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EVALUATING THE PERFORMANCE OF INORGANIC COAGULANTS (POLY ALUMINUM CHLORIDE, FERROUS SULFATE, FERRIC CHLORIDE AND ALUMINUM SULFATE) IN REMOVING THE TURBIDITY FROM AQUEOUS SOLUTIONS

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Abstract

One of the natural pollutant in surface water particularly rivers and lakes are colloidal impurities. Turbidity in addition to having a not desirable appearance, could be a haven for microorganism against differences. For this reason the aim of this study is evaluating and assessing the coagulants (poly aluminum chloride, ferrous sulfate, ferric chloride and aluminum sulfate) efficiency in removing the turbidity from aqueous solutions and also their effect on electrical conductivity and alkalinity.

The present research is a research-intervention and have done by a jar test device in a laboratory scale. For comparing the efficiency of coagulants in removing turbidity, various test have been done based on the variables such as various turbidity (50, 100, 200, 20, 10 NTU) and different concentration of coagulants (30, 25, 20, 15, 10, 5 mg/l). The upper water of sample was taken after the jar test operation for turbidity, EC and alkalinity evaluation. Settling characteristic of clots recorded after observing in the descriptive form by words such as poor, fair, good and excellent. The results showed that, poly aluminum chloride with 5mg/l concentration is the best coagulant for removing turbidity (99-99.8%). With this description by increasing the amount of this coagulant, the clot size in turbidity of 200, 100, 50, 20, 10 NTU were still fine but the settling speed of them is very good. By increasing the coagulant concentration the EC level was increased and alkalinity was reduced. Also the most and the least increase of EC and TDS was in ferric chloride and poly aluminum coagulant respectively. The results of this evaluation showed that poly aluminum chloride is the best coagulant for removing the turbidity. With this description the clots size was fine but the settling speed of it was good.

Keywords: Coagulant, turbidity, EC, alkalinity, aqueous solution.

Introduction

Population growth, improve of living standards, development of urbanization, industry and agriculture are factors that caused the increasing of water consumption and sewage production in the community that caused environmental pollution. Colloidal impurities are natural contaminants in surface waters, especially rivers and lakes(1-6). Their presence causes turbidity and some deal color. To colloids removal, the colloidal particles must be gathered and be large in size. For this aim can be used of chemicals materials. These materials are neutralized the forces which causes table of colloidal particles. Then, particles be unstable while being gently stirred to create the flocs. This process is to say flocculation. Ultimately, the water pass from the settling basin where the solids flocculated and will be removed by sedimentation(7). The main affecting factors in coagulation process efficiency are pH, ions of solution(ionic strength of water), humic substances concentration, water temperature and the type of coagulant (8). Generally, turbidity or color of the water are due to the presence of suspended matter such asalgae, clay, silt, viruses, bacteria, minerals like asbestos, silica, particular organic matter and dissolved solids. Turbidity in spite of create undesirable appearance, can be a haven for disinfection of microorganisms, while exceeded turbidity can indicate the failure in the treatment system(9). The particle settling ability is depends on the density and size of them. So, particles with higher density than water are deposited under influence of gravity force. Smaller particles such as bacteria and colloidal particles that their density are close to the water, May never would been deposited and remain as suspended in the water. Thus the aggregation of particles and increasing their size is a main step in them sedimentation (10). Water that has been contaminated naturally or man-made, must be operated various treatment processes for convert to drinking water. Conventional water treatment processes are coagulation, flocculation, sedimentation, filtration and disinfection. The size of colloidal particles in water is between0.001 - 1µ,while the rate of spontaneous particle sedimentation with 1 µ of diameter is about 3metersinamillionyears. Therefor the water filtration process is impossible without the use of chemical materials that cause boost colloid particle sedimentation rate(11). Normally, metal salts such as aluminum sulfate, ferric sulfate, ferrous sulfate, ferric chloride and poly aluminum chloride as a coagulant, and compounds such as sodium aluminate, bentonite, sodium silicate (active silica) and various cationic, anionic and nonionic polyelectrolyte as coagulant aidused to turbidity removal in the water treatment (12). Aluminum and iron salts are common coagulants that have been used for water and waste water treatment. But in recent years a new type of coagulant were prepared using iron and aluminum salts as inorganic polymer coagulant (Inorganic Polymer Flocculants) (13, 14). Which this material is used increasingly in many parts of the worldwide, especially China, Japan, Russia and the countries of Western Europe (13).

Among the prominence of inorganic polymer coagulant than conventional coagulants can be noted is good performance in a wide range of pH and better performance at different temperatures, especially at low temperatures(15, 16). Poly aluminum chloride is one of the IPF that has more usage than other species(13, 14). Based on the study of Omelia et al. (1985) Eric (2002), Malhutra (1994), Tang et al. (1996), Luan (1998), poly aluminum chloride in medium and high turbidity condition was better performance compared with other coagulants such as aluminum sulfate, ferric chloride and etc.

For example less dosage utilizable due to more ionic charge, produce larger flocs, reducing the sedimentation time of flock, less sludge production, unneeded to adjust pH due to lower decrease of pH, better performance at lower temperatures, increase the period work of filter and etc. (17-24).

