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Optimization of treatment process of Bushigan treatment plant in respect of turbidity and total organic carbon reduction

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ABSTRACT

Aims: The aim of the present study was to investigate the optimization of the treatment process of Bushigan water treatment plant (South of Iran) in respect of turbidity and total organic carbon (TOC) removal.

Materials and Methods: The water samples were collected from Shapoor river the influent water to Bushigan treatment plant. A conventional jar test apparatus was used to evaluate the coagulation process. Different dosages of poly aluminum chloride (PACl), powdered activated carbon (PAC) and chlorine (Cl_2) alone and with each other was used to determine their effects on removal of the turbidity and TOC.

Results: The average of TOC and turbidity in raw water were 5.81 mg/L and 29 NTU respectively in all seasons. The study result showed that the removal efficiency of TOC and turbidity were improved with increasing the PACl and PAC dose. With the application of 12 mg/L PACl alone, the maximum TOC and turbidity removal efficiencies were 41% and 31%, respectively. At constant PACl dose, application of PAC as coagulant aid and adsorbent improved the removal efficiency of TOC and turbidity.

Conclusion: The results were showed that by common water treatment method (coagulation and precipitation) using PACl as a coagulant and also PAC and Cl_2 as an adsorbent and coagulant aid, the TOC and turbidity of water reduced to below 1 mg/L. So PAC and Cl_2 can improve the coagulation process. This method can be used for water treatment plant with drinking water contain the average TOC less than 6 mg/L.

Key words: Chlorine, poly aluminium chloride, total organic carbon, turbidity, water treatment plant

Access this article online
Quick Response Code:
Website: www.ijehe.org
DOI: 10.4103/2277-9183.132681

INTRODUCTION

Climate change such as a rainfall can change the quality of influent waters that are received to water treatment plants. In some of the cases, these changes caused increasing the turbidity of influent water. High turbidity can increase the

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This article may be cited as:
Borazjan MK, Bina B, Amin MM, Taheri E, Hassanzadeh A, Modarresi M. Optimization of treatment process of Bushigan treatment plant in respect of turbidity and total organic carbon reduction. Int J Env Health Eng 2014;3:9.

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contamination of influent waters, because some of the organic contaminants are related to suspended particles.[1-3] Natural organic matter (NOM) and also both dissolved and inorganic suspended particulate matter can produce water turbidity. NOM is widely existed in different drinking water sources such as lakes, rivers, reservoirs and etc. It may be controlled by minimizing the discharge of wastewater. However, a great challenge for many of drinking water treatment plants (DWTPs) in different countries is the control of NOMs that caused disinfection by products (DBPs) formation.[4–6] Addition to DBPs formation NOM, may cause another important problems in drinking water such as increasing the consume chlorine, supporting bacterial re-growth and creating color, taste and odor.[7] In water treatment plant depending on the treatment systems, different technologies can be used. Select of technologies are depend on raw water qualities, aim of water treatment, the best economically and practically available options. Different technologies can be used for removing NOMs from surface waters such as coagulation/enhanced coagulation,[4,5] membrane filtration,[6] adsorption,[8,9] ion exchange[10] and advance oxidation processes.[11]

The aim of coagulants application in surface water treatment is removal enhancement of particulate, colloidal and dissolved substances.[12–14] Coagulation can be operated with metal salts such as Al-based compounds or with polymers such as aluminum sulphate (alum), aluminum chloride, poly aluminum chloride (PACl). The mechanisms of the coagulation are change of the negative surface charge of organic matter to neutral by metal cations, transfer of small particles into larger flocs by adsorption and entrapment. This phenomenon will result in the promotion of NOMs agglomeration. This agglomeration occur on the surfaces of insoluble metal hydrous oxide ($Me[OH]_3$) and will resulted in precipitation of NOMs.[15] The major factors in assessment of enhanced coagulation includes type, dose and pH of coagulation. The coagulant concentrations are an important factor for reduction of turbidity and total organic carbon that can be determined using jar test method. Even in the optimal condition, enhanced coagulation can only remove 48% of THMs formation potential in surface water.[16] The organic matter removal efficiency by coagulation has Inverse relationship with pH and total hardness.[17] Furthermore, the coagulation efficiency decreases with increasing total hardness and pH.[18] Previous studies demonstrated that removal of turbidity and TOC has high efficiency using PACl. Iriarte-Velasco *et al*., evaluates and compared the effectiveness of alum and PACl as coagulants. In their researches PACl under both high and low alkalinity–hardness conditions showed higher removal efficiency in compare with alum.[16] Either enhanced coagulation or granular activated carbon (GAC) has recognized as the best available technology (BAT) for controlling DBP precursors by the US Environmental Protection Agency (EPA).[19]

