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The effectiveness of chitosan as coagulant aid in turbidity removal from water

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ABSTRACT

Aims: In this study, the effectiveness of chitosan as a coagulant aid in the removal of turbidity from surface water was investigated.
Materials and Methods: A conventional jar test apparatus was used to evaluate the coagulation process. Coagulation of turbidity in river water using chitosan as coagulant aid and ferric chloride as coagulant was studied in the pH range 4-9 and initial turbidity concentrations in the range of 20-200 mg/l.
Results: The findings showed that the optimum pH for $FeCl_3$ as a coagulant on turbidity removal was seven. About 95% removal of turbidity is achieved at this pH, without filtration and the residual turbidity drops below 5 NTU. The optimum dosage of $FeCl_3$ was achieved 10 mg/l. The optimal chitosan concentration required to effect coagulation is 0.5 mg/l. Restabilization of the turbidity is observed at higher concentrations of chitosan. When chitosan (0.5 mg/l) used as a coagulant aid, efficiency removal turbidity was increased and optimal dosage of $FeCl_3$ turbidity removal was reduced to 50% of initial dosage of $FeCl_3$.
Conclusion: Chitosan as natural coagulant aid improved turbidity removal efficiency by coagulation process. And $FeCl_3$ concentration as coagulant was reduced then residual iron decreased in treated water. Also by using natural coagulant considerable savings in chemicals and sludge handling cost may be achieved.

Key words: Chitosan, coagulant aid, coagulation and flocculation, ferric chloride, turbidity

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INTRODUCTION

Surface waters contain, generally, impurities that affect their appearance and may have adverse effects for consumers. These impurities may be dissolved or in the form of colloidal suspension. Particulates responsible for water turbidity include suspended particles, clay and silt, bacteria and algae. In the drinking water treatment process, turbidity is of great importance, partly because turbid water is aesthetically displeasing and also because

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the presence of tiny colloidal particles makes it more difficult to remove or inactivate pathogenic organisms.[1] Turbidity is caused by colloidal particles characterized by a very small diameter and is electronegatively charged generating intercolloidal repulsion forces. These two properties give to colloids a lower sedimentation speed. The process of coagulation flocculation allows, in two stages, to accelerate the colloids sedimentation.[2] The most commonly coagulants used are metal salts (especially ferric chloride, ferrous sulfate and aluminum sulfate).[3-5] The flocculation permits by the slant of slow mixture, the contact between the destabilized particles. These particles gather to form a floc easily eliminated by decantation. However these chemicals, particularly aluminum, generate secondary products, which can be harmful and associated to human health and environment problems. High concentrations of aluminum in water may have human health implications such as Alzheimer and disease other carcinogenic properties.[6,7]

Commercial synthetic polymers have been utilized in coagulation/flocculation processes for water purification for at least four decades In comparison with alum, some of the advantages of these polymers are: Lower coagulant dose requirements, increase in the rate of separating the solid and water phases arising from larger agglomerate sizes, efficiency at low temperatures (hydrolyzing metal coagulants perform less well at low temperatures), a smaller volume of sludge, a smaller increase in the ionic load of the treated water, a less pH-dependent process and a reduced level of aluminum in the treated water. Polymer-based products also improve settlement properties and increase the floc toughness. However, although synthetic water-soluble polymers find a wide range of applications as coagulants and flocculants, the potential problems associated with their use are high cost, lack of biodegradability and polymer toxicity. It is important to note that the use of polyelectrolytes is also a source of debate.[8] Contaminants of synthetic polymers used in water and wastewater treatment generally arise from residual unreacted monomers (such as acrylamide ethyleneimine and trimethylolmelamine), unreacted chemicals used to produce the monomer units (such as epichlorohydrin, formaldehyde and dimethylamine) and reaction by-products of the polymers in water. Different environmentally friendly coagulants are proposed as an important alternative for water treatment.[9]

