The application of Polyaluminium Ferric Chloride for Turbidity and Color Removal from Low to Medium Turbid Water

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Background & Aims of the Study: Coagulation is an essential process for the removal of fine particulate matter in water treatment. Polyaluminium ferric chloride (PAFC) is a composite inorganic polymer of Aluminium and ferric salt. This study was conducted to find out the optimum coagulation conditions for the removal of turbidity, color and organic matter (UV absorbance) in low to medium turbid water.

Materials & Methods: For evaluation of the coagulation procedure, conventional Jar Test apparatus was used. Low to medium synthetic turbid water (10 to 60 NTU) was prepared by kaolin and river bed soli. Then all samples were analyzed for residual turbidity, true color, UV absorbance, residual Aluminium (Al^{3+}), Iron (Fe^{2+}), and residual heavy metals like Arsenic, Lead, Nickel and Chromium.

Results: Optimum dose of PAFC for first, second, third and fourth sample with initial turbidity of 10, 20, 40 and 60 NTU was 7, 10, 11 and 11 mg/L respectively. After coagulation with optimum dose, residual turbidity in treated water was 0.4, 0.34, 0.28 and 0.3 NTU respectively. Also color removal efficiency for mentioned samples was 97%, 98%, 99% and 99% respectively at optimum dose PAFC. Optimum pH for maximum removal with PAFC was 7.8 (pH range 7.5 to 8).

Conclusions: Polyaluminium ferric chloride has a good efficiency for removal of turbidity, color and organic matter. It can be select as a new coagulant for water treatment plants. Also residual Aluminium, Iron and some heavy metals (chromium, lead, cadmium and nickel) in treated water was investigated. Their concentration in treated water didn't have any adverse effect on consumer health according to their standards in EPA.

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Background

Natural surface waters are usually polluted by organic or inorganic impurities. The colloidal dispersion due to electrostatic repulsive forces is stable. Water treatment plants remove these impurities by sedimentation and filtration, following the processing of water by coagulation/flocculation (1,2). Natural organic matter (NOM) is a chemically complex and heterogeneous mixture of organic material broken down from decaying plant and animal origins. NOM is crudely quantified as total organic carbon (TOC) which is the combination of particulate organic carbon and largely dissolved organic carbon (DOC). Natural organic matter acts as a precursor to disinfection by-products (3-5). Concern related to NOM in potable water including taste and odor, fouling of membranes, slime growth in distribution systems and react with chlorine to form disinfection byproducts (DBPs). These compounds have been linked to the development of various cancers and birth defects (6-9).

Turbidity is an important physical characteristic of water. It is caused by suspended matter or impurities like clay, silt, finely divided inorganic and organic matter, soluble colored organic compounds, and plankton and other microscopic organisms. Turbidity is also an important operational parameter in process control and can indicate problems with treatment processes, particularly coagulation/sedimentation and filtration. The turbidity levels in the water to be disinfected must be <1.0 NTU. High levels of turbidity can protect microorganisms from the effects of disinfection and may also indicate Cryptosporidium can break through the filters and enter the water supply. Changes in turbidity are an important process control parameter (10,11).

A very important step in water treatment that essential for the removal of fine particulate matter is coagulation-flocculation process. It is involving colloid charge neutralization followed by aggregation into floc that are amenable to separate with subsequent processes such as sedimentation or filtration (12-14). Addition to conventional coagulant, Interest to more efficient treatment, especially regarding the removal of suspended solid, colloidal particles and NOM, has lead to the development of a new category of coagulants in term of Inorganic Polymeric Flocculants (IPFs). Polyaluminium ferric chloride (PAFC) is a composite inorganic polymer that has both the characteristics of aluminium and iron coagulants (15,16).

Aims of the study: The aim of this study is to find out the optimum coagulation conditions and suitability of PAFC for the removal turbidity, color, and organic material absorb UV 254 in low to medium turbid water and also determination of residual Aluminium (Al^{3+}), Iron (Fe^{2+}) and some heavy metals in treated water.