Uyak and Toroz in 2007 showed that that optimized coagulation can enhance the removal of dissolved organic carbon (DOC) from the current average of 15% to an average of 56%.[20] In this study, PACl was used for optimization of turbidity and TOC removal. NOM removal through coagulation is more effective for organic matter with high molecular weight, such as humic acid.[21] However, more hydrophilic molecules because of their low molecular weight cannot be removed during the coagulation process.[22] So, NOMs as a medium - or low-molecular weight materials is removed just via powdered activated carbon (PAC).[23,24] The dose of required PAC for desired NOM removal depends on the type of PAC and quality of the source water.[25,26] PAC treatment has also been used in combined with coagulation, enhanced coagulation, or ultra-filtration to improve the removal of NOM.[25,26] Several studies have investigated the combined use of coagulation and adsorption with PAC to maximize the overall removal of NOM.[25,27,28]

In order to the optimization of the treatment process of Bushigan water treatment plant (south of Iran), the objective of this study was:

1. Evaluation of raw water quality of Shapoor river as inlet stream to Bushigan water treatment plant,
2. Determining the optimal dose of residual chlorine and pH in per-chlorination stage,
3. Investigating the optimal dose of PACl coagulant for reduction of turbidity and TOC according to IRAN, EPA and world health organization (WHO) standards and
4. Determining the optimal dose of PACl and PAC for simultaneous reduction of turbidity and TOC according to Iran, EPA and WHO standards.

MATERIALS AND METHODS

Study water treatment plant

The Bushigan water treatment plant is located in southern Iran in Fars province at the crossroads near Kazeroon city. Operation of the plant began in 1974. Inflow to Bushigan WTP consists of a mixture from Shapoor river and Sasan spring. The total capacity of the plant is 50,000 m^3/day. At present 12,500 m^3/day of the total capacity of the treatment plant is used. Flow entering (Q_i) to the plant is 2000 m^3/h. Temperature of the warmest and the coldest day in months July to August and December to February in the year is 48 and −4°C, respectively.

The study was performed from 2011 to 2012. Physical and chemical characteristic of influent water to Bushigan treatment plant and characteristics of Shapoor river are presented in Table 1. The water treatment process are used in Bushigan water treatment plant including screening, intake, pre-chlorination (>2 mg/L residual chlorine), rapid mixing (without application of coagulants and absorbent powder), flocculation, sedimentation, filtration, post chlorination before of the transmission system and final chlorination before of the distribution system.

Chemical and instrument

The powder activated carbon was obtained from Merck Co, Germany. Furthermore, PACl and calcium hypochlorite was

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purchased from the local market with commercial grade. All other chemicals were analytical grade and used without further purification.

Experiments

In the laboratory, six beakers jar test apparatus (Phipps and Bird. Co) was used for this study and each jar was filled with 1L water. The PACl (0-70 mg/L) and PAC (0-90 mg/L) was added to each test and agitated for rapid mixing of the coagulants and adsorbents, respectively. After that, the samples allowed to agitate at 20 rpm for 20 min. The samples are allowed to settle down for 30 min and the supernatant filtered using 0.45 μm filters. The operational parameters were showed at Table 2. The experimental temperature in all coagulation steps was 25°C.

