ORIGINAL PAPER

Removal of Natural Organic Matter (NOM), Turbidity, and Color of Surface Water by Integration of Enhanced Coagulation Process and Direct Filtration

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ABSTRACT

This work assesses the efficiency of integrated enhanced coagulation and direct filtration processes for the removal of color, turbidity, and natural organic matter (NOM) from surface water. The processes were conducted in a simulated pilot. The operating conditions of the treatment process, including pH, $FeCl_3$ dose, and influent flow, were investigated. Following that, its efficiency was evaluated by measuring specific water quality parameters in the output stream including NOM, turbidity, and color. The results showed that under optimum conditions (pH, $FeCl_3$ dose, and influent flow of 6.2, 95 L/h, and 40 mg/l, respectively), the color and turbidity were removed 96% and 95% respectively. According to factors analysis by the Taguchi method, the influence of these factors on the removal of pollutants decreased as follows: pH → $FeCl_3$ dose → influent flow. The results revealed that the integrated enhanced coagulation process and direct filtration can improve the efficiency of colors, turbidity, and NOM removal in water treatment plants.

Keywords: Enhanced coagulation, Color, NOM, Turbidity, $FeCl_3$.

Introduction

Organic and mineral impurities like turbidity and color are major pollutants for aquatic environment pollution. The colloidal matter or turbidity is stable in an aqueous solution mostly because of the electrostatic repulsive force. Hence, it is not removed by sedimentation.[1] Natural organic matter (NOM) in aquatic environments can be derived from both natural and anthropogenic sources. However, its main source is terrestrial vegetation and soils.[2] The presence of NOM in surface water is not harmful. But problems arise when the source water containing NOM is treated with a disinfectant like chlorine. The organic matter reacts with the chlorine and forms chlorination byproducts (CBPs) in the drinking water, such as haloacetic acids (HAAs) and trihalomethanes (THMs), which have been linked to dangerous diseases.[3] In addition, NOM causes water to turn yellow, which is aesthetically unpleasant for consumers and is also the energy source for bacterial regrowth. Furthermore, NOM can facilitate the transportation of mineral and organic content in waterbodies due to humic complexation.[4] To avoid these outcomes, it is necessary to decolorize water and remove these impurities before discharging surface water into the environment.

Different types of treatment are used in the removal of NOM, turbidity, and color from raw water; they consist of enhanced coagulation–flocculation–sedimentation,[5] rapid sand filtration,[6] adsorption,[7] electro-coagulation,[8] membrane filtration,[9] and advanced oxidation.[10]

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Among these methods, enhanced coagulation and filtration are widely used in aqueous solution treatments as they are very effective to control a wide range of contaminants that include turbidity, NOM, color, algae, and inorganic substances. Moreover, the USEPA indicates that enhanced coagulation is the best available technology to control NOM and turbidity in drinking water treatment plants.[11] In recent years, instead of the conventional coagulation-flocculation method, these techniques were noticed to control color, taste and odour, known and unknown disinfection byproducts (DBPs), and micropollutants associated with NOM.[12] Furthermore, these methods have certain advantages such as relatively low costs, simple chemical reagents, and low capital cost, and they do not need monitoring of the breakthrough point.[13]

The enhanced coagulation and filtration processes normally consist of a coagulation process, a flocculation step, and a separation step such as direct filtration.[11] Enhanced coagulation is a physicochemical technique, which uses coagulant more for destabilizing and collecting or coagulating pollutants. The most common coagulants used in this process are aluminum sulfate (generally known as alum) and ferric chloride.[14] Among these, ferric chloride ($FeCl_3$) is the most common coagulant used to achieve coagulation because of its relative solubility and high efficiency within the range of different pH levels. Mesdaghinia et al. (2006) studied the effectiveness of enhanced coagulation in the removal of disinfection byproducts. They reported that $FeCl_3$ was consistently more effective than $Al_2(SO_4)_3$ in removing NOM.[15] Direct filtration is another process that improves the control of NOM as well as turbidity in water; it also provides optimum or near-optimum coagulation, with filtration conditions and management being in place.[11]

Aligned to the objective of this research, the effects of variations, such as pH, $FeCl_3$ dose, and influent flow on the removal pollutant, were investigated on a pilot scale.

Materials and Methods

In order to identify the optimum enhanced coagulation and direct filtration conditions for the treatment, experimental studies were conducted. Table 1 presents the characteristics of the water used during experimental works.