Most of the treatment plants water of country provided from dams reservoir which have low turbidity. While the low turbidity removal is somehow difficult and the water treatment plants conductors, in most cases by increasing the clay of water caused the artificial turbidity in order to remove the turbidity better.

In some treatment plants by increasing the water alkalinity (adding lime), the low turbidity removal have been done by trapping the turbidity in hydroxide precipitation. In recent years increasing the amount of polymeric coagulants particularly in anionic type for more removal of low turbidity in raw water is become common which because of having hygienic risk for consumers health and reducing monomers in treated water and also regulating the certain amount of consuming with the turbidity of raw water, its consumption is still controversial.

For this reason the present study have done with the aim of evaluating and assessing the coagulant efficiency of poly aluminum chloride in removing low and medium turbidity of water and also its effect on EC and alkalinity level in order to without the increase of natural and artificial coagulant which cause the increase of conducting cost, the producing sludge and its disposal problem and health issues, the proper coagulant and practical condition would be selected.

Materials & Methods

This study was conducted as tentative – interferere search in a laboratory scale using Jar test in water and wastewater chemistry laboratory in faculty of public health of Kermanshah University of medical sciences. To compare the efficiency of poly aluminum chloride, ferrous sulfate, ferric chloride and aluminum sulphate coagulants in removing of turbidity, experiments were carried out on various parameters including different turbidity(10, 20, 50,100 and 200 NTU)and different concentrations of coagulants(5, 10, 15, 20, 25 and 30 mg/L). For turbidity providing, firstly clay and herbaceous soil were mixed and convert to fine particles after sieved it. Then obtained material was dissolved in urban water and allow to settling for 30 minutes, subsequently supernatant was used for preparing of different turbidity. Given that high consumption of stock solution, one stock prepared for any coagulant. Then different turbidity was prepared using diluting of stock by deionized water. Subsequently, one liter of sample by certain turbidity was added to Jar test's flaks and pH, temperature, electrical conductivity and alkalinity parameters were measured as the response process. Coagulants in 5, 10, 15, 20, 25 and 30 mg /L were added to first until sixth flacks, then the sample was evacuated to Jar plant (HACH) and rapid mixing was carried out with 80 rpm for one minute and slow mixing was performed with 30 rpm for 20 min. Then the sample was kept in static conditions for 30 minutes in order settling. A 25 mL sample was taken and turbidity of the samples was measured by turbidity meter Turbidimeter 2100P model. Flocs features were observed and their features were record by observing as descriptive terms such as poor, fair, good and excellent. Also, size of flocs was described as very fine, fine, medium, coarse and very coarse. pH and electrical conductivity were measured using pH-meter (Microprocessor 537) and EC cymbal (Conductivity Meter BA380).

After determining the optimal concentration of each coagulant with high dose, the minor concentration dose for optimal coagulant (8) is determined. For reducing the errors and achieving the reliable data, each stage of test for each sample repeated three times which the results are obtained from the average of this three time repeating test. All sampling and experiments conditions, was performed according to standard methods of examination of water and wastewater (25).

Results

The results of this study about the efficiency of four common coagulant (poly aluminum chloride, ferrous sulfate, ferric chloride and aluminum sulfate) in turbidity removal of drinking water and its effect on the alkalinity and EC level is as bellows:

The results showed that after using the poly aluminum chloride, ferrous sulfate, ferric chloride and aluminum sulfate coagulants, in the turbidity of 200, 100, 50, 20, 10 NTU, the pH level have reduced in a way that by increasing each mg/l poly aluminum chloride, ferrous sulfate, ferric chloride about 0.01 unit pH have reduced. While for each mg/l ferric chloride about 0.02 unit pH have reduced. Also by increasing each mg/l poly aluminum chloride, ferrous sulfate about 0.04 and 0.06 °c temperature have reduced respectively and for aluminum sulfate and ferrous sulfate 0.03 and 0.015°c temperature increased respectively. The results of the poly aluminum chloride coagulant test showed that by adding 5mg/l of this coagulant the water turbidity in each five initial type of coagulant is reach to less than 0.01NTU. The results of the other poly aluminum chloride concentration increased in all the initial turbidity and showed that the samples reach to zero after the jar test. The clot size of this coagulant in the amount of 5-30mg/l was fine and the settling speed in the amount of 5-20 mg/l was good and in 25-30mg/l was excellent. The result of the ferrous sulfate coagulant showed that by adding 5mg/l of this type of coagulant the turbidity reach from 200NTU to 7 and from 100NTU to 5. The clot size in this coagulant for 200and 100 NTU in the consumed amount of 5, 10, 15, 20, 25, 30 mg/l coagulant were very fine, fine, medium, medium, medium, large, medium, medium, medium, large, large and large. Its sedimentation rate in these doses for 10 and 200 NTU turbidity were poor, poor, fair, good, good, excellent, poor, fair, good, good, good, good and excellent. The clot size of this coagulant in the amount of5, 10, 15, 20, 25, 30 mg/l were very fine, fine, medium, large, large and very large respectively and its sedimentation rate in these amounts were poor, poor, fair, good, good and excellent respectively. The turbidity evaluation for ferrous sulfate in initial turbidity of 10, 20, 50 NTU have done which by adding 5mg/l coagulant the turbidity rate become 3. The clot size in this coagulant for 10, 20, 50 NTU turbidity in the amount of consumed coagulant of 10, 15, 20, 25, 30 mg/l were very fine, fine, medium, large, large, very large, very fine, fine, medium, medium, medium, large and medium, medium, medium, large, large and large respectively. Their sedimentation rate in these doses for 10, 20, 50 NTU turbidity was very poor, fair, fair, good, good and excellent, fair, good, good, good, good, good and very poor, poor, fair, good, good and excellent respectively. By increasing the other concentration of ferrous sulfate (10-30 mg/l) the samples initial turbidity remain stable for 0.1NTU. The results of the aluminum sulfate test showed that by adding 5mg/l of this coagulant, the initial turbidity (10, 20, 50, 100, 200NTU) reach to less than 0.3NTU. The clot size by this coagulant in the amount of 30, 25, 20, 15, 10, 5 mg/l were very fine, fine, medium, medium, large and very large respectively and its sedimentation rate in these doses were very poor, poor, fair,

