran.

## EXPERIMENTAL

The present study was conducted at Ahwaz Water Treatment Plant No. 2 in 2009 using JLT6 as testing device. Raw water sample was taken from inflow to the treatment plant and the following experiments were performed:

(1) Determination of pH, turbidity, alkalinity of raw water sample.

(2) Optimum pH: pH of raw water samples in ranges of 5, 5.5, 6, 6.5, 7, 7.5, 8 and its normal pH were adjusted and JAR test was carried out on raw water samples. pH adjustment was done by choleric acid and normal 0.01 hydroxide sodium.

(3) For determination of optimum poly aluminum chloride dose, concentrations of 3, 5, 8, 10, 15, 20, 25, 30, 40 and 50 mg/L were used.

(4) For determination of optimum rapid entrainment rate, speeds of 80, 100 and 120 rpm were used.

(5) Turbidity, total coliform, heterotrophic bacteria removal, pH, alkalinity and the amount of deposited sludge under optimum conditions were also determined using JLT6. Rapid mix [coagulation] with 120 rpm continued for one minute while slow agitation [flocculation] with 30 rpm went on for 10 min, with 20 rpm for 10 min and with 10 rpm for 10 min. After flocculation, the solution was then allowed to settle for 30 min. Then, samples were taken from 5 cm beneath water surface inside JLT6 using a pipet. At the end of each stage, the effect of each parameter on turbidity removal was determined using covariance and Duncan analyses and the related graphs were depicted in an MS Excel Sheet and ( $P < 0.05$ ) was significant.

## RESULTS AND DISCUSSION

**Effect of pH on coagulation performance:** The effect of the solution pH on the removal of COD during coagulation and flocculation was studied at the pH values equal to 5, 5.5, 6, 6.5, 7, 7.5 and 8. pH affects the balance between the

reactions of organic functional groups with hydrogen ions or hydrolyzed Al(III) products. The results of these tests are presented in the Fig. 1.

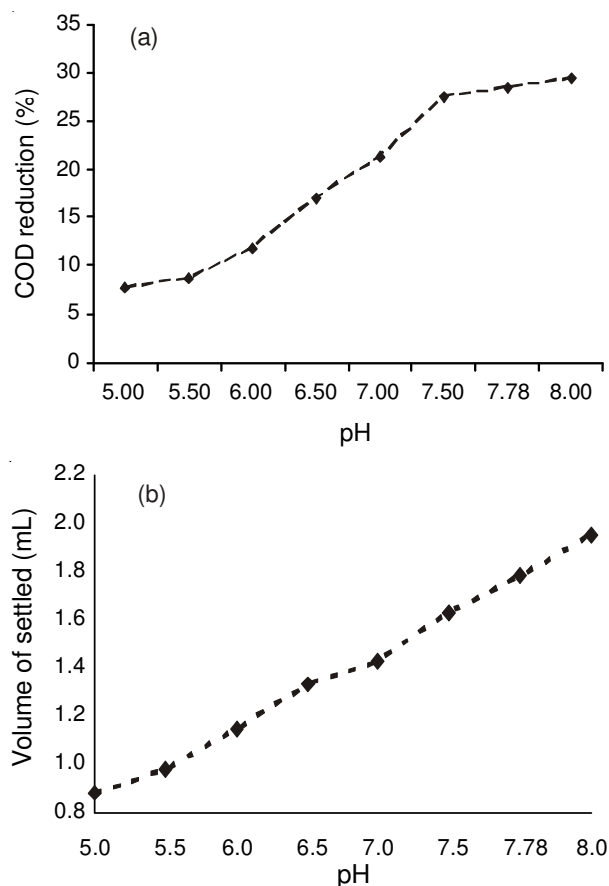


Fig. 1. Effect of pH on (a) COD, (b) volume of settled sludge

As it can be inferred from Fig. 1(a), the removal of COD from water during coagulation for poly aluminum chloride was strongly affected by the pH of the solution. The results show that the COD reduction is gradually improved with increasing solution pH. It may be stated that the higher removal rate was observed at a higher solution pH. The results of the experiments indicate that the optimal value for the COD removal was pH = 8. At the poly aluminum chloride optimum pH of 8, COD reduction is 29.47%. The average COD to the system is 7.62 mg/L.