Table 1. Water quality studied characteristics

Parameter	Unit	Value
Color	Pt-co	140 ± 15
Turbidity	NTU	32 ± 6
pH	-	8.2 ± 0.4
Total Hardness	mg/l $CaCo_3$	382 ± 35
Alkalinity	mg/l $CaCo_3$	229 ± 35
Sulfate	mg/l	27 ± 9
Fe	mg/l	0.51 ± 0.1
Ca	mg/l	98 ± 10
Chloride	mg/l	59 ± 5
Manganese	mg/l	0.021 ± 0.015
Mg	mg/l	31 ± 4
Nitrate	mg/l	2.9 ± 0.5
Nitrite	mg/l	0.02 ± 0.01
Phosphate	mg/l	0.5 ± 0.2
EC	μS/cm	546 ± 56

The enhanced coagulation-direct filtration pilot plant was designed as a mixer with a two-layer filter that helped in the flocculation step. Fig. 1 shows the treatment process of enhanced coagulation with direct filtration on the pilot scale. The applied method was based on a two-stage operation. At first, ferric chloride was added to the contaminated water and the coagulation-flocculation action was carried out in the presence of coagulant. The next step involved direct filtration for the removal of clots from water. After performing the treatment process, turbidity, color, NOM, and pH of the samples were measured by TN-100 (EUTECH) turbidimeter, DR 5000-HACH LANGE, and pH-meter model CG 824 respectively.

To evaluate the effects of pH, $FeCl_3$ doses, and influent flow on the removal of turbidity, color, and NOM, data analysis and number reduction by design of experiments (DOE) were

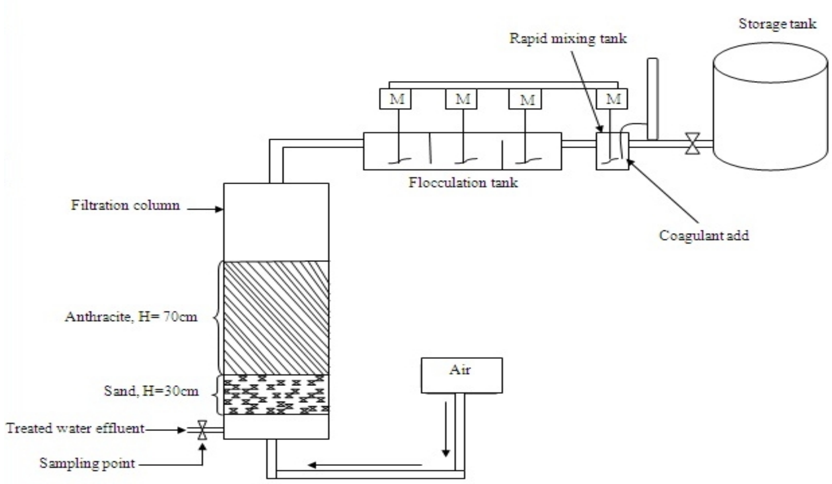

Fig. 1. A schematic of the pilot used in this study

carried out through software (Matlab software). The Taguchi plan was applied by three factors at five levels (Table 2). The matrix involved 16 runs, and each run was triplicated.

Table 2. Analysis of variance for the effect coagulant dose, pH and flow rate on removal of color, turbidity and NOM

Parameter	Factor	df	F	Mean of variation	P	Impact	Rating
Color and Turbidity	Ferric chloride concentration (mg/l)	4	7.29	110.99	0.003	1.3	2
	pH	4	14.8	225.33	<0.001	1.57	1
	Flow rate	4	2	30.43	0.159	0.66	3
NOM	Ferric chloride concentration (mg/l)	4	91.79	275.647	<0.001	2.05	1
	pH	4	29.06	87.264	<0.001	1.20	2
	Flow rate	4	2.04	6.139	<0.152	0.26	3

