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PRETREATMENT OF THE RAW SEWAGE AT THE MUNICIPAL WASTEWATER TREATMENT PLANT (WWTP) IN ALGERIA BY COAGULATION/FLOCCULATION USING ALUMINUM AND FERRIC SALTS: OPTIMIZATION OF PROCESS PARAMETERS

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Abstract

The coagulation-flocculation process is an essential step in the water treatment chain. It consists of eliminating suspended matter and colloidal substances responsible for the transfer of contaminants into the environment. The efficiency of the process depends on several factors, mainly the pH of the wastewater, the dosage of the coagulant used, the speed and the time of stirring during coagulation.

This study aims to optimize the coagulation stage in the municipal wastewater treatment plant of the town of Sidi Bel Abbes (Algeria). Four key factors in this process have been optimized: the initial pH of the wastewater (pH_i from 4.5 to 11), doses of coagulants $AlCl_3,6H_2O$ and $FeCl_3,6H_2O$ (from 0.1 to 1.5g/L of effluent), stirring speed (from 50 to 200rpm) and stirring time (from 5 to 15mn). Two main response parameters were measured: turbidity and the final pH of the treated wastewater.

The results showed that the dosage of $AlCl_3,6H_2O$ of 1g/L at pH 6.5 and $FeCl_3,6H_2O$ of 0.1g/L at pH 11 provided the best turbidity removal. The optimum agitation speed is 100 rpm for 5 min.

Keywords: Process, Coagulation, Flocculation, Optimization, Wastewater, Aluminum, Iron, Environment.

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1. Introduction

Demographic and economic developments are two factors that have contributed to water pollution [1,2,3,4]. Natural phenomena such as evaporation and volcanization, as well as human activities, such as agriculture and industry, generate liquid discharge including contaminating chemicals [5,6]. Consequently, these effluents must be treated before being discharged into the receiving environment which is generally surface water resources (seas, oceans, etc.).

In Algeria, urban effluent liquid treatment is carried out in municipal wastewater treatment plants (WWTP), which represent a structure of the National Sanitation Office (NSO). This one is a public establishment of an industrial and commercial nature, created by decree No. 01-102 of the 21st of April, 2001, under the tutelage of the Algerian Water Resources Ministry [7]. Coagulation/flocculation, sedimentation, filtration and disinfection are the main steps in the conventional treatment processes. Coagulation is a chemical treatment consists of destabilization of colloidal particles using inorganic salts or polymers so that they can aggregate and form larger flocs that are easily removed by sedimentation [8,9]. In wastewater, the coagulation process eliminates turbidity, suspended solids, and organic matter. Its efficiency is related to the characteristics of the composition of the raw water, the type of coagulant and the dosage used [1,10,11,12].

Iron and aluminum frequently employed in the treatment of water [13]. Iron and aluminum salts dissociate and react in aqueous solution to form hydrolyzed complexes which act as coagulant species responsible for the removal of turbidity and color [14].

Several parameters govern the coagulation phenomena, such as the dosage, time, speed of agitation and especially the pH value which represents a key parameter of coagulation because it influences hydrolysis, polymerization and the resulting species [15,16]. This parameter has been largely neglected in several studies on the subject. Primarily, the optimization studies have taken into account the optimization of the coagulant dosage at a fixed pH; thus, no emphasis has been placed on pH as a distinct variable. However, without optimizing the pH value, it is difficult to know whether the highest coagulation efficiencies are truly attained. Generally, studies are concerned with the measurement of the resulting final pH after coagulation, while it is uncertain whether coagulation efficiency was achieved with the dosage applied or the resulting pH, or both.

In this study, we designed a methodology to optimize four essential parameters of the coagulation step during the treatment of urban wastewater at the WWTP in the town of Sidi Bel Abbes in Algeria. These parameters are: the dosage of the coagulant, the pH value as well as the time and the speed of coagulation.

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We present a real example showing the impact of each parameter on coagulation efficiency. This optimization of the quantity of coagulant and of electrical energy, linked to the speed and the stirring time, increases the efficiency of the process and reduces the total cost of the treatment.

2. Material and methods

Using 1000 mL HDPE bottles, water samples were taken at the entrance to the clarification pond. The water samples were transported to the laboratory for analysis and stored at 4 ° C.

The turbidity and the pH of the wastewater were measured using AQUALYTIC infrared **turbidity meter model AL250T-IR** and a HI-2211 Bench Top pH & mV Meter.

The raw wastewater had a pH 7.25, turbidity 288 NTU, an electrical conductivity of 950 µS/cm, and Total Dissolved Solids (TDS) 440 mg/L.

On a laboratory scale, the coagulation/flocculation tests were performed, at room temperature (20 ± 1.0 ° C) and using a Jar Test device (model AOUA / UTC) equipped with four stainless steel blades and whose stirring speed varies from 0 to 200 rpm while the stirring time is from 0 to 30 min.

