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Approbation of alternative polymeric coagulants to eliminate turbidity of model surface water

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ABSTRACT

Performance to remove turbidity was studied in model waters for five coagulants: ferric chloride, alum, polyaluminum chloride, polyferric sulfate and polyaluminum chloride ferrous. In waters with high turbidity (100-300 NTU) performance of coagulants are similar (over 90%). Polymer coagulants showed better performance and low optimal dosages in waters with low turbidity (10 NTU). In general, polyferric sulfate showed better performance in removal of turbidity.

Content

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1. Introduction

Growing population, improving of living standards, urbanization, industrial development and agriculture are the main factors that increased water consumption and wastewater production in communities, consequently giving rise to environmental pollution [1, 2].

The water that is polluted by human activity or natural water from unpolluted sources should pass through a number of treatment stages to become potable. The common processes for drinking water treatment include coagulation, flocculation, sedimentation, filtration and disinfection. After addition of coagulants, series of reactions and chemical-physical processes occur in water. They start with hydrolysis of coagulant (in most cases salts of iron or aluminium), formation of aggregates with positive charge (on basis of aluminium or ferric hydroxide). Flocs arise because of interaction of these aggregates with each other and with dissolved and suspended impurities of water. Finally precipitates are formed that can be removed by sedimentation or filtration [3, 4].

Impurities of colloidal size (from 1 nm to 1 mkm) cause water turbidity. They can arise due to action of physical, chemical and biological factors [5 - 8]. Settling velocity of colloids calculated from Stokes` law is extremely low and do not allow removal of such particles solely by sedimentation. Due to this, coagulation and flocculation turn to be necessary stages of turbid water treatment [4, 9].

In order to remove health pathogens drinking water treatment systems should reduce turbidity to certain levels. The values of 0.3 nephelometric turbidity units (NTU) are required for conventional and direct filtration devices in more than 90% of samples and in no case turbidity should exceed 1 NTU. For slow sand or diatomaceous earth filters these values are 1 and 3 NTU, respectively. For effective disinfection and good operation of pipelines, it is recommended to have turbidity 1.0 NTU or less in water entering distribution system [10].

History of alum (aluminum sulfate) application for treatment of colored and turbid waters returns back to the era of civilizations of Assyria and Babylonia. An exploration carried out around 100 kilometer near Ziggurat temple in south Ahvaz (Iran) discovered sedimentation ponds for river water treatment [11]. Egyptians had used alum for water treatment 1500 years B.C. [12, 13].

In the Mediterranean region, alum was widely produced and used from ancient Romans to Middle Ages. The first application of alum in water treatment systems was registered at Bolton, England in 1881. Soon after, treatment with coagulants was introduced and recommended as prerequisite for sedimentation and filtration [14].

By the middle of XX century, alum and iron salts were only coagulants applied in water treatment. Since that time coagulation technology rapidly developed and application of polymeric materials as coagulant aid began in 1960s [15]. Inorganic polymer coagulants debuted after much research in 1970s, resulting in further reduction of water turbidity and improving of water quality [16].

One of the examples of such polymers is polyaluminum chloride. This coagulant is manufactured as powder containing about 30% of Al_2O_3. Chemical formula for structural unit of the polymer is $Al_2(OH)_3Cl_3$. Compared to traditionally used aluminium sulfate it has the following advantages: it is effective over broader range of pH, consumes less alkalinity, results in less amount of residual aluminium and sulfates in treated water [17]. Also it has better performance in removal of organic matter and color in wastewater [18]. Polyaluminum chloride ferrous is a composite coagulant containing about 30% of Al_2O_3 and about several percent of iron compounds [22].

In the last years application and production of polyferric sulfate increased [19]. This polymeric coagulant is based on trivalent iron connected with sulfate and hydroxyl groups. [20]. The material contains about 20% or trivalent iron. It is able to treat raw water with high and low turbidity at low temperatures, improves efficiency of coagulation and sedimentation [21].

Ability of coagulants to remove impurities depends on water properties (turbidity, color, pH, temperature, concentrations of impurities), dosage of coagulant and additives (coagulant aid, alkalizing agents). Difference in price can also influence on selection of coagulant type (polymeric coagulants are more expensive). That is why coagulant type and optimal dosages had to be proved by tests. The aim of the present work was to compare ability of several coagulants to remove colloids from model solutions imitating surface water with various turbidity.