Materials & Methods

In this study, four synthetic turbid samples of water with low to medium turbidity of 10, 20, 40 and 60 NTU was prepared. Table 1 shows the characteristics of the samples. The coagulation was carried out according to Jar Test at 6 beakers of 1000 ml volume with rapid mixing at 120 rpm for 2 minutes, flocculation with slow mixing at 40 rpm for 10 min and settlement by a settling period of 20 min. Samples of the treated water were collected at a depth of 2.5 cm below the supernatant surface. All samples were analyzed for residual turbidity, true color, UV 254 nm, residual Aluminium (Al^{3+}), Iron (Fe^{2+}), and residual heavy metals like Arsenic, Lead, Nickel and Chromium. All examination was conducted according to standard method for examination of water and wastewater (17). Turbidity, Color, UV absorbance at 254 nm, TDS & EC and pH of samples were measured by TN-100(EUTECH) Turbidimeter, DR 5000- HACH LANGE, DR 5000- HACH LANGE, EC meter SENSION5 (HACH LANGE) and pH-meter CG 824 model respectively. For true color and UV absorbance at 254 nm procedures, treated water has been passed through a 0.45-µm filter.

UV absorbance at 254 nm reported in cm^{-1}. The specific ultraviolet absorbance (SUVA) was expressed as a ratio between UV254 and DOC values.

Preparation of turbidity: 10 grams of kaolin, heavy grade (BDH Chemicals) was added to 2 liter distilled water. 0.5 kg of river bed soli added to 2 liter of distilled water and mixed for 1 hour. Then after sedimentation about 30 minutes, suspended solution up to sediment added to prepared kaolin solution. Total volume was made up to 4 liter. The suspension was stirred slowly at 30 rpm for 24 hours for hydration of the particles and uniform dispersion (18). Then the stock solution was used in the preparation of varied water turbidity of 10, 20, 40 and 60 NTU by serial dilution.

The adjustment of pH was conducted with 0.1 M H_2SO_4 solution or 0.1 M NaOH solution.

For optimal pH selection, constant dose of PAFC was added to sample and jar test conducted at various pH. The best output in cording to maximum removal selected as optimum pH. Of course latest study showed that best pH for PAFC performance was 7 to 8. Based on optimal pH, selection of optimal polyaluminium ferric chloride dose was carried out.

Table1) Characteristics of samples before coagulation

parameter	Sample1	Sample 2	Sample 3	Sample 4
Turbidity (NTU)	10	20	40	60
Color (Pt.Co)	35	47	78	122
EC (µs/cm)	358	355	359	351
TDS (mg/L)	178	175	177	173
pH	7.8	7.8	7.8	7.8
UV 254 nm (cm^{-1})	0.058	0.072	0.088	0.09
Fe (mg/L)	0.154	0.170	0.195	0.215
Al (mg/L)	0.005	0.009	0.013	0.017
Temperature ^{0}C	22	22	22	22
TOC mg/L	2	3.1	11	18
Sludge volume (ml/L)	negligible	0.1	0.15	0.2

Results

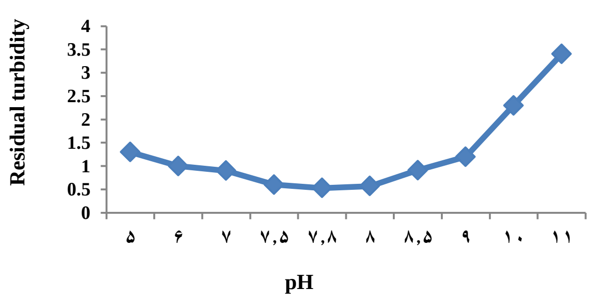

Figure 1) Optimum pH selection base 6 mg/L of PAFC. Initial turbidity of raw water sample was10 NTU. Residual turbidity at pH 7.5 to 8 was ≤ 0.6 and best results happened at pH 7.8.