fair, good and excellent respectively. By increasing the aluminum sulfate concentration (10-30 mg/l) the turbidity removal level have increased in a way that in the 20-30mg/l concentration the turbidity removal level was become 100%. The results of the ferric chloride coagulant test showed that by adding 5mg/l of this coagulant the initial turbidity reach to less than 0.2 NTU. The clot size by this coagulant in the amount of 5, 10, 15, 25, 30 mg/l were very fine, fine, medium, large, large, and very large respectively. And its sedimentation rate in these amount were very poor, poor, fair, good, good and excellent respectively. Results in other concentration of increasing the ferric chloride is similar to aluminum sulfate. Increasing the minor concentration of coagulant materials (1, 3mg/l) results and its effect on turbidity have been presented in table1.

Figures 1 to 10 showed the coagulant concentrations effect on alkalinity and EC level of 10, 20, 50, 100, 200 NTU turbidities. Based on the 1-5 figures which represent the coagulants concentration effect on alkalinity level of 10, 20, 50, 100, 200NTU turbidities, by increasing the coagulant concentrations, the alkalinity level have been reduced. Based on the figure 6-10 which represent the coagulant concentrations effect on the level of 10, 20, 50, 100, 200NTU turbidities, by increasing the coagulant concentrations, the EC level have been increased.

Table -1: Turbidity of water after using the optimal coagulants dosage (repeated three times).

Initial Turbidity (NTU)	Poly aluminum chloride (mg/l)				Aluminum sulfate (mg/l)				Ferrous sulfate (mg/l)				Ferric chloride (mg/l)			
	1	R(%)	3	R(%)	1	R(%)	3	R(%)	1	R(%)	3	R(%)	1	R(%)	3	R(%)
10	2.5	75	1.1	89	3.7	63	2.2	78	5.8	42	4.1	59	3.1	69	1.6	84
20	7.7	62	4.3	79	10.5	48	6.7	67	12.2	39	9.3	54	8.9	56	5.2	74
50	15.4	69	6.6	87	23.3	53	10.1	80	27.4	45	16.3	67	20.4	59	9.6	81
100	28.9	71	10.3	89	45.8	55	18.2	82	49.1	51	29.1	71	38.5	62	16.6	83
200	41.3	79	15.1	92	81.6	59	31.7	84	88.6	56	42.2	78	65.2	67	25.3	87

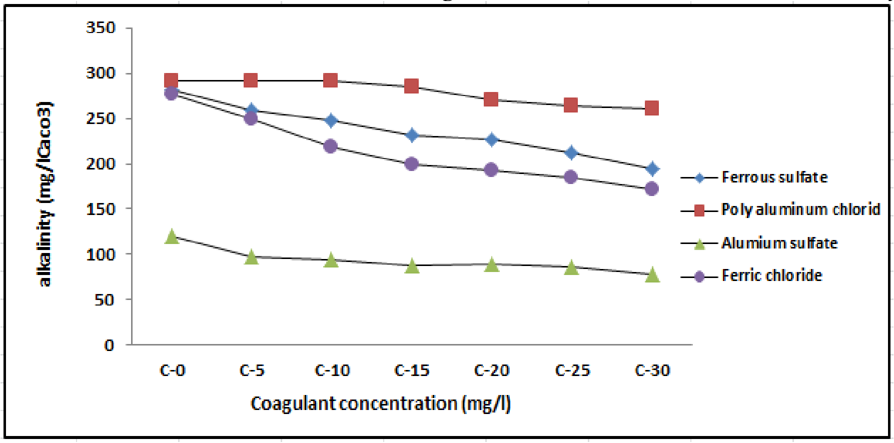

Figure-1. Effect of coagulants concentration on alkalinity in initial turbidity 10 NTU