Coagulation aids are sometimes used to achieve optimum conditions for coagulation and flocculation. The aim is to obtain faster floc formation, produce denser and stronger flocs, decrease the coagulant dosage and improve the removal of turbidity and other impurities.[10] One of the natural coagulant aids in water treatment processes is Chitosan. Chitosan as cationic polysaccharide is an important natural coagulant biopolymer obtained by deacetylation of chitin which is manufactured from the outer shell of crustaceans (particularly crabs and shrimp), has recently been proposed for applications in drinking water treatment.[5,9,11,12] Compared with traditional chemical flocculants, chitosan has some advantages such as low required dosage, a higher efficiency of removing COD, SS and metal ions, formation of bulk flocs, a quicker depositing velocity, biological degradation, easy sludge treatment, high efficiency in removal of suspended solids and metal ions, anti-bacterial and without secondary pollution.[7,11,13,14]

No studies on turbidity removal by chitosan as coagulant aid with $FeCl_3$ have been found, but There are many studies on the removal of turbidity by chitosan as coagulant alone or coagulant aid in combination with other materials.[5,7-9,11-17] Bina *et al.* found that by chitosan as coagulant aid with alum as coagulant increased turbidity removal efficiency from 74.3% to 98.2% and residual Al^{+3} was decreased.[11] Divakaran and Pillai indicated that Chitosan effectively reduces turbidity due to silt by flocculation and settling.[13] Pan *et al.* showed that Coagulation of colloidal particles with chitosan produced larger floc with higher settling velocity.[8]

Present study is aimed to examine the effects of $FeCl_3$ as a coagulant in conjunction with chitosan as natural coagulants aid on removal of turbidity from turbid waters at various concentrations of turbidity.

MATERIALS AND METHODS

Preparation of solutions

Chitosan (Aldrich) whose viscosity and deacetylating degrees were about 20-300 cP, 1 wt. % in 1% acetic acid (25°C) and 85% respectively. Chitosan powder (100 mg) was accurately weighed into a glass beaker, mixed with 10 ml of 0.1 M HCl solution and kept aside for about 1 h to dissolve. It was then diluted to 100 ml with distilled water. This solution should be prepared daily. HCl was considered to be a better choice as acid environment compared to acetic acid to avoid the entrance of organic matter to the sample by acetic acid.[11,13] $FeCl_3$ solution was prepared by dissolution of $FeCl_3.6H_2O$ (Merck) in distilled water at a concentration of 10000 mg/l.[5]

Preparation of water samples

To prepare turbid water, 10 g of kaolin was added to 1 L of distilled water. The suspension was stirred slowly at 20 rpm for 1 h for uniform dispersion of kaolin particle. The suspension was then permitted to stand for 24 h to allow for complete hydration of the kaolin. This suspension was used as the stock solution for the preparation of water samples of varying turbidities for the coagulation tests.

Experimental procedure

A conventional jar test apparatus was employed for the tests. All tests were carried out with 1 L samples. After determining of optimum mixing intensity and duration, the experiments were run by using synthetic water having low (20 mg/l), medium (100 mg/l) and high (200 mg/l) turbidities and water samples taken from Isfahan Zyendeh Rood River. The pH of water sample was adjusted using hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions. After the coagulant ($FeCl_3$) was added to the suspension, the beaker was rapidly mixed at 100 ± 2 rpm for 1 min followed by 20 min of slow mixing at 45 ± 2 rpm and afterward the samples were allowed to settle for 30 min.[11] The experiments were done at environment temperature (25°C). After 1 min, the desired dose of chitosan as natural coagulant aid was added to the solution at the end of rapid mix stage.[11] The samples were taken from the top 4 cm of the suspension.

Analytical methods

The residual turbidity was determined using a turbidimeter (Eutech, TN-100). A pH-meter (CG 824) also was used for pH analysis. To analyze of residual iron after coagulation and sedimentation, atomic absorption (Perkin-Elmer model - 2380) was used. All the experiments were performed in triplicate to evaluate test reproducibility under identical conditions and all values represent the average of the triplicate experiments.

RESULTS

Effect of pH on synthetic turbid water flocculation with ferric chloride

Tests were conducted as described at pH values of 5, 6, 7, 8 and 9 using a coagulant concentration of 20 mg/l while other parameters were kept constant. The results are presented in Figure 1. From the figure, it can be seen that ferric chloride produces appreciable reduction of turbidity only between pH 7 and 7.5. The maximum efficiency is observed at pH 7. About 95% removal of turbidity is achieved at this pH-without filtration-and the residual turbidity drops below 5 NTU.