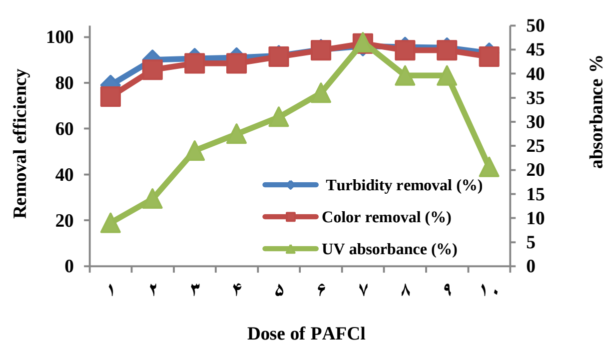

Figure 2) Optimum polyAluminium ferric chloride dose selection based on pH 7.8, This diagram show the removal efficiency of turbidity and color with UV absorbance percent at optimum dose (initial turbidity, color and UV absorbance of raw water was 10 NTU, 35 Pt. C_o units and 0.058 cm^{-1})

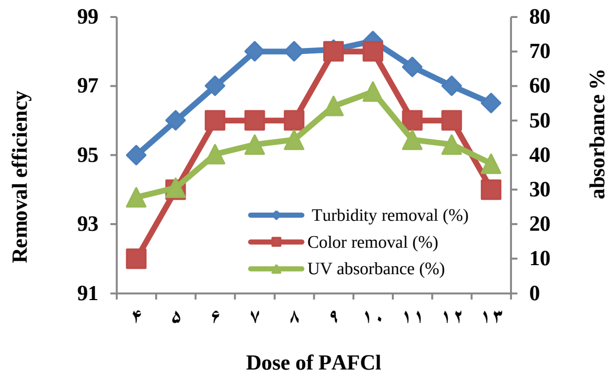

Figure 3) Optimum polyAluminium ferric chloride dose selection based on pH 7.8. This diagram show the removal efficiency of turbidity and color with UV absorbance percent at optimum dose – 10 mg/L- (initial turbidity, color and UV absorbance of raw water was 20 NTU, 47 Pt. C_o units and 0.072 cm^{-1})

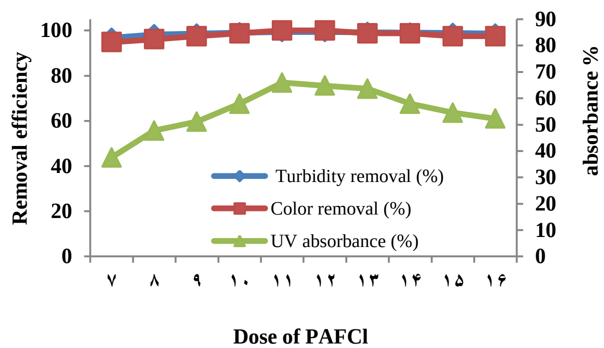

Figure 4) Optimum polyAluminium ferric chloride dose selection based on pH 7.8. This diagram shows the Removal efficiency of PAFC for removal of turbidity, color and UV 254nm absorbance at optimum dose (11 mg/L), initial turbidity, color and UV 254nm absorbance was 40 NTU, 78 Pt. C_o units and 0.088 cm^{-1} respectively

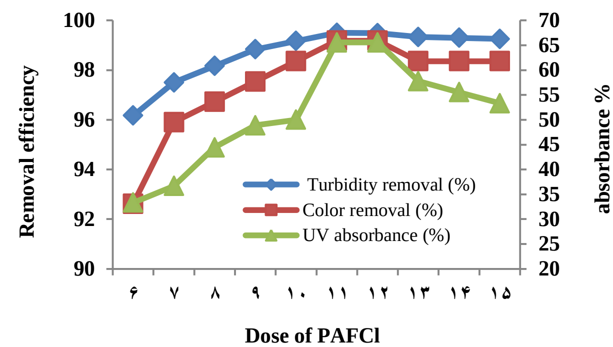

Figure 5) Removal efficiency of PAFC for removal of turbidity, color and UV 254nm absorbance at optimum dose (11 mg/L), initial turbidity, color and UV 254nm absorbance was 60 NTU, 122 Pt. C_o units and 0.09 cm^{-1} respectively.