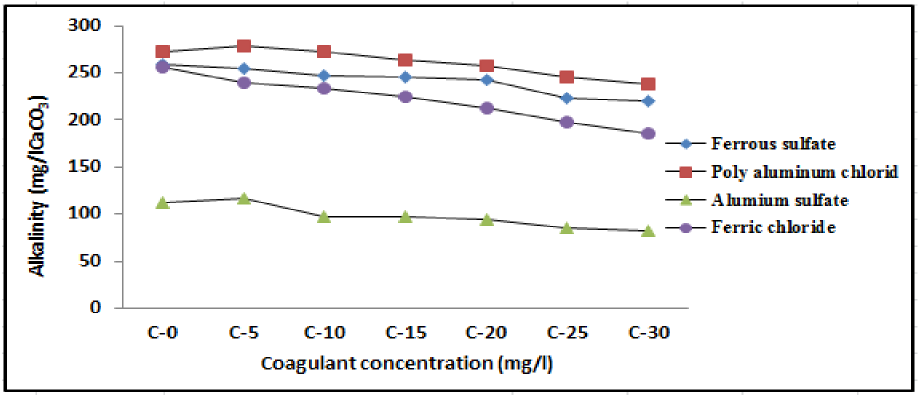

Figure-2. Effect of coagulants concentration on alkalinity in initial turbidity 20 NTU.

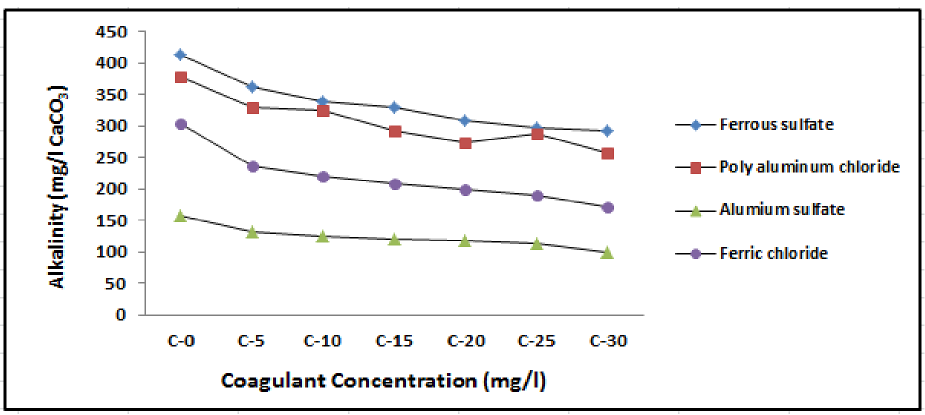

Figure-3. Effect of coagulants concentration on alkalinity in initial turbidity 50 NTU.

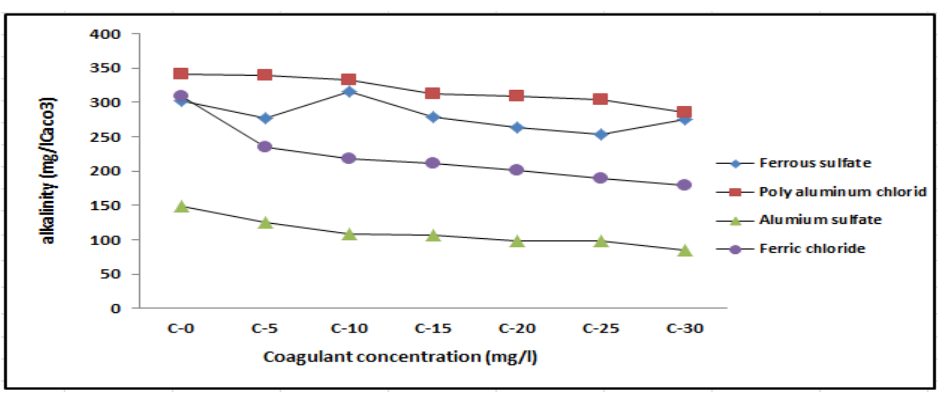

Figure-4. Effect of coagulants concentration on alkalinity in initial turbidity 100 NTU.

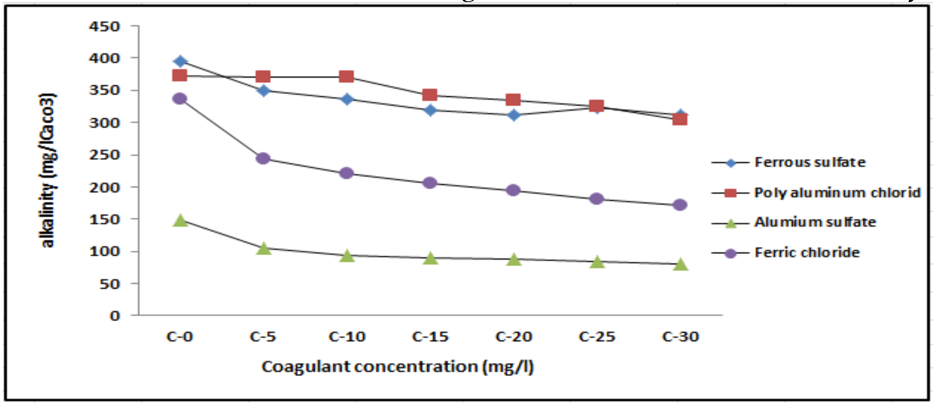

Figure-5. Effect of coagulants concentration on alkalinity in initial turbidity 200 NTU.