A number of experiments were conducted with reference to the set of experiments designed for optimization. All tests were carried out in 600 ml beakers, which were filled with 400 ml of wastewater. The initial pH of the wastewater was adjusted to the desired value using two solutions of HCl 0.1N and NaOH 0.1N.

The coagulants used are aluminum chloride hexahydrate $AlCl_3,6H_2O$ and ferric chloride hexahydrate $FeCl_3,6H_2O$. The use of these coagulant reagents is known in the literature, in addition to their low cost, they are distinguished by their ability to act as both a coagulant and a flocculant at the same time by promoting the agglomeration of small particles and then facilitating their separation by settling.

For the coagulation tests, different agitation speeds were used (50, 100 and 200 rpm) for time intervals varying from 5 to 15 min. Then, and for each test, the stirring was reduced to 20 rpm for 20 min to promote the formation of flocs (flocculation). After flocculation, samples were left to stand for 60 minutes. Then, 200 mL of the supernatant was taken for analysis. The rate of removal of a parameter X, expressed as a percentage, was calculated using the following formula:

$$\% \text{ removal of } (X) = [(Xi - X) / Xi] * 100$$

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Xi: initial concentration of X in the effluent (before treatment).
X: final concentration of X in the effluent (after treatment).

3. Results and discussions

3.1 Optimization of coagulant dosage

The dosage of the coagulant is the first factor influencing coagulation. It's defined as a value above which adding more coagulant has no significant effect on the removal efficiency [17]. Mainly, an insufficient dose or an overdose would lead to poor flocculation performance [18], hence the existence of an optimum coagulant dosage to be determined in order to minimize the cost and obtain the performance of optimal treatment. This concentration can be evaluated by measuring the variation in the turbidity of the effluent which is directly related to the colloids present.

The optimum coagulant dosage was determined over a range of varying concentrations of 0.01 to 1.5 g of coagulant / liter of effluent. Coagulation was carried out at 200 rpm for 5 min and the coagulant was added to the wastewater immediately at the start of rapid stirring.

Depending on the zone of predominance of aluminum hydroxides (5.8 to 7.2) and iron hydroxides (5.5 to 8.5), the pH was adjusted to 6.5 for $AlCl_3,6H_2O$ and to 8.5 for $FeCl_3,6H_2O$. In this pH range, dissolved forms Al^{3+} and Fe^{3+} are almost non-existent, which minimizes the risk of water contamination by Al^{3+}, network corrosion and color pollution due to the presence of Fe^{3+}. Results are shown in table 1.

TABLE 1

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EXPERIMENTAL CONDITIONS AND RESULTS FOR COAGULANT DOSAGE OPTIMIZATION

Coagulant dosage (g/L)	$AlCl_3$, $6H_2O$			$FeCl_3$, $6H_2O$		
	pH_i	pH_f	Turbidity removal (%)	pH_i	pH_f	Turbidity removal (%)
00	6.5	6.5	00	8.5	8.5	00
0.01		6.3	17		8.0	19
0.03		6.2	55		7.4	44
0.05		6.0	83		6.8	71
0.10		5.7	96		6.4	99
0.50		4.5	97		4.0	97
0.70		4.4	97		3.0	96
1.00		4.3	98		2.3	93
1.30		4.2	96		2.2	89
1.50		4.1	96		2.2	87

The optimal dosage was noted at 1 g/L for $AlCl_3$,$6H_2O$ and at 0.1 g/L for $FeCl_3$,$6H_2O$ (fig. 1). At these concentrations, the best turbidity removal rate was obtained, reaching a maximum of 98% and 99% respectively. The elimination phenomenon is due to the fact that the coagulating particles destabilize the negatively charged colloids by neutralizing the charges that generate the repulsive forces between them. Beyond this content, and by exceeding the optimum dose of the coagulant, a gradual drop in this rate has occurred due to the enrichment of the reaction medium with cations. This causes excessive adsorption of the cations and reverses the charge of the particles, which then become positive. Thus, the particles would be dispersed.

Mineral coagulants like iron and aluminum chlorides that consume alkalinity can lead to reduced pH [19]. The gradual addition of $AlCl_3$,$6H_2O$ and $FeCl_3$,$6H_2O$ to the wastewater caused a significant drop in pH to acidic values of around 4 and 2 respectively (fig. 2). This decrease in pH is due to the hydrolysis of coagulants according to the following reactions:

$$Fe^{3+} + n\ H_2O \Rightarrow Fe(OH)_n + n\ H^+ \quad (1)$$

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$$Al^{3+} + n\ H_2O \Rightarrow Al(OH)_n + n\ H^+ \quad (2)$$