Determination of optimum dosage of $FeCl_3$ as main coagulant

As maximum efficiency of coagulant was around pH 7, experiments were conducted by varying the dosage of $FeCl_3$ at this pH on kaolin suspensions having initial turbidities ranging from 20 NTU to 200 NTU. The results are presented in Figure 2. The optimum dosage of $FeCl_3$ was achieved 10 mg/l.

Relationship between initial turbidity and dosage of ferric chloride

Results shown in Figure 2 indicate that the effectiveness of ferric chloride in removing turbidity is highly dependent on flocculant concentration.

Determination of optimum dosage of chitosan as a coagulant aid

Tests were run using 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0 mg/l of chitosan as a coagulant aid and 10 mg/l of ferric chloride as a main coagulant. Optimum dosage of chitosan as a coagulant aid was obtained 0.5 mg/l [Figure 3]. Beyond this dosage, turbidity increases, probably due to restabilization of suspended.

In the present study, it is observed that irrespective of initial turbidity, application of 0.5 mg/l of chitosan leaves a residual turbidity of only less than 5 NTU, before filtration, under test conditions. It was also observed that at higher initial turbidities, flocs appear rapidly and grow to a larger size.

The effect of $FeCl_3$ (0-30 mg/l) as a coagulant and chitosan (0.5 mg/l) as a coagulant aid on turbidity removal is shown in Figure 4. Our finding showed that efficiency removal turbidity was increased and optimal dosage of $FeCl_3$ was decreased from 10 mg/l to 5 mg/l.

Confirmation of results using naturally turbid river water

Results obtained in the laboratory studies using river turbidity were confirmed in experiments carried out using

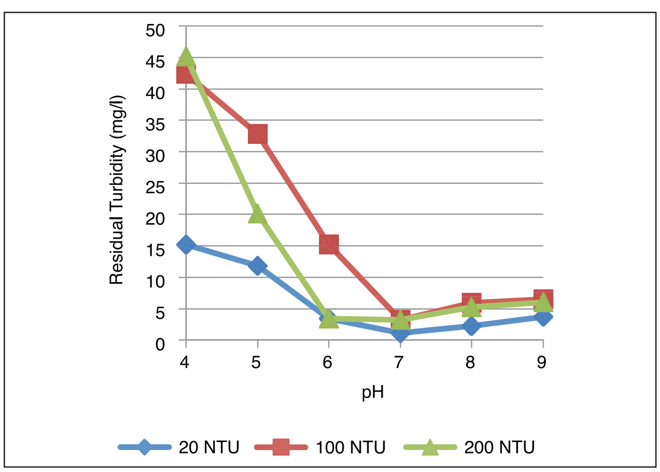

Figure 1: Effect of pH on the turbidity removal in water, using $FeCl_3$ and $FeCl_3$ dosage 20 mg/l

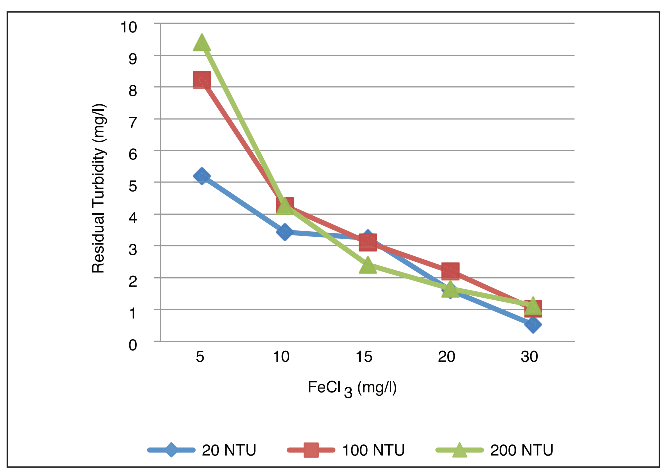

Figure 2: Determination of $FeCl_3$ optimum dosage (mg/l) for removal of turbidity in synthetic water at pH of 7