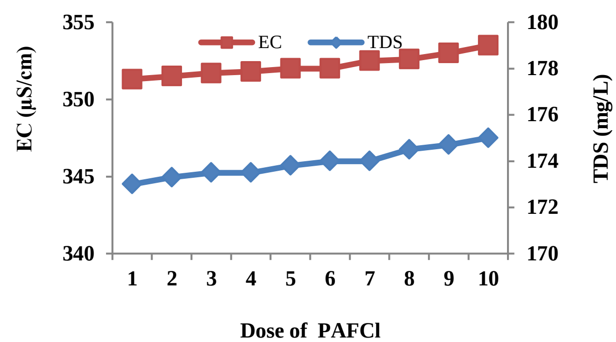

Figure 6) TDS & EC variation in treated water with PAFC, optimum dose was 7 mg/L.

Table 2) the concentration of heavy metals before and after coagulation، Amounts of UVA254 nm and SUVA after coagulation with PAFC

Heavy metals	Sample 1		Sample 2		Sample 3		Sample 4	
	C.B.Co*	C.A.Co**	C.B.Co*	C.A.Co**	C.B.Co*	C.A.Co**	C.B.Co*	C.A.Co**
Al (µg/L)	5	9	9	13	13	18	17	23
As (µg/L)	1.187	1.187	1.27	1.27	1.31	1.31	1.39	1.39
Cd (µg/L)	0.049	0.049	0.052	0.052	0.055	0.055	0.059	0.059
Co (µg/L)	1	1	1.4	1.4	1.7	1.7	2	2
Cr (µg/L)	5	4	7	4	9	5	13	7
Cu (µg/L)	39	15	43	18	51	20	61	21
Fe (µg/L)	154	42	170	48	195	55	215	62
Ni (µg/L)	0.286	0.286	0.298	0.298	0.33	0.33	0.41	0.41
Pb (µg/L)	8	2.1	10	2.2	13.4	3	17.2	3.25
UVA-254nm (cm^{-1})	0.058	0.03	0.072	0.03	0.088	0.03	0.09	0.031
SUVA* **	3.86	2.97	3.28	4	1.06	3.84	0.66	4.3

*** Concentration before coagulation.** ***** SUVA=** $\frac{(\text{uv 254 in} \frac{1}{cm})100}{\text{DOC in mg/l}}$

**** Concentration after coagulation.**

Discussion

Optimum pH selection

Effective chemical coagulation of water occurs only within a specific pH range. Optimal pH determination is very important in coagulation processes. Lower and higher amount of pH from optimum range can cause problems like high residual of color, turbidity and metals in the finished water. Figure 1 shows the optimum pH selection base 6 mg/L of PAFC. In this examination pH range from 5 to 11 selected to coagulation at 6 mg/L dose of PAFC. It can be showed that effective pH for maximum removal of turbidity was 7.8 or pH range 7.5 to 8. For turbidity goal ≤1 NTU pH range can be selected as 6 to 9. Other researchers have stated as the pH value is in the range of 7.0 to 8.4, the low positive-charge and high-polymerized species of PAFC could effectively make kaolin particles destabilize by charge-neutralization and adsorption- bridge function, so excellent coagulation performance can be achieved (13).