Table 1: Characteristics of Shapoor river and physicochemical quality of influent water to Bushigan water treatment plant

Parameter	Unit	Value
Inflow	(m^3/h)	2,000
Diameter	(m)	0.75
Area	m^3	0.44
Velocity	(m/s)	1.26
pH	–	7.53
EC	μ S/cm	740
Temperature	°C	15
Turbidity	NTU	29
TOC	mg/L	5.81
Hardness	ma/L $CaCO_3$	436
Ca^{2+}	mg/L	88
Mg^{2+}	mg/L	51.84
Alkalinity	ma/L $CaCO_3$	224

TOC: Total organic carbon, NTU: Nephlometric turbidity units, EC: Electrical conductivity

Table 2: Protocol of jar test

Step	RPM	Duration
PACl addition	120	90 s
PAC addition	120	2 min
Slow mixing	20	20 min
Settling	—	30 min

PACl: Poly aluminum chloride, PAC: Powdered activated carbon, RPM: Revolutions per minute

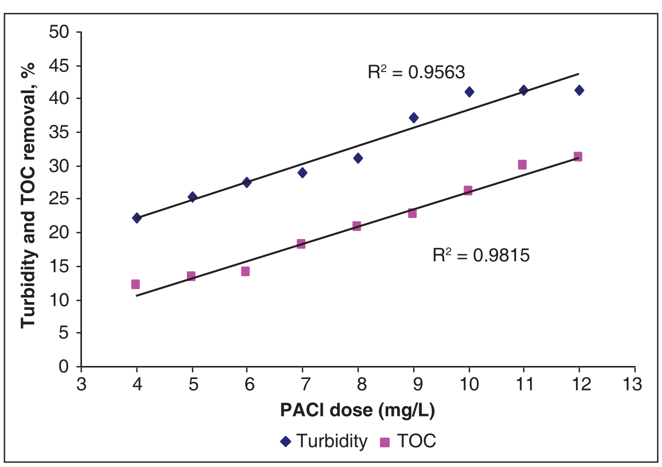

Figure 1: Effect of PACl alone on TOC and turbidity removal

Analytical and statistical procedure

Turbidity and solution pH were determined by Turbidity Meter (EUTEOH ECTNIOOIR) and Crison (GLP-22) pH-meter, respectively. The residual chlorine was measured using the DPD titrimetric method of 4500-Cl-F. All test methods were adopted from Standard Methods.[29] The TOC concentration was measured by using a Shimadzu TOC-5000 analyzer according to the combustion-infrared method.

Tests for significant differences between treatments (various influent parameters) were determined by tow sample *t*-test. Pearson correlation coefficients were used to examine the relationship between PACl, PAC and Cl_2 dose and related removal efficiency. The results were considered as significant when $P < 0.05$. All calculations were performed through the use of SPSS version 18.0 software for windows.

RESULT

Reduction of TOC and turbidity by PACl alone

Standard jar tests were used to investigate the impact of the coagulation process on the organic matter and turbidity. The influence of PACl dose on TOC and turbidity removal was depicted graphically in Figure 1. The result showed that the removal efficiency of TOC and turbidity was improved with increasing the PACl dose. As seen in Figure 1, a transition in TOC and turbidity removal occurred above 2 and 3%, when the PACl dose increased 1 mg/L, respectively. One-way ANOVA showed that the difference was significant at the 95% confidence level ($P < 0.05$).

Effect of PAC dose on TOC and turbidity removal

In this stage, jar tests were conducted at different PAC dosages and at fixed coagulant dose (PACl: 10 mg/L). As shown in Figure 2, the result of TOC and turbidity removal efficiency of coagulation by PACl and PAC addition. Figure 2 shows that the increasing the PAC dosage from 3 to 9 mg/L, the removal efficiency of TOC and turbidity improving