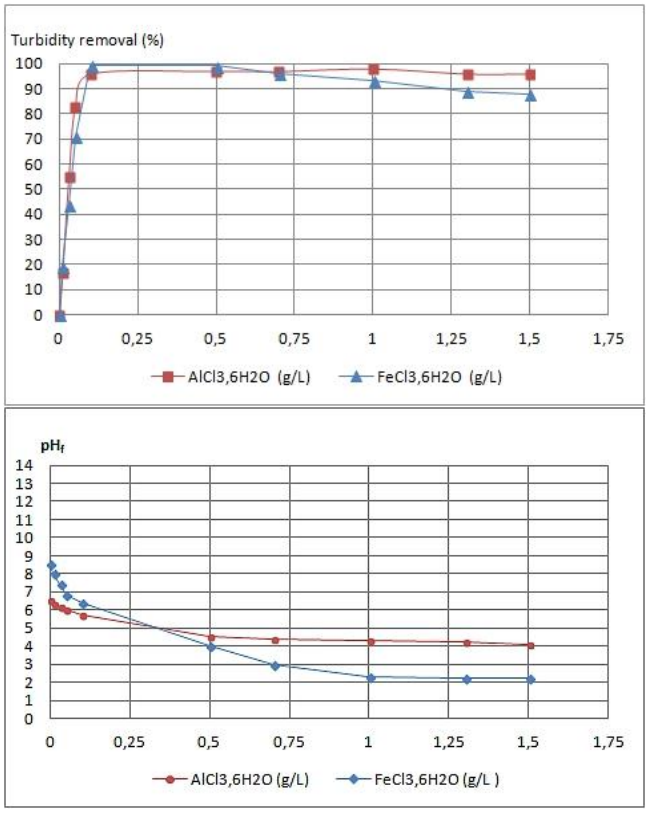

Fig. 1. Variation of removed turbidity as a function of coagulant dosage
Fig. 2. Variation of pH_f as a function of coagulant dosage

3.2 Optimization of pH

Based on the previous results and to determine the optimum pH, we set the optimum dosage of each coagulant, and we proceeded under the same operating conditions (speed and stirring time during coagulation and flocculation). The pH values were adjusted to 4.5 , 6.5 , 8.5 , and 11. The results are collated in table 2.

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TABLE 2

EXPERIMENTAL CONDITIONS AND RESULTS FOR pH OPTIMIZATION

$AlCl_3$, $6H_2O$				$FeCl_3$, $6H_2O$			
Coagulant dosage (g/L)	pH_i	pH_f	Turbidity removal (%)	Coagulant dosage (g/L)	pH_i	pH_f	Turbidity removal (%)
1.0	4.5	3.5	90	0.1	4.5	3.9	83
	6.5	4.3	98		6.5	2.9	89
	8.5	6.3	96		8.5	5.9	97
	11	8.9	97		11	8.4	99

Depending on their nature and the pH level, colloids will have either a positively or negatively charged surface. This is directly related to the effectiveness of coagulation-flocculation by the addition of cationic coagulants.

The best turbidity elimination was noted at pH 6.5 in the presence of $AlCl_3$,$6H_2O$ and at pH 11 in the presence of $FeCl_3$,$6H_2O$. The elimination rates reached 98.0% and 99.2%, respectively (fig. 3). For the most frequently used coagulants, such as iron or aluminum salts, pH values influence hydrolysis, polymerization, and the resulting species [15].

At low pH values (2.2 for ferric coagulants and 4.5 for aluminum coagulants), Fe3+ and Al3+ ions in an aqueous medium appear as hexaaqua complexes $[Fe(H_2O)_6]^{3+}$ and $[Al(H_2O)_6]^{3+}$ [20,21,22]. Hydrolysis occurs in parallel with increasing pH, forming coagulant species that destabilize negatively charged particles [23,24].

The graphs in figs. 4 and 5 clearly show that there is a close relationship between the initial pH and the final pH of the wastewater. The value of the coefficient of linearity R^2 for $AlCl_3$,$6H_2O$ and $FeCl_3$,$6H_2O$ is of the order of 0.9698 and 0.9131, respectively, which shows a dependent relationship.

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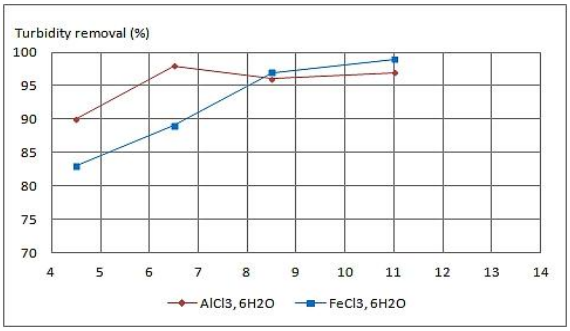