Optimum dose selection for removal of turbidity, color and UV 254

After optimum pH selection, determination of optimum polyAluminium ferric chloride dose was conducted. For first raw water sample with initial turbidity, color and UV absorbance of 10 NTU, 35 Pt. Co units and 0.058 cm^{-1} it can be seen (Figure 2) that by 2 mg/L of PAFC turbidity removal efficiency reached to 96% (residual turbidity equal to 1 NTU). Maximum removal efficiency of turbidity, color and UV 254nm absorbance was observed at optimum dose of 7 mg/L. The percent removals increase as the PAFC dose increases until reach to optimum dose. In this situation removal efficiency for turbidity, color and UV 254nm absorbance was 96%, 97.1% and 46.5% respectively. In other words after coagulation, initial turbidity, color and UV 254nm absorbance from 10 NTU, 35 Pt.Co units and 0.058 cm^{-1} reached to 0.4 NTU, 1 Pt.Co units and 0.03 cm^{-1} respectively. Other research (13) showed that PAFC removes approximately 100% of the color at dosages of more than 10 mg/L. PAFC is an inorganic polymer and can aggregate the destabilized dyes together by adsorption-bridge function of the coagulant. So dyes can be separated from water by coagulation of PAFC. The results of coagulation by PAFC on second sample can be seen in Figure 3. Initial turbidity, true color and UV 254nm absorbance of second sample was 20 NTU, 47 Pt.Co units and 0.072 cm^{-1}respectively. Optimum dose for second sample was 10 mg/L. At this dose residual turbidity, color and UV 254nm absorbance was 0.34 NTU, 1Pt.Co units and 0.03 cm^{-1} respectively. In this stage removal efficiency for turbidity, color and UV 254nm absorbance was 98.3%, 98% and 58% respectively (Figure 3). With application of 4 mg/L of PAFC residual turbidity was reached to 1 NTU. The residual turbidity was decrease as the PAFC dose increases and maximum depletion of turbidity occur at optimum dose (10 mg/L). Increasing dosage resulted in increasing residual turbidity' implying restabilization of destabilized flocs during the coagulation process (19). The percent removals increase as the PAFC dose increases until reach to optimum dose. The results of coagulation studies on sample 3 model turbid water with initial turbidity of 40 NTU can be seen in Figure 4. It was observed that from a rapid reduction in residual turbidity to 0.28 NTU at 11mg/L of PAFC (selected as optimum dose). At this dose color from 78 1Pt.Co units was reached to zero Pt.Co unitss and UV 254nm absorbance from 0.088 cm^{-1} was reached to 0.03 cm^{-1}. In this stage removal efficiency for turbidity, color and UV 254nm absorbance was 99%, 100% and 66% respectively. The residual turbidity was decrease as the PAFC dose increases until get to optimum dose, after this Increasing dosage resulted in increasing residual turbidity' implying restabilization of destabilized flocs during the coagulation process. If object of coagulation is 1 NTU of residual turbidity, with application of 7 mg/L this goal may be achievable. Results of coagulation studies on sample 4 model turbid water with initial turbidity of 60 NTU can be seen in Figure 5. It was observed that from a rapid reduction in residual turbidity to 0.3 NTU at 11mg/L of PAFC (selected as optimum dose). At this dose color from 122 Pt.Co units was reached to 1 Pt.Co units and UV 254nm absorbance from 0.09 cm^{-1} was reached to 0.031 cm^{-1}. In this stage removal efficiency for turbidity, color and UV 254nm absorbance was 99.5%, 99.2% and 66% respectively (Figure 5). The residual turbidity was decrease as the PAFC dose increases until get to optimum dose, after this point Increasing dosage resulted in increasing residual turbidity.

In 1984, WHO guidelines recommended turbidity should be maintained at less than 5 NTU, but if water was disinfected, it would be better to aim for values of less than 1 NTU (20). In the 1980s and 1990s, there was recognition that several outbreaks were caused by Giardia whose cysts was found to be much more resistant to disinfection than bacteria and viruses. The U.S. Environmental Protection Agency (USEPA) decided to require all surface water sources to be filtered and set a 1 NTU level (21). In this study results shown that coagulation of water with initial turbidity of 60 NTU with PAFC can reduce turbidity to 0.3 NTU. It is very important as a point of view for production of safe water, reduction of loading rate in filters and finally reduction of operation and maintenance cost for subsequent processor plant after coagulation.

Effect of PAFC on TDS and EC

Inorganic coagulants especially conventional coagulants will increase the total dissolved solids concentration of the treated water. In this study initial TDS and EC for first, second, third and fourth sample were 178 mg/L and 358 µs/cm, 175 mg/L and 355µs/cm, 177 mg/L and 359µs/cm and 173 mg/L and 351µs/cm respectively before coagulation. After coagulation this parameter reached to 180 mg/L and 361 µs/cm, 177 mg/L and 360µs/cm, 177.8 mg/L and 360.3µs/cm and 174 mg/L and 352µs/cm respectively. So addition of PAFC didn’t have any magnitude effect on amount of TDS and EC of treated water (Figure 6). Other study showed that use of chemicals such as polyAluminium chloride and polyAluminium hydroxychloride could result in a smaller or even negligible increase in TDS (22).