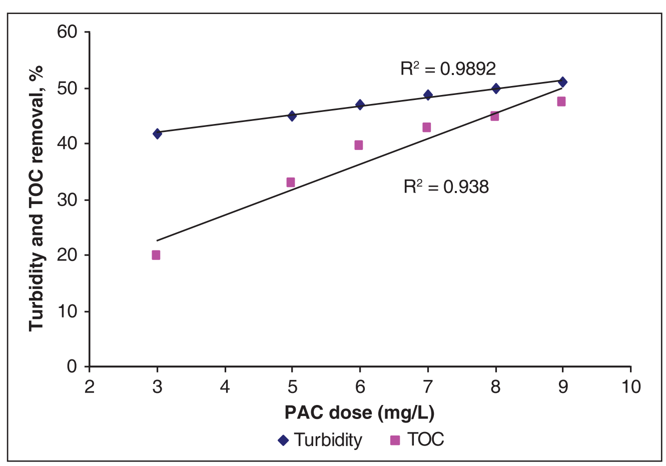

Figure 2: Effect of PACl and PAC on turbidity and TOC removal (PACl dose: 10 mg/L)

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about 30 and 10%, respectively. Transition in TOC and turbidity removal was above 1.5 and 4.5 %, when the PAC dose increased 1 mg/L, respectively. Relatively high correlation was observed between TOC and turbidity removal and PAC dose ($r > 0.96$, $P < 0.01$).

TOC and turbidity reduction at different PACl dose

In this stage, effect of different dose of PACl on TOC and turbidity reduction at constant dosage of PAC (50 mg/L) ware examined. Figure 3 indicates the effect of PACl dosage on the residual TOC and turbidity in the jar test. As seen in Figure 3, with increasing the PACl dosage from 10 to 70 mg/L, the residual of TOC and turbidity was decreased and removal efficiency progressed. The optimum dosage of PACl for TOC and turbidity elimination was obtained 20 and 50 mg/L, respectively. One-way ANOVA showed that the significant difference was observed between the amount of TOC and turbidity in the influent and effluent of the coagulation process ($P < 0.05$).

Effect of pre-chlorination

The influence of pre-chlorination on TOC and turbidity reduction in the range of 0.5 to 2 mg/L was studied. The effects of pre-chlorination on TOC and turbidity removal efficiency were presented graphically in Figure 4. As shown in Figure 4, the pre-chlorination slightly increased the TOC removal efficiency. The maximum and minimum removal efficiency of TOC was obtained at 2 and 0.5 mg/L of Cl_2, respectively. Furthermore, the pre-chlorination slightly diminished the turbidity removal. Hence, the highest removal efficiency of turbidity was obtained at 0.5 m/L of Cl_2. The application of pre-chlorination demonstrated a significant ($P < 0.01$) effect on TOC removal. Transition in TOC and turbidity removal was above 2.5 and 3%, when the Cl_2 dose increased 0.5 mg/L, respectively. Relatively high correlation was observed between TOC and turbidity removal and PAC dose ($P < 0.01$).

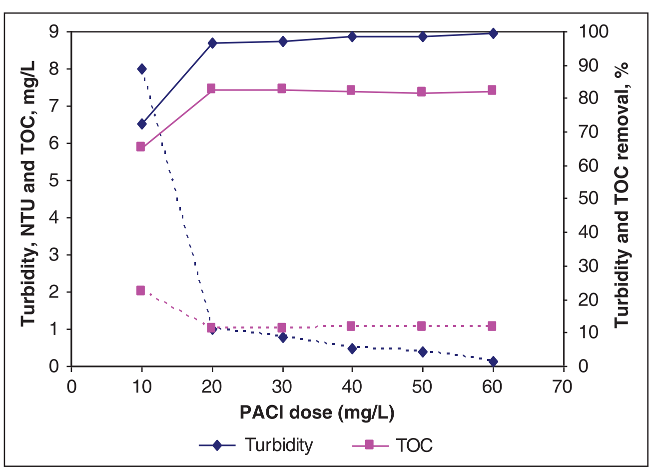

Figure 3: Effect of PACl dose on turbidity and TOC removal at constant weight of PAC) dose (PAC dose: 50 mg/L), dotted lines are for the TOC and turbidity residual and sold lines are for the TOC and turbidity removal