2. Objects and Methods

In this study, model solution of natural water with various values of turbidity was used. It was made artificially by adding clay powder to tap water of Tehran, Iran. Clay powder was sieved through sieve number 200 (size of mesh 0.074 mm). Tap water had concentration of total dissolved solids about 450 mg/L.

The tests were carried out in laboratory scale using jar test machine. Five coagulants were tested: polyferric sulfate, ferric chloride, alum, polyaluminum chloride and polyaluminum chloride ferrous.

The following parameters of model solutions were varied: concentration of coagulants (from 3 to 20 mg/L), pH (values from 6 to 12) and turbidity (values of 300, 150, 100, 10 NTU). For adjusting pH 0.5 M solution of hydrochloric acid and 0.1 M solution of sodium hydroxide were used with control by pH-meter. Normal temperature in laboratory was averagely 20°C and temperature of studied water during experiment was maintained at about 12°C to meet the conditions in water source (which are less favorable for treatment than room temperature).

After preparation of samples, the test with jar machine was conducted with 1-Liter beakers each containing 900 ml of water. The samples in jar test device were under rapid mixing at a speed of 120 rpm for one minute and after that mixed gently at the speed of 25 rpm for 20 minutes. Afterwards, they were put into stillness condition for 30 minutes for sedimentation. The remaining turbidity was determined by turbidity meter. The performance of each coagulant in removing turbidity was determined and corresponding charts were drawn. After the jar test the optimum values of pH and coagulant dose for removal of turbidity were determined.

3. Results and Discussion

The results of the model water treatment with five coagulants are given below. It was found that optimum pH values for treatment with coagulants were 7 or 8. Figures 1 and 2 show dependence of treatment efficiency from coagulant dosage for selected conditions.

It can be seen from figures and tables that several values are very close to each other and the difference between them is explained by measurement error. However, tendencies of efficiency changing with dose are clearly observed.

Information about the most effective conditions (coagulant dosage and pH, observed in this experiment) and their efficiency is summarized in Tables 1 and Table 2.

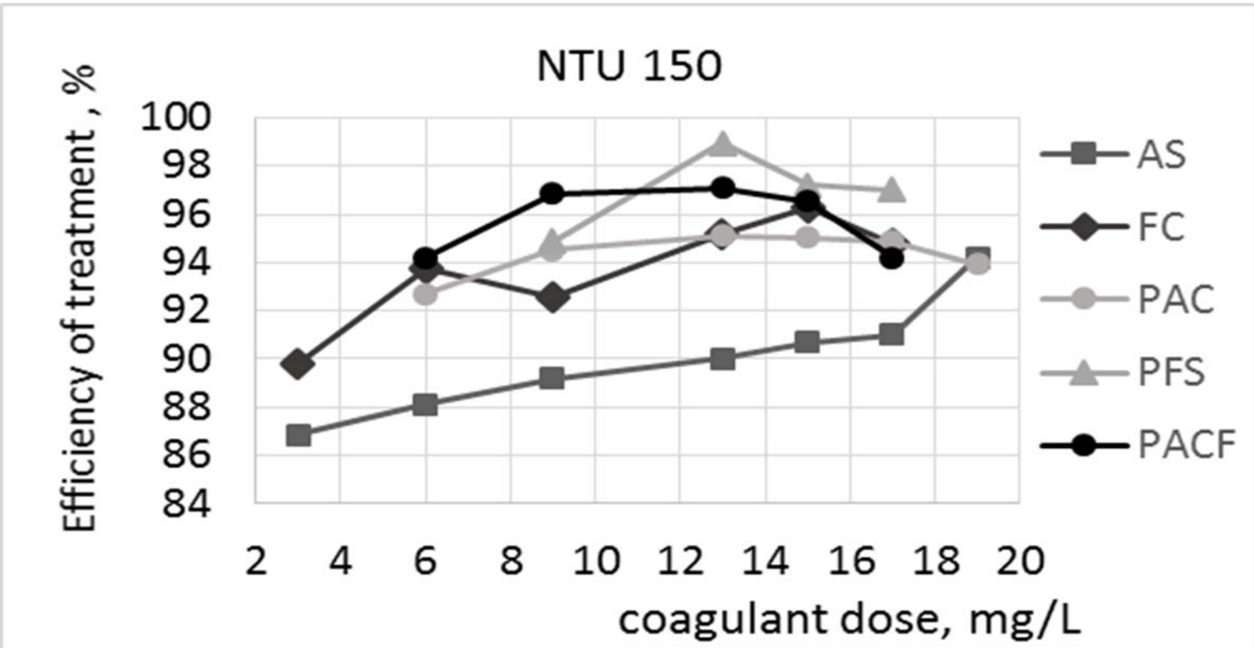

Figure 1. Efficiency of model water treatment with turbidity 150 NTU at optimal pH with various doses of coagulants. AS - aluminum sulfate, FC - ferric chloride, PAC - polyaluminum chloride, PFS - polyferric sulfate, PACF - polyaluminum chloride ferrous