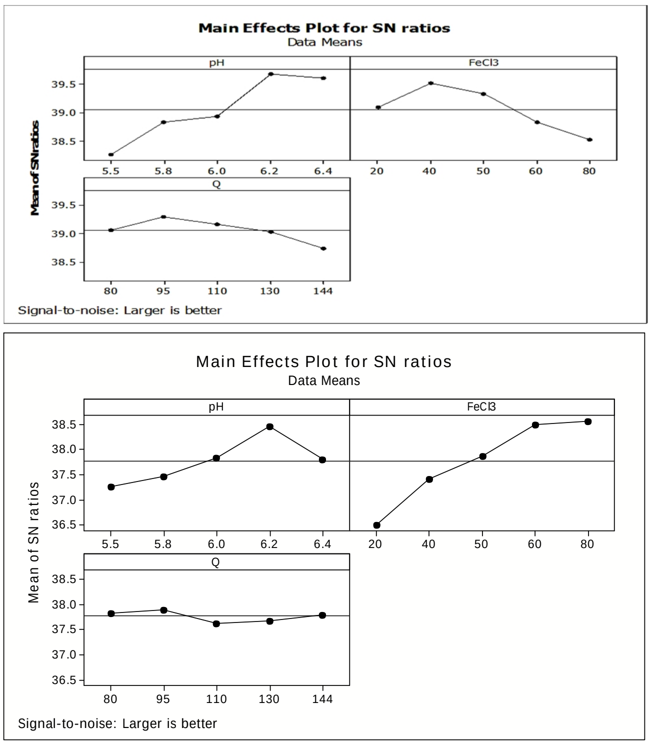

Fig. 2.The mean of signal to noise(S/N) of effluent for pH, coagulant dose and flow rate on the color and turbidity removal (a) and the NOM (b)

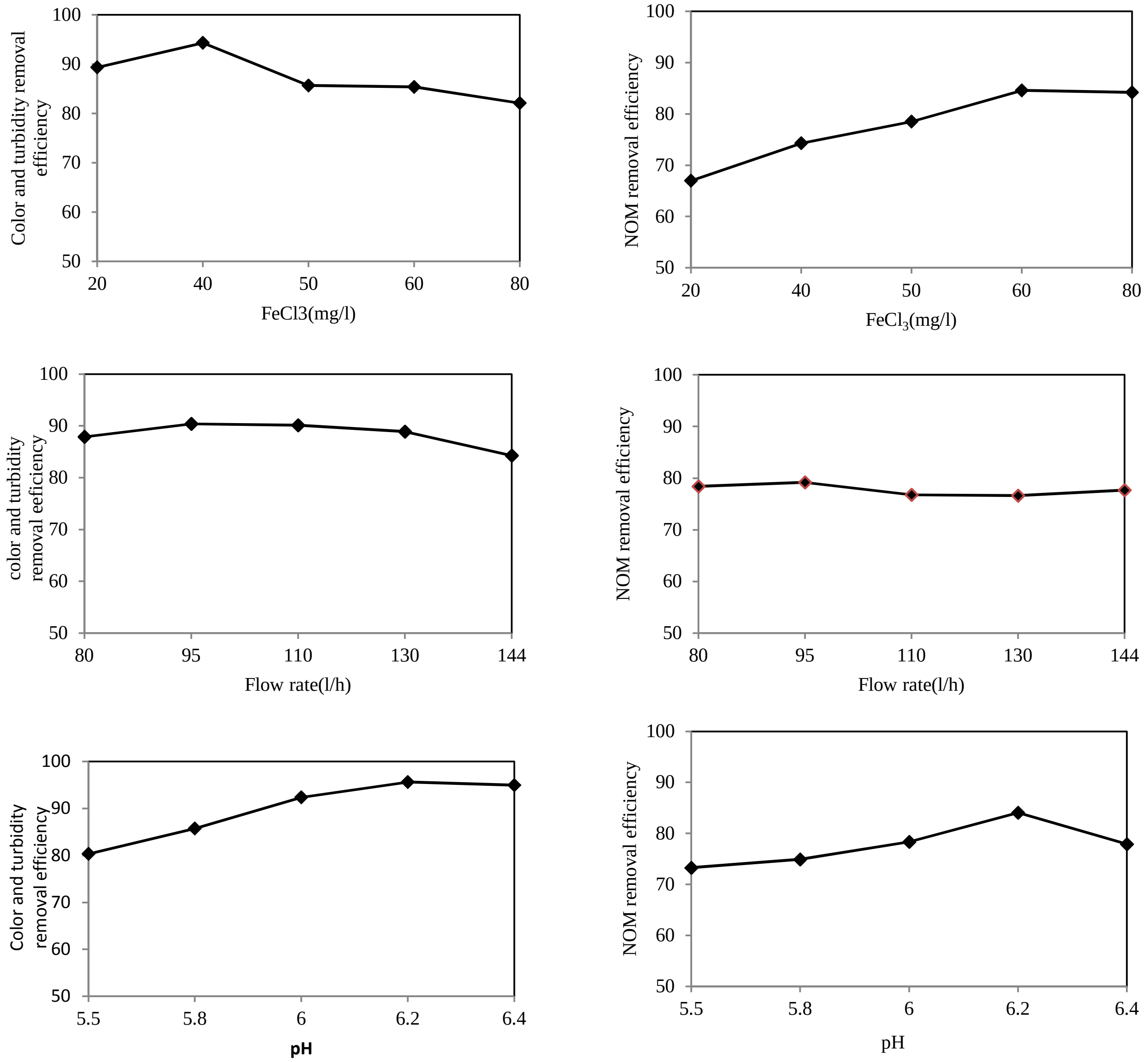

Fig. 3.The effect of changes pH, coagulant dose of Ferric chloride and influent flow on the color, turbidity and NOM removal efficiency