DISCUSSION

In this study, coagulant tests determined the rate of TOC and turbidity removal from SRRW using various dosages of PACl (0-12 mg/L) and pH 7.53 [Figure 1]. According to Figure 1, it can be seen that the highest TOC and turbidity removal efficiency was occurred at highest PACl dose (13 mg/L) and the amount of TOC and turbidity removal was significantly increased with increasing PACl dose. So, adsorption and charge neutralization was most effective mechanism in floc formation. The TOC removal requirement in respect of alkalinity recommended by USEPA are summarized in Table 3.[30]

According to SRRW quality [Table 1], TOC concentration and alkalinity was 5.81 mg/L and 244 mg/L as $CaCO_3$. The TOC removal requirement was 25% for SRRW and in this study; it can be met in PACl dose of 10 mg/L. At this dosage, the percent removal of TOC and turbidity were 41.1 and 26.2%, respectively [Figure 1]. At this step, 10 mg/L of PACl concentration was selected as the optimum coagulant dose for other step.

The removal of turbidity and organic matter using inorganic coagulants is influenced by several factors including the character and concentration of the organic matter, temperature, the raw water alkalinity, coagulation pH and flash mixing intensity.[16] Rizzo *et al*. reported that 80 mg/L ferric chloride yielded 42 and 35% DOC and 56 and 48% UV_{254} removal in two Italian surface water sources,

Table 3: Total organic carbon percent removal requirements for enhanced coagulation

TOC (mg/L)	Source water alkalinity (mg/L as $CaCO_3$)		
	<60	60-120	>120
2-4	40	30	20
4-8	45	35	25
>8	50	40	30

TOC: Total activated carbon

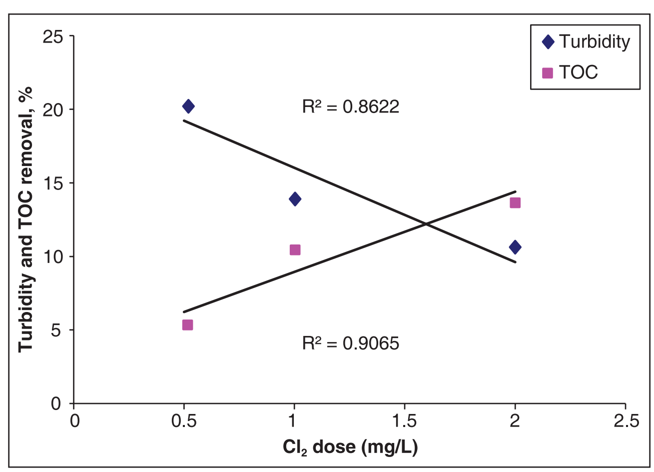

Figure 4: Effect of pre-chlorination on turbidity and TOC reduction

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respectively.[31] Bina *et al*. (2007) showed that the optimal dose of PACl for turbidity removal was 30 mg/L at pH 8 that in this dose, 99.6% efficiency of turbidity removal was achieved.[32] The removal of THMs precursor increased with increasing turbidity removal of raw water, As a result, amounts of THMs also reduced after chlorinated.[33] Malakootian *et al*. demonstrated that the significant advantage of poly aluminum chloride silicate can be achieved in compared with electrocoagulation (EC) for NOM and turbidity removal.[34]

Enhanced coagulation — a higher dose of coagulants — is also a common procedure for reduction of total organic carbon (THMs Precursors). The coagulation is more effective for removal of NOMs with high molecular weight, such as humic acid. However, PAC is more effective for removal of medium or low-molecular-weight NOMs.[35] Several studies have investigated the combined use of coagulation and adsorption with PAC in order to maximize the overall removal of NOM and achieving removal percentages of 45-80%.[28,30,33]

The jar tests determined the rate of TOC and turbidity removal from SRRW using various combinations of 0, 4, 5, 6, 7, 8 and 9 mg/L PAC dosages at 10 mg/L of PACL concentration [Figure 2]. The maximum TOC and turbidity removal amount was achieved at 9 mg/L of PAC dosage. At this dosage, the percent removal of TOC and turbidity were 51 and 47%, respectively. According to the USEPA[30] and as shown in Figure 2, the minimum concentration of PAC for 25% requires removal of TOC was 5 mg/L. At PAC dose of 5 mg/L, the TOC and turbidity removal efficiency was 45 and 29%, respectively. Therefore, the 5 mg/L dose of PAC was chosen as the required optimal dose of PAC.