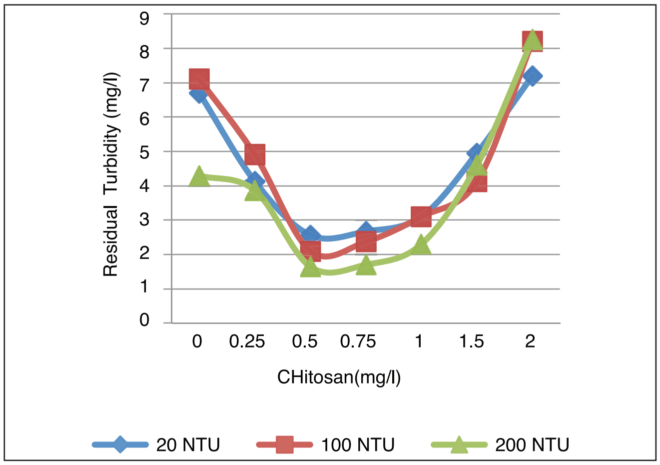

Figure 3: Determination of optimum dosage of chitosan as a coagulant aid to removal of turbidity at an initial concentration of 20-200 NTU and $FeCl_3$ concentration of 20 mg/l at pH 7

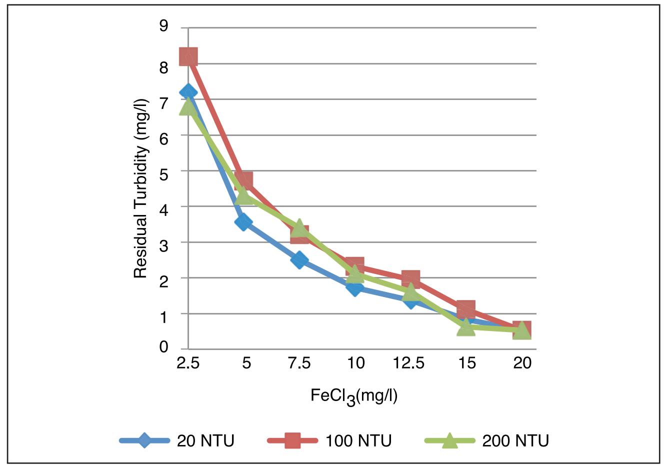

Figure 4: Determination of optimum dosage of $FeCl_3$ as a coagulant in the company with chitosan as coagulant aid on removal of turbidity. Chitosan concentration=0.5 mg/l and pH=7

Table 1: The Zayendeh Rood River water quality characteristics used for the experiments.

Parameter	Concentration	
	Mean	SD
pH	8.2	0.2
Turbidity (NTU)	8.1	0.5
soluble solids (mg/l)	650	8.5
Total alkalinity (mg/l)	168	5.56
Total hardness (mg/l)	156	12.06
Sulfate (mg/l)	35	2.17
Chloride (mg/l)	28	3.21
Carbonate (mg/l)	0	0
Bicarbonate (mg/l)	168	4.73
Iron (mg/l)	0.15	0.05

SD: Standard deviation

turbid raw water collected from Zayendeh Rood River. Important parameters for the collected water are presented in Table 1. The effect of varying pH while keeping the coagulant concentration at 1 mg/l is shown in Figure 5. Effect of increasing coagulant dosage of $FeCl_3$ and optimum dosage of chitosan keeping the pH at 7 is shown in Figures 6-8. These agree well with the results for turbidity removal shown in Figures 1-4.

Residual iron: The result of residual iron after coagulation was shown in Figure 9.

DISCUSSION

Experiments were conducted to determine the chitosan ability as natural coagulant aid for treatment of surface water. Jar tests were carried out on two kinds of water. The first one was Synthetic water and the second was raw water from Zayendeh Rood River of Isfahan, collected before water treatment station.