Alkalinity and pH variation in treated water

Inorganic coagulants will decrease the alkalinity of water as a consequence the pH of the chemically dosed raw water will decrease. In this study, application of PAFC didn’t have very adverse effect on pH reduction. For all samples application of 7 mg/L, 10 mg/L, 11 mg/L and 11 mg/L (as optimum dose) only 0.1 units reduction happened to pH. So the raw water pH from 7.8 reached to 7.7 in treated water. Inorganic coagulants often increase the total dissolved solids concentration of the treated water. PolyAluminium chloride and polyAluminium hydroxychloride could result in a smaller or even negligible increase in TDS (22). Results from this study shown that application of PAFC have very little effects or negligible effects on TDS and EC quantity of treated water. As a consequence it is one of the advantages of PAFC that needing for alkalinity addition in water treatment plants can be deleted or reduced very much.

Specific UV absorbance

UV absorbance at a wavelength of 254 nm has been widely accepted by water treatment operators as parameters to assess the performance of a plant with regard to NOM removal.

Today's it showed that the raw water specific UV absorbance (SUVA) can be used to control coagulation. Basically for water with intermediate to high SUVA (< 2), the NOM control the coagulant dose but for low SUVA (2 or less), turbidity controls coagulation process (23). From Table 2 it can be seen that in sample 1 and 2, NOM removal can control coagulation but for sample 3 and 4 it's not performed and coagulation controlled by turbidity.

The removal of natural organic matter from solution occurs by precipitation of metal-humic complexes and adsorption of humic substances onto metal hydroxide precipitates (24). Generally, precipitation of metal-humic complexes is the dominant mechanism at lower coagulant doses and lower pH conditions; adsorption of humics onto metal hydroxide precipitates is dominant at higher coagulant doses and higher pH conditions (25). In this study our samples pH was high (7.8) and our coagulant dosage was medium (7 to 11 mg/L) so both of mentioned mechanism are effective in reduction of natural organic matter.

Heavy Metals

One of the concerns attributed to pre polymerized coagulant is the heavy metals give back to treated water. From Table 2 it can be shown that application of PAFC didn’t show any effect for increase in heavy metals concentration in treated water. It also decreases the concentration of chromium and lead about 40% and 70% respectively. Another important subject in application of coagulant is the residual concentration of Al and Fe in treated water. In drinking-water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt. Turbidity and color may develop in piped systems at iron levels above 0.05–0.1 mg/L (26). Fortunately all treated water didn’t show any concern about Fe concentration (Table 2) according to EPA national secondary drinking water regulation. At this regulation MCLs for Fe was 0.3 mg/L (27).

Residual Aluminium and Iron in treated water

Aluminium is the most abundant metal in the earth's crust and therefore is likely to be present at some level in most ground water. The correlation of Aluminium consumption to nervous system disorders is currently being researched. Al^{3+} is a suspected causative agent of neurological disorders such as Alzheimer’s disease and prehensile dementia. EPA national secondary drinking water regulation set 0.05 to 0.2 mg/L as MCLs for Al concentration in drinking water. Fortunately all treated water didn’t show any concern about Fe concentration (Table 2) according to EPA national secondary drinking water regulation. The survey results indicated that PAFC has a good effect for turbidity, color and organic matter removal. Optimum dose of PAFC for samples with initial turbidity of 10, 20, 40 and 60 NTU was 7, 10, 11 and 11 mg/L respectively. After coagulation with optimum dose, residual turbidity in treated water was 0.4, 0.34, 0.28 and 0.3 NTU respectively. Also color removal efficiency for mentioned samples was 97%, 98%, 99% and 99% respectively at optimum dose PAFC. Other study showed that removal efficiency of PAFC for color was near to 100% (13). So it was can be used as a new coagulant for water treatment plants. Effective pH for maximum removal of turbidity and color with PAFC was 7.8 (pH range 7.5 to 8) and it was reported that PAFC gives better turbidity and color removal performance in the range of pH from 7.0 to 8.4 (13). The variation in treated water's pH with PAFC was very was very little (about 0.1 reductions). So it can be useful because there are no need for alkalinity and pH adjustment in water treatment plant. Residual Fe^{2+} and Al^{3+} in treated water didn’t exceed from EPA standards and PAFC didn’t increase heavy metals concentration in treated water so it can be used for water treatment without any worriment about public or consumer health.

Footnotes

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