Results and Discussion

The efficiency of the removal of pollutants by enhanced coagulation and direct filtration processes depends on various factors such as pH, coagulant dose, and influent flow. In this study, the effect of these parameters was investigated on the performance of the enhanced coagulation process. Figures 2 and 3 present the efficiency of the removal of pollutants at various conditions. According to the figures, an increase in the pH level of the solution increases the efficiency of the removal of color, turbidity, and NOM. This increase of pollutant removal ratio by $FeCl_3$ can be explained on the basis of groups formed through the hydrolysis of $FeCl_3$ in various pH levels. When ferric chloride is added to aqueous solutions, the lower pH of 8 is hydrolyzed to groups of Fe^{3+}, $Fe(OH)^{2+}$, $Fe(OH)_3$, and $Fe(OH)_2^+$. Among these species of iron, $Fe(OH)_2^+$ and $Fe(OH)_3$ represent more than 90% of the impurities at the intermediate pH values.[16] Further in the intermediate pH range, the functional groups of NOM are partially ionized, yielding anionic species. Therefore, the charge neutralization/ precipitation mechanism takes place through chemical reaction between soluble humic anions and cationic species produced by ferric hydrolysis.[17] Sperczynska et al. studied the removal of turbidity and NOM from surface water by coagulation with polyaluminium chlorides (PACl). They reported that when pH decreased from 8.2 to 6.2, the effectiveness of organic compounds removal increased.[18] Jaafarzadeh et al. studied the influence of polyaluminum chloride on the removal of heavy metal from aqueous solutions. The results showed that heavy metal removal is significantly enhanced by coagulation at high pH levels.[14] The results obtained for NOM removal by Tubić et al. show that the greatest efficacy was achieved when PACl and $FeCl_3$ were applied in neutral pH.[19]

Fig. 3 shows the effect of $FeCl_3$ dose on the removal of pollutants. First, by increasing the $FeCl_3$ dosage, pollutant removal ratio is increased and then decreased. So the maximum removal percentage was about 94.3% and then 84.6% at coagulant dosage equal to 40 mg/L and 60 mg/L, respectively. This initial increase in the pollutant removal ratio can be attributed to the addition of $FeCl_3$ and an increase in $Fe(OH)_2^+$ and $Fe(OH)_3$ species. Further, by increasing the $FeCl_3$ dosage, coagulated pollutant becomes stable again, and returns to the solution. This explains the reduction in pollutant removal percentages at high dosages.[14] Jaafarzadeh et al. obtained the same results and showed that by increasing PACl dosage, Zn and Ni removal ratio are increased and then decreased.[14] Pang et al. studied the removal of lead, zinc, and iron from aqueous solution by aluminium sulfate (alum), polyaluminium chloride (PACl), and magnesium chloride ($MgCl_2$). Their results showed that the removal of heavy metal was reduced when the PACl dosage was increased to high level. This could be due to the restabilization of the colloidal particles in the presence of excess coagulant.[20] Fig. 3 also shows that the amount of pollutant removed increased and then decreased, when the flow rate was increased from 80 L/h to 144 L/h. This decrease can be related to the accumulation of flocs in pores of the filtration media. Bojic et al. reported that the amount of copper removed increased, when the flow rate was increased from1 L/min to 120 L/min.[21]

Analysis of varience (ANOVA) on the pH, flow rate, and coagulant concentration factors shows that the P-value was less than 0.05 for the coagulant concentration and pH, but it was more than 0.05 for flow rate (Table 2). This means that the concentration and pH factors had significant effects on the NOM, color, and turbidity removal. Moreover, based on the analysis of results, it was found that coagulant concentration and pH had the greatest effect on the NOM, color, and turbidity removal.

Conclusion

The results of this study have shown the applicability of the enhanced coagulation process and direct filtration in the treatment of surface water containing turbidity, color, and NOM in the intermediate pH. Using the enhanced coagulation treatment, pollutants are removed from water through direct reduction by $Fe(OH)_2^+$ and $Fe(OH)_3$, formed through the hydrolysis of $FeCl_3$ coagulant on the filtration media surface. By increasing the concentration of $FeCl_3$, the amount of turbidity, color, and NOM removal efficiencies increased. Furthermore, according to the obtained results, high levels of input current leads to the reduction of pollutant removal because of the accumulation of flocs in pores of the filtration media. Hence the increase of input flow during enhanced coagulation and direct filtration did not have any significant effect on the removal of pollutants.

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