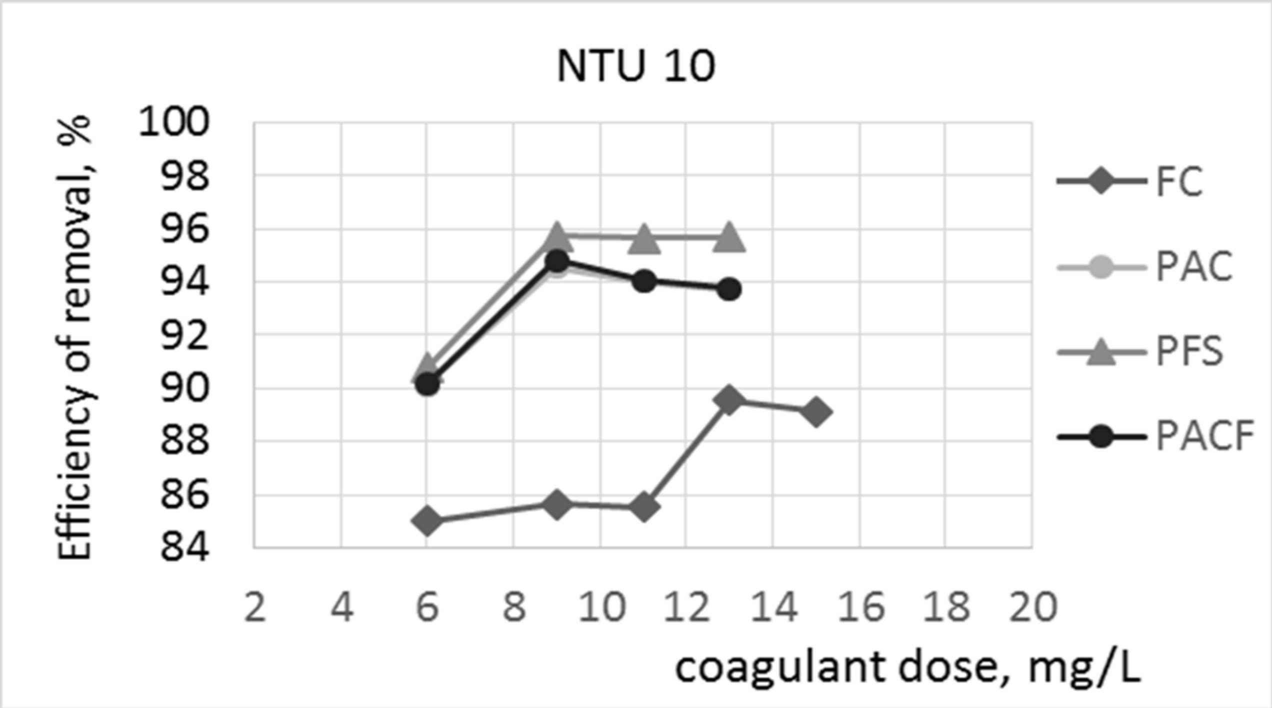

Figure 2. Efficiency of model water treatment with turbidity 10 NTU at optimal pH with various doses of coagulants. FC - ferric chloride, PAC - polyaluminum chloride, PFS - polyferric sulfate, PACF - polyaluminum chloride ferrous

Table 1. Efficiency of turbidity removal by coagulants in model water with high turbidity

Parameter	**Alum**	**Ferric chloride**	**Polyaluminu m chloride**	**Polyferric sulfate**	**Polyaluminum chloride ferrous**
Turbidity of model water 300 NTU					
Optimum pH	8	8	8	7	7
Optimum coagulant dose, mg/L	21	15	15	15	17
Efficiency of treatment, %	95.2	92.3	96.8	98.2	99.0
Turbidity of model water 150 NTU					
Optimum pH	8	8	8	7	7
Optimum coagulant dose, mg/L	19	15	13	13	13
Efficiency of treatment, %	94.2	96.2	95.1	98.9	97.1
Turbidity of model water 100 NTU					
Optimum pH	8	8	8	7	7
Optimum coagulant dose, mg/L	17	13	13	11	11
Efficiency of treatment, %	92.6	94.8	95.6	99.0	95.4

In model waters with high turbidity (100-300 NTU) the efficiency of treatment for all tested coagulants in optimum conditions (pH and dosage) was close to each other and exceeded 90% (see table 1). This result corresponds with observation that large amount of suspended matter enhances formation and sedimentation of flocs [4, 22].