Fig. 1(b) shows the effect of the solution pH on the volume of settled sludge during coagulation and flocculation. The volume of settled sludge was studied at the pH values equal to 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0. A review of Fig. 1(b) shows that with the decrease of pH, the volume of settled sludge decreases and the fine flocs were produced that these were settled slowly.

Fig. 2 shows the effect of pH on turbidity removal and indicates that as pH increases, turbidity removal effectiveness increases. The highest average per cent of turbidity removal equal to 93.90% which occurs at pH = 8.

### Effect of mixing speed on coagulation performance:

In this study, rapid mixing speed of 80, 100 and 120 rpm were used with respect to covariance test ( $P < 0.05$ ) which had significant difference with these. Turbidity removal efficiency for mixing speed of 120 rpm was more optimal. The average

turbidity removal efficiency for 80, 100 and 120 rpm were 95.83, 95.98 and 96.88 %, respectively (Fig. 3).

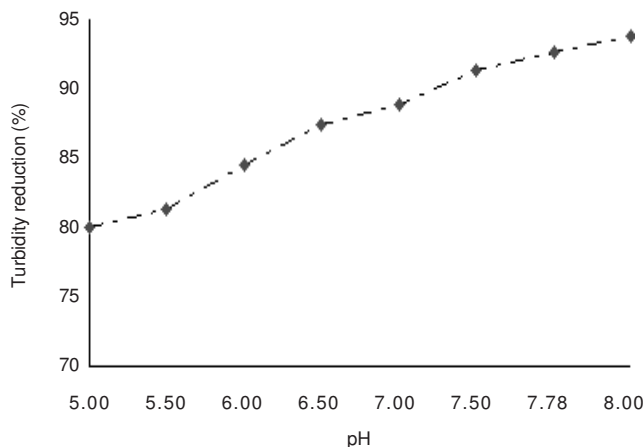


Fig. 2. Effect of pH on per cent of turbidity reduction

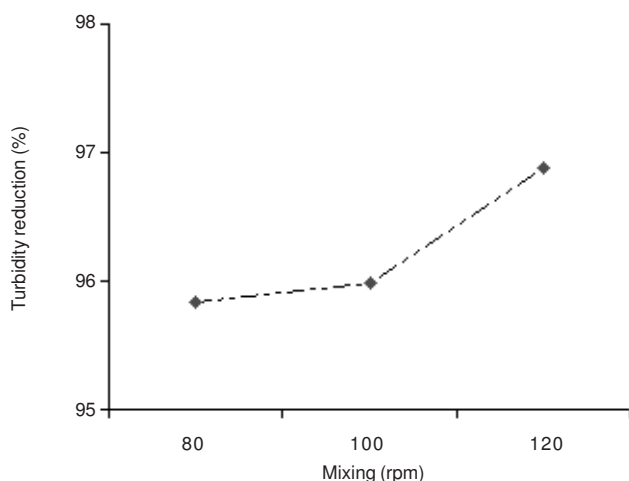


Fig. 3. Effect of mixing speed on per cent of turbidity removal

**Effect of poly aluminum chloride dose on turbidity removal:** Fig. 4 and 5 show the effect of poly aluminum chloride on turbidity removal. Fig. 4 indicates that as the coagulant dose increases, turbidity removal efficiency increases in such that turbidity removal of 97.98 % with confidence of 95 % at 50 ppm is obtained. Regarding the results of Covariance test ( $P < 0.05$ ) a significant difference can be found between coagulant dose and turbidity reduction. However, regarding the results, the turbidity removal efficiency for 5 ppm of poly aluminum chloride show the lowest efficiency while doses of 10 to 50 ppm show no significant difference. Hence, poly aluminum chloride doses of 10 and 30 ppm were used for the purpose of this study. When charge neutrality dominates the coagulant mechanism, some of the particles in water, adsorb  $Al^{3+}$  or its variation unevenly, contain positive charge and flocculate with negative particles. There also exist many particles that can't congregate with other particles and they can be therefore considered as residual turbidity. Normally, the flocs formed by charge neutralization could be more compact in structure.