Fig. 3. Variation of removed turbidity as a function of pH_i

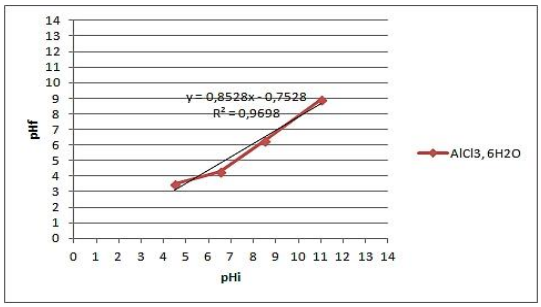

Fig. 4. Variation of pH_f as a function of pH_i for $AlCl_3,6H_2O$

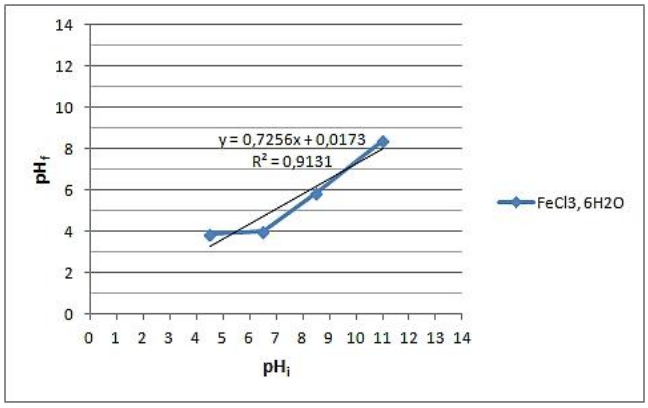

Fig. 5. Variation of pH_f as a function of pH_i for $FeCl_3,6H_2O$

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3.3 Optimization of stirring speed and time for the stage of coagulation

By setting the optimum coagulant dosage and pH, we evaluated different coagulation speeds and times:

- 100 rpm for 5min and 200 rpm for 5min: this choice was based on the fact that coagulation is a step which requires a rapid stirring speed for a short time, to ensure a very good diffusion of the coagulant and good chemical destabilization of the colloids.
- 50 rpm for 5min and 200 rpm for 15min: this choice was made to check the dependence between speed and coagulation time. The results are listed in Table 3.

TABLE 3.
EXPERIMENTAL CONDITIONS AND RESULTS FOR MIXING SPEED AND TIME OPTIMIZATION

$AlCl_3$, $6H_2O$					$FeCl_3$, $6H_2O$				
Coagulant dosage (g/L)	pH_i	**mixing speed (rpm)**	Mixing time (min)	Turbidity removal (%)	Coagulant dosage (g/L)	pH_i	**mixing speed (rpm)**	Mixing time (min)	Turbidity removal (%)
1.0	6.5	50	5	78	0.1	11	50	5	79
		100	5	99			100	5	99
		200	5	98			200	5	97
		200	15	86			200	15	79

Stirring speed acts on the possibility of meeting the particles. It must be high enough to allow the particles to meet. However, if it becomes too high, the flocs undergo mechanical shear, which causes their fragmentation.
The results indicate that the coagulation is better at a speed of the order of 100 rpm and for 5 minutes of time (fig. 6). This means that this step can reach its optimum for a short time and at a fast but not overdone stirring speed. This efficiency decreases by increasing the time devoted to it.

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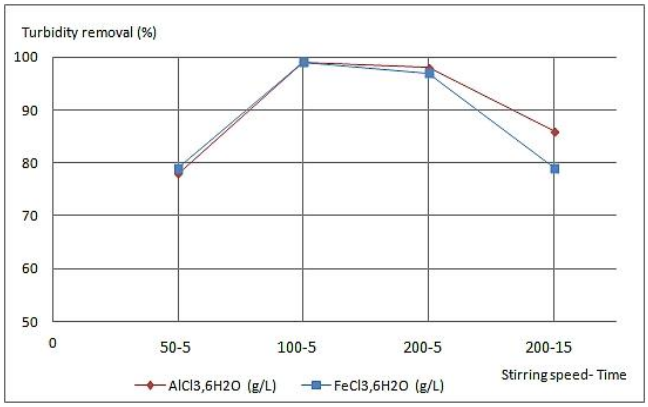

Fig. 6. Variation of removed turbidity as a function of stirring speed and time

4. CONCLUSION

In this study, the coagulation step applied in the pretreatment of the raw effluent in a municipal urban wastewater treatment plant in Algeria was optimized. The results showed that the performance of the process is linked to four optimized parameters (the dose of the coagulant, the pH, the speed, and the stirring time). The maximum elimination was achieved for 1g/l of $AlCl_3,6H_2O$ and 0.1g/l $FeCl_3,6H_2O$ at a stirring speed of 100 rpm for 5 min regardless of the coagulant. The results of this study make it possible to minimize the total cost of the treatment while achieving maximum performance from the coagulation process.

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