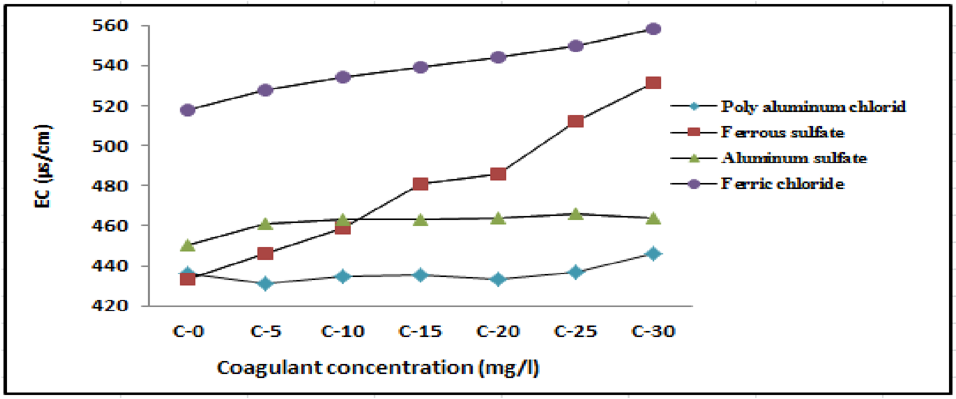

Figure-6. Effect of coagulants concentration on EC in initial turbidity 10 NTU.

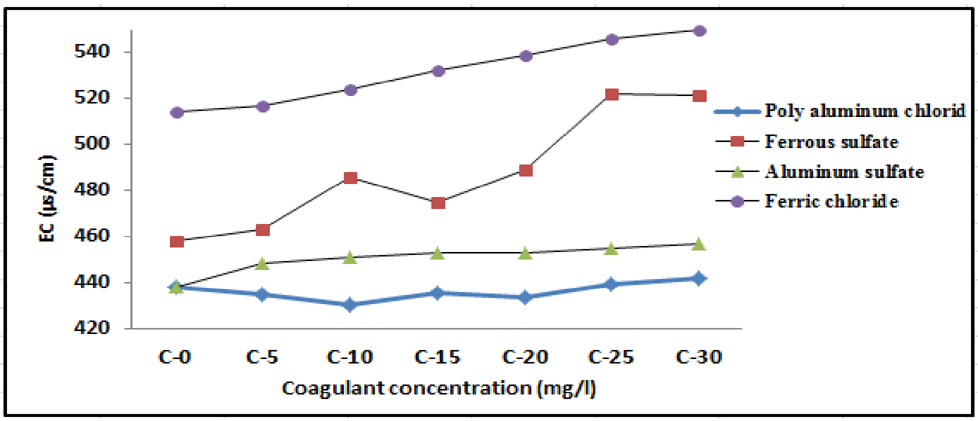

Figure-7. Effect of coagulants concentration on EC in initial turbidity 20 NTU.

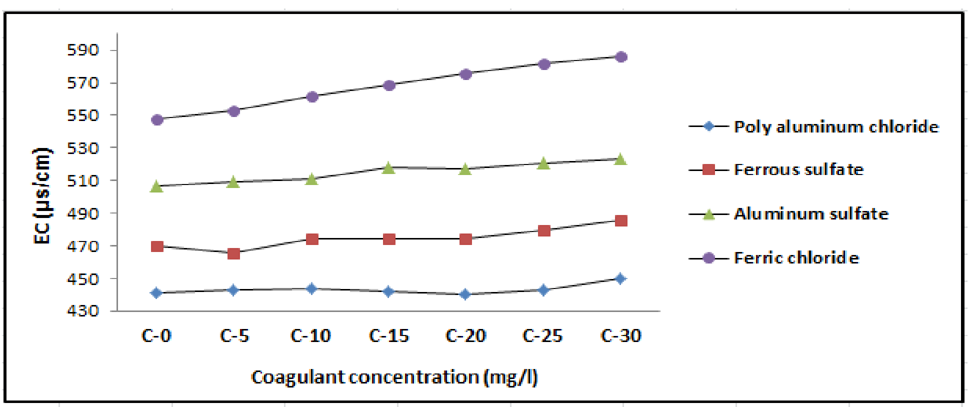

Figure-8. Effect of coagulants concentration on EC in initial turbidity 50 NTU.