When sweep flocculation dominates the coagulate mechanism, almost all the particles will trap positive charge,

while only a small portion of particles trap few positive charges and remain negative charged. These two species of particles can coagulate sufficiently with each other.

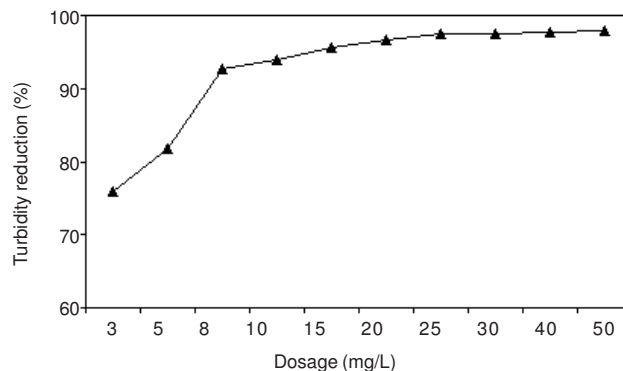


Fig. 4. Effect of poly aluminum chloride dosage on per cent of turbidity removal

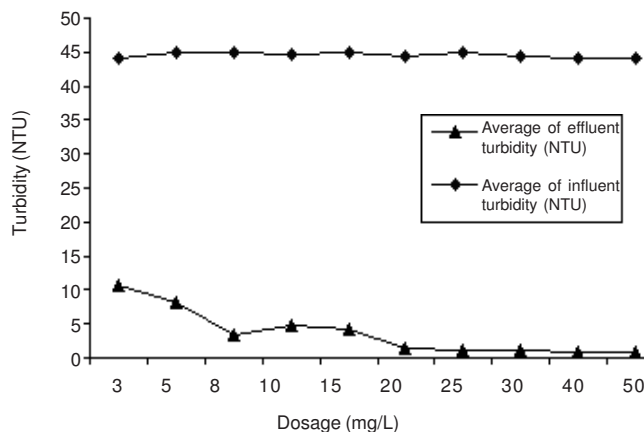


Fig. 5. Effect poly aluminum chloride dosage on turbidity removal

#### Effect of poly aluminum chloride dose on pH variations:

In coagulation-flocculation processes using inorganic coagulant, coagulant dosage and pH play an important role in determining the coagulation efficiency. In water treatment using inorganic coagulants, an optimum pH range in which metal hydroxide precipitates occur, should be determined. The addition of metal coagulants depresses the water pH to a lower value. The effect of poly aluminum chloride dose on pH variations are shown in Fig. 6. The change of solution pH occurred because the metal coagulants are acidic and they can consume large amounts of raw water alkalinity, dependent on the coagulant type. Higher alkalinity means more  $OH^-$  could be provided to meet the consumption of coagulant hydrolysis; solution pH is then more stable as coagulant was added. For water with lower alkalinity, pH decreases more obviously with dose increase. Alkalinity consumption is also related to the basicity of poly aluminum chloridel. By adding 80 mg/L of poly aluminum chloride, pH was reduced from 8 to 7.84.

**Effect of poly aluminum chloride dose on raw water alkalinity:** Fig. 7 shows effect of poly aluminum chloride on water alkalinity. Fig. 7 indicates that as the amount of poly aluminum chloride increases, the alkalinity of samples decreases. The best relationship between poly aluminum chloride dose and pH is nonlinear with a coefficient of  $R^2 = 0.9877$ .