Alvarez-Uriarte *et al*. (2010) reported that removal of final trihalomethanes formation potential significantly increased by the addition of 50 mg/L PAC. In this regards removal efficiency increased from 42% to 66%.[36] Uyak *et al*. reported that 40 mg/L PAC with 20, 40 and 80 mg/L ferric chloride lead to 52, 68 and 76% of DOC removal in Terkos lake water. The removal amount of DOC was gradually decreased after 40 mg/L of PAC dosages. Thus, the PAC dose of 40 mg/L could be chosen as an optimum PAC dosage.[20]

In the present study, maximum PAC dosage of 50 mg/L was selected according to previous studies. By jar experiment, the rate of TOC and turbidity removal from SRRW using various PACl dosages (0, 10, 20, 30, 40, 50 and 60 mg/L and constant dose of PAC (50 mg/L) was determined. Our finding showed that by the increase of PACl dose, the TOC and turbidity removal efficiency was increased due to the increase of particle accumulation and formation of more flocs [Figure 3]. At these doses of PACl, TOC removal 65.4, 82.7, 82.7, 82.3, 81.7 and 81.9% and turbidity removal of 72.4, 96.6, 97.3, 98.4, 98.7 and 99.5% was achieved, respectively. The reason for the good efficiency of PACl for TOC and turbidity removal could be the high neutralization ability of this coagulant. The removal of TOC was slowed at PACl dose of up to 20 mg/L, but the turbidity removal increasing up to 60 mg/L of PACl. With increasing coagulant dose in water treatment process, the costs of treatment will increase. As results of this study, the PACl dosage of 20 mg/L was recommended as maximum and economic dosage of PACl. This concentration can yield 96.6 and 82.7 % of turbidity and TOC removal efficiency.

With evaluating the amount of residual chlorine and pH with THMs formation, Navalon *et al*. have found that the effect of pH is significant and lead to increasing the chlorine consumption. In general, the solution pH of 11 leads to higher THMFP compared with pH of 8.[37] The chlorination at acidic pH clearly reduces the amount of THMs formed.[38,39] Previous study reported that in order to prevent of THM_S formation, the amount of pH 7.53 was adjusted. In addition, the residual chlorine concentration of approximately 0.3 mg/L should be maintained that pre-chlorination can be practiced without producing significant levels of THMs at all times.[29]

In the present study, the variation of turbidity and TOC with pre-chlorination in the range of 0.5-2 mg/L of residual chlorine was examined. According to Figure 4, as the residual chlorine dosage increased, the reduction in TOC increased gradually. It may be due to the formation of THMs from TOC. In previous studies it has been proved that increasing the hypochlorite concentration leads to increasing the oxidation rate and a decrease of remaining TOC during the 30 min oxidation time. The decrease of TOC was likely due to the appearance of some volatile oregano chlorine compounds.[40,41] In fact, with increasing residual chlorine TOC removal efficiency increases according to Figure 4. With increasing residual chlorine of water to 0.5 ppm, the amount of turbidity reducing from 29 to 23 NTU. After that, the amounts of residual turbidity was augmented from 25 to 26 NTU with increasing residual chlorine from 1 and 2 mg/L respectivey.

The results of the experiments showed that by common water treatment method (coagulation and precipitation) using PACl as a coagulant and PAC and Cl_2 as an adsorbent and coagulant aid, the TOC and turbidity of water reduced to below 1 mg/L and PAC and Cl_2 improved the coagulation process. This method can be used for water treatment plant with drinking water contain the average TOC less than 6 mg/L.

ACKNOWLEDGMENT

This study was the result of the MSc approved project, # 391305, by Isfahan University of Medical Sciences. The researchers, thereby, appreciate the help and cooperation of the Department of Environmental Health Engineering and Environment Research Center.

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Source of Support: Isfahan University of Medical Sciences, **Conflict of Interest:** None declared.