For the most turbid water the best treatment efficiency was caused by polyaluminum chloride ferrous (99%, residual turbidity of water 3 NTU, see table 1). For waters with less turbidity (150 and 100 NTU) polyferric sulfate showed the best results. Efficiency of treatment was about 99% reducing turbidity from 150 NTU to 1.7 NTU or from 100 NTU to 1 NTU. The last value is the upper limit allowed for treated drinking water in various countries [10, 23].

In general polymeric coagulants demonstrated better efficiency for model waters both with high and low turbidity (see tables 1 and 2). For water with 10 NTU they reduced turbidity by 95-96%. The least efficiency in treatment of water with low turbidity was demonstrated by alum which reduced it only by 64% to 3.6 NTU.

Table 2. Efficiency of turbidity removal by coagulants in model water with low turbidity (10 NTU)

Parameter	Alum	Ferric chloride	Polyaluminum chloride	Polyferric sulfate	Polyaluminum chloride ferrous
Optimum pH	8	8	8	7	7
Optimum coagulant dose, mg/L	17	13	9	9	9
Efficiency of treatment, %	64.5	89.5	94.6	95.7	94.8

In all tests treatment with alum did not purify water to the limit allowed for turbidity (1 NTU). For ferric sulfate this limit was achieved only in treatment of water with small turbidity (10 NTU), while polymeric coagulants reached residual values 0.4 – 0.5 NTU. This data suggest application of other treatment methods in cases when coagulation, flocculation and sedimentation are not sufficient. Sorption technologies, addition of coagulant aid and contact filtration during which flocs are formed and trapped inside the filter bed can be recommended [22, 24, 25].

It can be seen from the data in tables that in most cases polymeric coagulants required less doses comparing with alum. In general the studied polymeric coagulants and especially polyferric sulfate and polyaluminum chloride ferrous showed the best ability to remove clay particles from prepared model waters. For application in real water treatment some additional considerations should be taken into account, such as optimal pH for reagent disinfection, optimal conditions for removal of organic matter, possible variation of water parameters during the year.

4. Conclusions

Ability of five coagulants to remove suspended matter from water was studied in jar test on model solutions. Tap water and fine clay powder were used to make four types of model water with turbidity from 10 to 300 NTU.

Optimal values of pH (pH=7 for polyferric sulfate and polyaluminum chloride ferrous, pH=8 for alum, ferric chloride and polyaluminium chloride) and coagulant dose (9-21 mg/L) were found. Efficiency of treatment at these conditions were calculated and compared.

At high turbidity of water (100-300 NTU) all studied coagulants removed more than 90% of turbidity. However, the residual values of turbidity in treated waters of the same type varied from 2 to 8 times.

Polymeric coagulants showed better treatment efficiency in model waters with both high and low turbidity, reducing it by 95-99%. In all water types they had less optimal dose than alum and ferric chloride. In water with low turbidity (10 NTU) values allowed for drinking water (less than 1 NTU) were achieved by polymeric coagulants.

Alum showed the least efficiency in treatment of water with low turbidity. Polymeric coagulants required less doses in comparison with alum.

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Апробация альтернативных полимерных коагулянтов для удаления мутности в модельной воде

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ИНФОРМАЦИЯ О СТАТЬЕ	ИСТОРИЯ	КЛЮЧЕВЫЕ СЛОВА
УДК 628.161 **doi: 10.18720/CUBS.53.3**	Подана в редакцию: 18.11.2016	водоподготовка; мутность; коагулянты; полимерные коагулянты; эффективность очистки;

АННОТАЦИЯ

Способность снижать мутность в модельных растворах изучали для пяти коагулянтов: хлорида железа(III), сульфата алюминия, полигидроксихлорида алюминия, полигидроксисульфата железа(III), полигидроксихлорида алюминия и железа (II). Эффективность очистки в растворах высокой мутности (100-300 НЕМ) для всех коагулянтов составила более 90%. Полимерные коагулянты характеризовались большей эффективностью очистки воды, меньшей оптимальной дозой, в том числе в растворах низкой мутности (10 НЕМ). Наилучшими характеристиками обладает полигидроксисульфат железа(III).

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