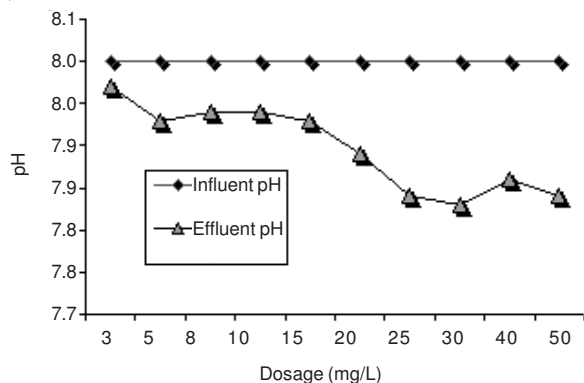


Fig. 6. Effect of poly aluminum chloride dosage on pH

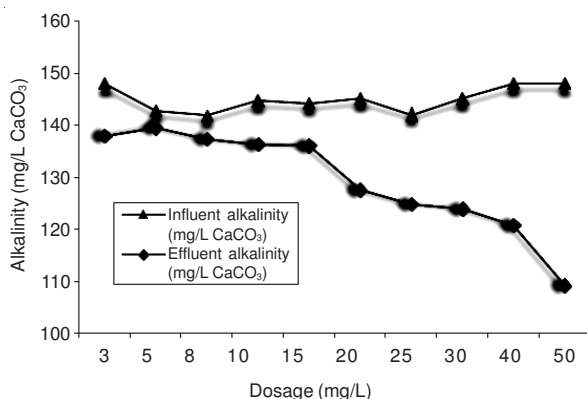


Fig. 7. Effect of poly aluminum chloride dosage on alkalinity

**Effect of poly aluminum chloride dose on settled sludge volume:**

The sludge produced in the physical-chemical treatment is due to the amount of organic matter and total solids in suspension that are removed and the compounds formed from the coagulant used, since practically almost all of the latter will form part of the sludge solids. In general, the amount and characteristics of the sludge produced during the coagulation flocculation process depend on the coagulants used and on the operating conditions. Fig. 8 shows the effect of poly aluminum chloride on deposited sludge volume in mL/L. Fig. 8 indicates that by the increase of coagulant dose, the settled sludge volume increases. This is consistent with a sweep floc mechanism, where the volume of precipitate formed is proportional to dosage. The results show that by the increase of coagulants, the flocculants are smaller, lighter and less stable with lower deposition rate in such that the tips of flocculants were observed in poly aluminum chloride doses of 10 to 20 ppm.

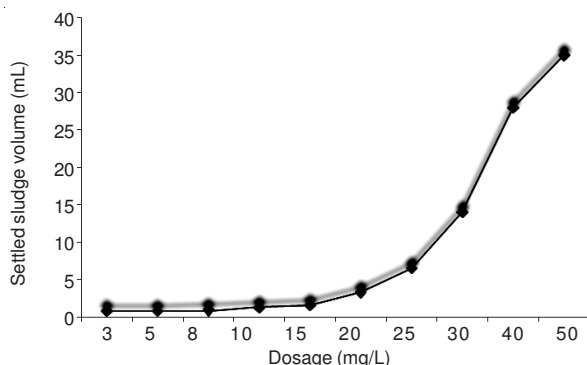


Fig. 8. Effect of poly aluminum chloride dosage on settled sludge volume

**Determination of turbidity, total coliform, fecal coliform and heterotrophic bacteria removal efficiency under optimal poly aluminum chloride performance conditions:**