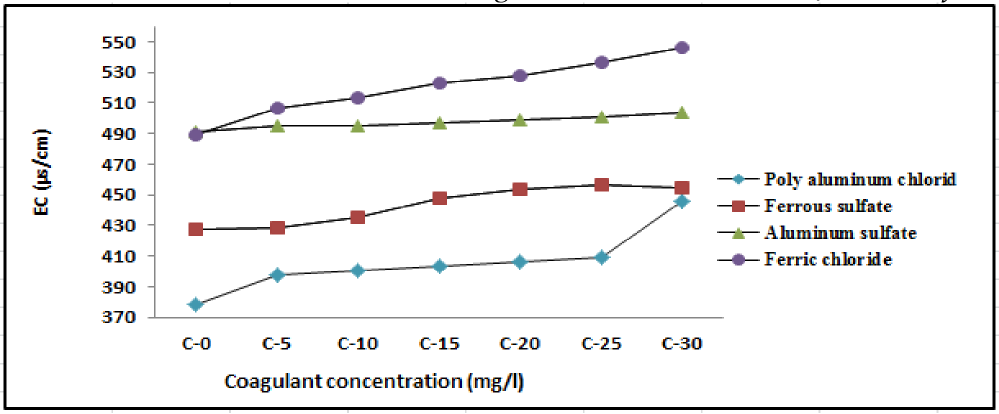

Figure-9. Effect of coagulants concentration on EC in initial turbidity 100 NTU.

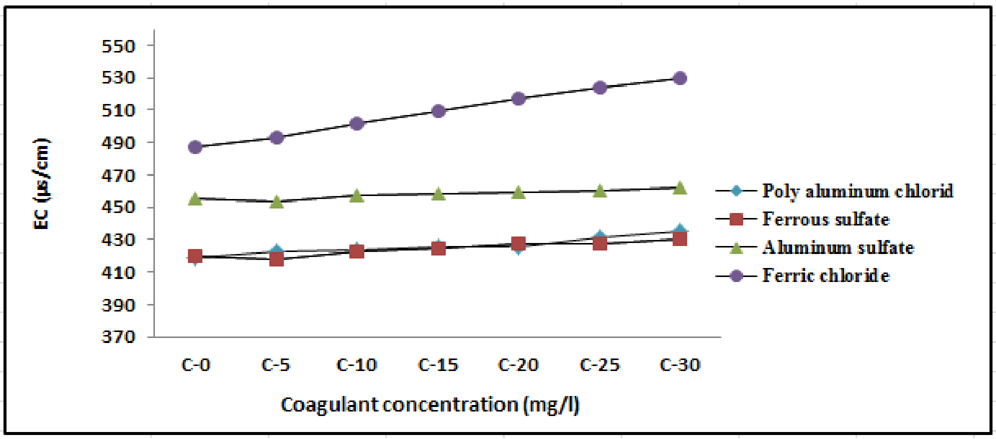

Figure-10. Effect of coagulants concentration on EC in initial turbidity 200 NTU.