The effect of different pH[5-9] on turbidity removal efficiency was investigated at initial turbidity concentration of 20-200 NTU and $FeCl_3$ concentration of 20 mg/l. In this study, optimum pH for turbidity removal was obtained to be 7 and in the high acidic and high alkaline pH, the effect of coagulant was markedly reduced [Figure 1]. The results obtained from the present study are in agreement with the values given in literatures.[18,19] Iron salts are rapidly hydrolyzed in water to give a range of products including cationic species, which can be absorbed by negatively charged particles and neutralize their charge. This is one mechanism whereby particles can be destabilized, so that flocculation can occur. Other mechanism for turbidity removal is related to solubility of amorphous hydroxides solid of ferric ions, because of the fact that the amorphous hydroxide solid is stable in neutral pH and particles absorbs to amorphous hydroxides solid of ferric ions in flocculation process.[4]

Our finding showed that by the increase of coagulant dose, turbidity removal efficiency was increased due to the increase of particle accumulation and formation of more flocs [Figure 2]. It was also observed that at higher initial turbidities, flocs appear rapidly and grow to a larger size. The results are in agreement with the studies conducted by Bina *et al*.[11]

Coagulant aid can be used for better coagulation and more decrease in turbidity. So that if low turbidity is required, it's possible to make bigger flocks by adding coagulant aid to make more particles sediment in addition to increase the rate of sedimentation. In this study, chitosan as natural coagulant aid is used. This type of coagulant aid, with high positive charges in water, causes the formation of flocks more quickly and increases the rate of sedimentation by the mechanism of bridging.[17] Optimum dosage of chitosan as a coagulant aid was obtained 0.5 mg/l [Figure 3]. Beyond this dosage, turbidity increases, probably due to restabilization

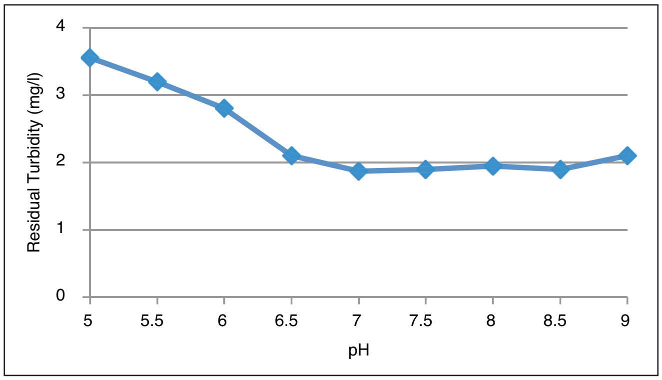

Figure 5: Effect of pH on turbidity removal in Zayendeh Rood River water using $FeCl_3$ (1 mg/l) as coagulant

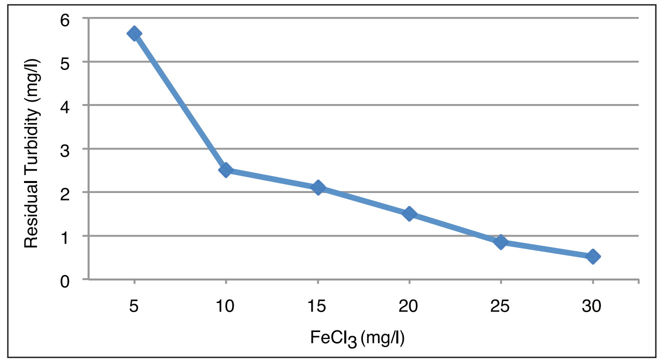

Figure 6: Determination of $FeCl_3$ optimum dosage (mg/l) for removal of turbidity in Zayendeh Rood River water at pH of 7

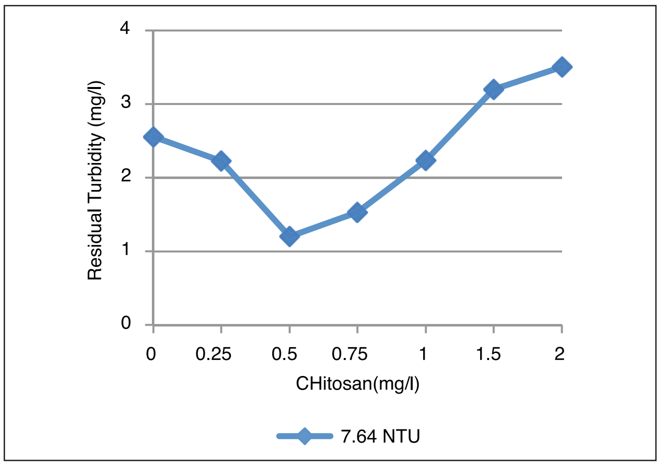

Figure 7: Determination of optimum dosage of chitosan as a coagulant aid on removal of turbidity in Zayendeh Rood River water. $FeCl_3$ concentration=20 mg/l and pH=7