After determining of the optimal conditions, turbidity, COD, total coliform, fecal coliform and heterotrophic bacteria removal efficiency of samples under pH =8 and poly aluminum chloride dose of 10 and 30 mg/L with rapid mixing speed of 120 rpm were measured. The results of ‘t’ test showed that the difference between turbidity removal efficiency for poly aluminum chloride of 10 and 30 mg/L with ( $P > 0.05$ ) is significantly meaningful. According to Fig. 9, one can observe that poly aluminum chloride dose of 30 ppm, turbidity removal efficiency was 99 %. Since ( $P > 0.05$ ), no significant difference was found between fecal coliform and COD with coagulant dose. If a significant difference is observed between heterotrophic bacteria removal and poly aluminum chloride dose with ( $P < 0.05$ ) (Fig. 10) shows that with the increase of poly aluminum chloride dose, heterotrophic bacteria removal efficiency increases in as such that for 30 ppm poly aluminum chloride, the highest heterotrophic bacteria removal of 90.47 % is obtained.

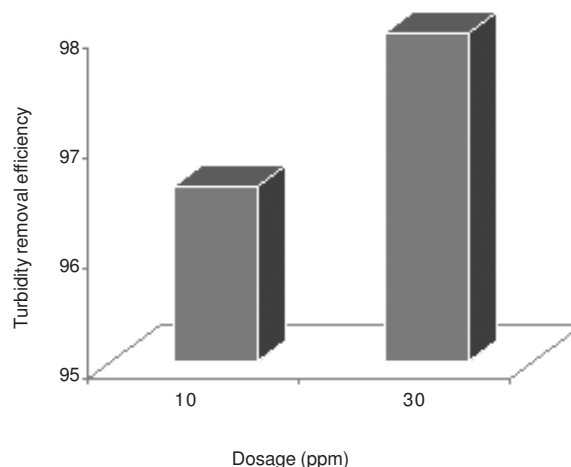


Fig. 9. Average of turbidity removal per cents for poly aluminum chloride dose of 10 and 30 mg/L

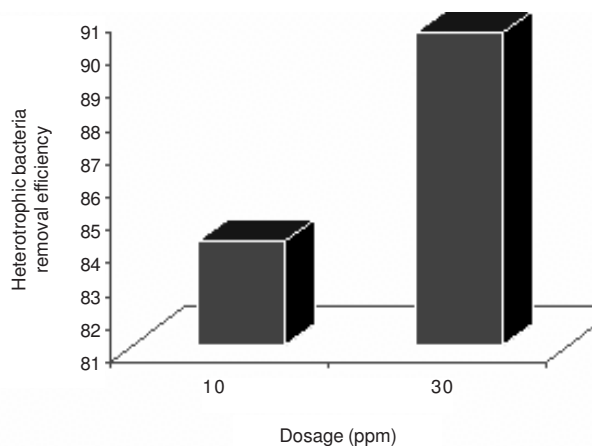


Fig. 10. Average of heterotrophic bacteria removal per cents for poly aluminum chloride dose of 10 and 30 mg/L

It is reported<sup>4</sup> that the average turbidity, total coliform and TOC removal percents for alum were 92.1, 94.43 and 40.43 %, respectively.

respectively. The average turbidity, total coliform and TOC removal percents for ferric chloric were 95.74, 97.80 and 55.60 % and for poly aluminum chloride were 95.30, 97.30 and 42.02, respectively<sup>4</sup>.

Shamsaee *et al.*<sup>9</sup> found that the turbidity removal with 50 % poly aluminum chloride was higher than that of ferric chloric while water clearness was increased between 40 to 60 %. Using poly aluminum chloride also reduced the produced silt volume down to 40 % indicating reduced water loss resulting from silt discharge. Using poly aluminum chloride as compared to ferric chloric resulting in reduced pH in such that no further assisting coagulant would be required<sup>9</sup>.

Bina *et al.*<sup>10</sup> obtained the optimal poly aluminum chloride dose (30 mL/g) for turbidity removal of 1000 NTU and pH of 8. poly aluminum chloride of 30 mL/g removed 99.6 % of turbidity of 1000 NTU, finally reducing turbidity to 4 NTU.

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