Discussion

The results of this study about ferrous sulfate showed that in 200, 100, 50, 20 and 10 NTU turbidity by adding 5mg/l coagulant, 97%, 95%, 94%, 85% and 70% turbidity have been removed respectively. The clot size of 10, 50, 100, 200 NTU in a mount of 15, 10, 5 mg/l ferrous sulfate is proper and in the amount of 20, 25, 30 mg/l is totally proper and for 20NTU turbidity just in the amount of 30mg/l is proper. Sedimentation rate of turbidity for 20, 50 NTU turbidity in the amount of 20, 25, 30 mg/l ferrous sulfate is good to excellent and for 10 NTU turbidity evaluated good in these amounts. By increasing the ferrous sulfate coagulant amount the pH, temperature and alkalinity have reduced and EC have increased. The pH range for 200, 100, 50, 20, 10 NTU turbidity were (6.5-7.2), (6.2-7), (6.25-7.06, (6.56-6.87) and (6.59-6.96) respectively. pH and temperature of water samples which obtained from the increase of ferrous sulfate showed a lower level than poly aluminum chloride while poly aluminum chloride showed a better efficiency in turbidity removal than ferrous sulfate. The 5 mg/l increased of aluminum sulfate coagulants result represent that in 200,100, 50, 20, 10 NTU turbidities, the turbidity removal level were 95.8, 96.5, 97, 98.99, and 5.4 respectively. The results showed that by increasing the coagulant amount, the pH and temperature level of water samples have reduced and the clot size in each three turbidity in the amount of 30, 25 mg/l aluminum sulfate is totally proper and the sedimentation rate in these amounts was evaluated good to excellent. The pH range in this research for aluminum sulfate in 200, 100, 50, 20, 10 NTU turbidities were (6.97-7.65), (6.89-7.68), (7.23-7.54), (6.54-6.87) and (7.14-7.46) respectively. Ferric chloride coagulants results showed that for200, 100, 50, 20, 10 NTU turbidity in 5mg/l coagulants dose, the turbidity have been removed for 97, 97.6, 98, 99 and 99.6% respectively. The results showed that by increasing the coagulants amount, the pH and temperature of water sample have reduced and the clot size in each five turbidity in the amount of 20, 15, 10, 5 mg/l coagulant was improper and in other amounts were proper. The sedimentation rate in the 25-30mg/l amount evaluated good to excellent. The pH range in this research for ferric chloride in 200, 10, 50, 20, 10 NTU turbidities were (6.97-7.65), (6.7-7.47), (6.98-7.67), (6.93-7.43) and (6.97-7.53) respectively. The poly aluminum chloride coagulants results showed that in 200, 100, 50, 20, 10 NTU turbidities of 5mg/l coagulant amounts, the removal turbidity were 99.8, 99.6, 99.5, 99.3 and 99% respectively. The results showed that by increasing the amount of coagulant the pH and temperature of water samples have reduced and the clot size in each three turbidities were improper and the sedimentation rate for the amount of 5-20 mg/l was good and for the 3, 25 mg/l amount was excellent. It means by increasing poly aluminum chloride amount the sedimentation rate have increased which this act is very effective in reducing the treatment time. The results showed that by increasing the amount of poly aluminum chloride coagulant the alkalinity and EC have reduced and increased respectively. The pH range for poly aluminum chloride in 200, 100, 50, 20, 10 NTU turbidities were (7.18-7.5), (6.7-7.45), (7.14-7.25), (6.96-7.43), (7.6-7.11) respectively. On the other hand the turbidity removal level in each five initial turbidity of 3 mg/l minor optimal dose in all consumed coagulant material were more than 1mg/l of their dose. Comparing this type of coagulant effect on the initial turbidity of samples showed that poly aluminum chloride have better performance in turbidity removal than other coagulants. This comparison have done based on the sedimentation rate, clot size and turbidity removal amount. The pH reduction level of water samples showed a higher level than the other consumed coagulant after increasing the ferric chloride. A study which have done by Mahvi, A.H., Ahmadi Moghaddam (2003) showed that lower concentration of poly aluminum chloride in comparison with other coagulants have been used and caused the reduction of consumed coagulant cost per each m3 treated water (26). The experimental study of Aluminum inorganic polymer application in turbidity removal of water have done by Banihashemi, et al. (2008). In this study without monitoring the initial turbidity of water the poly aluminum chloride coagulant have reported better than ferric chloride and aluminum sulfate in turbidity removal of water because of its higher sedimentation rate of flocks, lack of sensitivity to water temperature and lower turbidity residue of treated water (27). The consumed coagulant range in this research was 5-35mg/l which its result was similar to the main coagulant optimal dose results in this research. The results of the increasing minor optimal dose of poly aluminum chloride, ferrous sulfate, ferric chloride and aluminum sulfate coagulant (3, 1 mg/l) showed that the raw water turbidity of 200, 100, 50, 20, 10 NTU , the poly aluminum chloride, ferric chloride, aluminum sulfate and ferrous sulfate have the most efficiency in turbidity removal respectively. Abdolah Zadeh et al. (2009) study about the comparison of aluminum sulfate and ferric chloride performance in turbidity and organic material removal from water resources showed that in the turbidity range of this research (10, 20, 50 NTU), poly aluminum chloride efficiency in turbidity and TOC removal (one of the factors which caused surface water color) was more than ferric chloride (24-71.and. 85-99.75 vs. 16-46.7and 71-99.3) (28). In this research in all the coagulants by increasing the coagulants concentration, the alkalinity and EC have reduced and increased respectively. Waters EC is related to TDS. This parameter is a criterion for water capability in electrical conductivity. Due to the fact that the electricity in a solution transfer through the existed ions, by increasing the TDS the EC increased too.

The relationship between two parameters of EC and TDS in present study showed that the highest EC level (586μs/cm) for ferric chloride coagulant is in 30 mg/l concentration and the least EC level (443 μs/cm) for poly aluminum chloride is in 5mg/l concentration. Based on relationship between EC and TDS (29) the TDS level of water sample which ferric chloride and poly aluminum chloride were added to them were 293 mg/l and 22mg/l respectively. EPA suggested at last 500mg/l TDS in drinking water (30).

Conclusion

Based on the results it was concluded that poly aluminum chloride coagulant in the main optimal doses and minor optimal doses have the highest efficiency in turbidity removal of water. On the other hand this coagulant have the least effect on alkalinity and pH reduction. Therefore, in regions which their surface water have low natural alkalinity, without artificial increased of alkalinity theyhave high turbidity removal efficiency.

According to the low effect of alkalinity on this coagulant efficiency, probably the colloidal particles removal mechanism would be surface adsorption and neutralization.