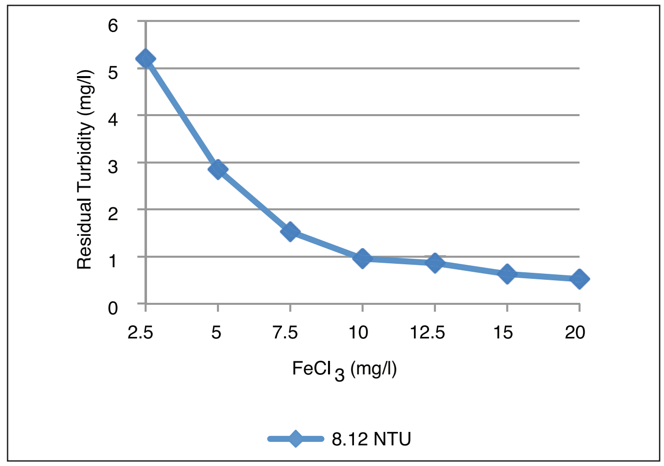

Figure 8: Determination of optimum dosage of $FeCl_3$ as a coagulant in the company with chitosan as coagulant aid on removal of turbidity in Zayendeh Rood River water. Chitosan concentration=0.5 mg/l and pH=7

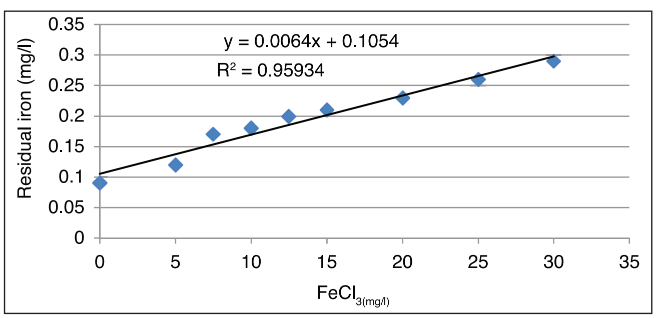

Figure 9: Residual iron after coagulation using $FeCl_3$ at pH 7

of suspended particles.[8] According to the achieved results, the use of chitosan as a coagulant aid could play a key role in reducing the amount of FeCl3 as the main coagulant [Figure 4] and consequently decreasing the generated sludge. Koohestanian *et al.* studied the effect of the Separation Method for Removing of Colloidal Particles from Raw Water by $FeCl_3$ and alum, They found that high turbidity removal can be achieved when coagulant aid was used with ferric chloride and optimal dosage of coagulant was reduced.[20]

Because it is a long — chain polymer with positive charges of chitosan at natural water pH, it can effectively coagulate natural particulate and colloidal materials, which are negatively charged, through adsorption, charge neutralization, inter-particle bridging as well as hydrophobic flocculation.[21]

These results show that chitosan as a coagulant aid (0.5 mg/l) is effective for the turbidity reduction of raw water from the Zayendeh Rood River of Isfahan with a low initial turbidity (8 NTU) at natural pH of water.

According to the results of this study, it could be concluded that by common water treatment method (coagulation and precipitation) using $FeCl_3$ as a coagulant and chitosan as a natural coagulant aid, the turbidity of water reduced to below the maximum contaminant level of Iran (5 NTU) at low to high initial turbidity in water before filtration and chitosan improved the coagulation process. And $FeCl_3$ concentration as main coagulant was reduced then residual iron decreased in treated water. Also by using natural coagulant considerable savings in chemicals and sludge handling cost may be achieved.

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