References

1. Pirsaheb M, Khosravi T, Sharafi K, Babajani L, Rezaei M. Measurement of Heavy Metals Concentration in Drinking Water from Source to Consumption Site in Kermanshah—Iran. World Applied Sciences Journal. 2013;21(3):416-23.
2. Pirsaheb M, Khosravi T, Sharafi K, Mouradi M. Comparing operational cost and performance evaluation of electrodialysis and reverse osmosis systems in nitrate removal from drinking water in Golshahr, Mashhad. Desalination and Water Treatment. 2015; 30:1-7.
3. Moradi M, Hemati L, Pirsaheb M, Sharafi K. Removal of hexavalent chromium from aqueous solution by powdered scoria-equilibrium isotherms and kinetic studies. World Applied Sciences Journal. 2015;33(3):393-400.
4. Sharafi K, Karami A, Pirsaheb M, Moradi M. Physicochemical Quality of Drinking Water of Kermanshah Province. Zahedan Journal of Research in Medical Sciences. 2013;15(12):44.
5. Pirsaheb M, Moradi M, Ghaffari H R, Sharafi K. Application of response surface methodology for efficiency analysis of strong non-selective ion exchange resin column (a 400 e) in nitrate removal from groundwater. International Journal Of Pharmacy & Technology. 2016; 8(1): 11023-11034.
6. Graham NJ. Orthokinetic flocculation in rapid filtration. Water Research. 1986;20(6):715-24.
7. Sharafi K, Mansouri AM, Zinatizadeh AA, Pirsaheb M. Adsorptive removal of methylene blue from aqueous solutions by pumice powder: process modelling and kinetic evaluation. Environmental Engineering & Management Journal (EEMJ). 2015;14(5): 1067-1078.
8. Chapman DV, editor. Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 1996.
9. Williams RB, Culp GL. Handbook of public water systems. Van Nostrand Reinhold; 1986.
10. Crittenden JC, Trussell RR, Hand DW, Howe KJ, Tchobanoglous G. MWH's Water Treatment: Principles and Design. John Wiley & Sons; 2012.
11. Shahmansouri M, Neshat A. Comparison of poly aluminum chloride, aluminum sulfate and ferric chloride in removal of TOC and total coli form. Water and Waste Water. 2003;48:30-44.
12. Letterman RD, Pero RW. Contaminants in polyelectrolytes used in water treatment. Journal (American Water Works Association). 1990 ; 1:87-97.

13. Shi B, Li G, Wang D, Feng C, Tang H. Removal of direct dyes by coagulation: The performance of preformed polymeric aluminum species. Journal of Hazardous Materials. 2007;143(1):567-74.
14. Wang D, Sun W, Xu Y, Tang H, Gregory J. Speciation stability of inorganic polymer flocculant–PACl. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2004;243(1):1.
15. Jiang JQ. Development of coagulation theory and pre-polymerized coagulants for water treatment. Separation & Purification Reviews. 2001;30(1):127-41.
16. Ye C, Wang D, Shi B, Yu J, Qu J, Edwards M, Tang H. Alkalinity effect of coagulation with polyaluminum chlorides: Role of electrostatic patch. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2007;294(1):163-73.
17. O'Melia CR, Shin JY. Removal of particles using dual media filtration: modeling and experimental studies. Water Science and Technology: Water Supply. 2001;1(4):73-9.
18. AbdolahZadeh M, Torabian A, Hassani AH. Comparison of the performance of poly chloride (PACI), ferric chloride (FeCl3), in turbidity and organic matter removal; from water source, casestudy; Karag river, in Tehran water treatment plant no. 2. Journal of Water and Wastewater. 2009;70:23-31.
19. Hart E. Optimizing Coagulant Conditions For The Worcester Water Filtration Plant (Doctoral dissertation, Worcester Polytechnic Institute), 2001.
20. Malhotra MS. Poly aluminium chloride as an alternative coagulant. In20th WEDC Conference Colombo: Affordable Water Supply and Sanitation, Sri Lanka, Aug 1994.
21. Hongxiao T, Zhaokun L. Features and mechanism for coagulation-flocculation processes of polyaluminum chloride. J. Environmental sciences. 1995;7(2):204-11.
22. Luan ZK. Theory and application of inorganic polymer flocculant-polyaluminium chloride. Doctorial Dissertation, Research Center for Eco-Enviromental Sciences, Chinese Academy of Sciences, Beijing. 1997.
23. Zeng D, Wu J, Kennedy JF. Application of a chitosan flocculant to water treatment. Carbohydrate polymers. 2008;71(1):135-9.
24. Pirsaheb M, Zinatizadeh AA, Dargahi A. Performance evaluation of coagulation process in removal of low turbidity and color from water using different inorganic coagulants. 2011; 23(1): 111-118.

25. Dargahi A, Moradi M, Savadpour MT, Sharafi K. The study of coagulation process in medium turbidity removal from drinking water. Archives of Hygiene Sciences. 2014;3(4): 192-200.
26. APHA, AWWA and WPC, Standard Method for the Examination of Water and Wastewater, nineteenth ed., American Public Health Association, Washington, DC, 1995.
27. Mahvl A, Ahmadi Mm, Naseri S, Nadafi K. Technical, Economical And Healthy Evaluation Of PAC (Poly Aluminum Chloride) Application In Water Treatment.Iranian Journal Of Public Health, 2003, 32(2): 6-8.
28. Bani HA, Alavi MS, Maknoun R, Nikazar M. Lab-scale study of water turbidity removal using aluminum inorganic polymer.Water And Wastewater. 2008; 19 (2): 82-86.
29. Tchobanoglous G, Schroeder EE. Water quality: characteristics, modeling, modification. 1985.
30. USEPA. National secondary drinking water regulation. Federal Register, 1970, 44(153), 42195- 42202.

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