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Optimization of Coagulation-floculation of Water from the Djoué River at the Drinking Water Treatment Station in Brazzaville

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Abstract

The present work proposes to study the clarification of raw water by the elimination of organic (OM), mineral and colored matter thanks to the process of coagulation-flocculation by aluminum sulfate. We were first interested in a first part in the study of the process applied to the drinking water treatment plant. In a second part, we carried out this same process at the laboratory level by jar-test. A comparison of turbidity reduction by aluminum sulfate coagulation was estimated. For all samples, a sharp drop in turbidity was observed in the first three beakers for doses ranging from 0.06 to 0.08 g/L of aluminum sulfate. These doses were adopted in the study of the effect of pH set at 7. The resulting turbidity after 30 minutes of settling varies between (reduction of 25 to 81 %) depending on the dose and the sample. Very good elimination is observed with a dose of aluminum sulfate equal to 0.08 g/L (reduction in the order of 67.31 to 81.06 %). At this optimum dose, it can be considered that all the surface charges have been neutralized.

Keywords: Turbidity; coagulation-flocculation; aluminum sulfate; jar-test; abatement.

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1. Introduction

Water is the most common mineral substance on the earth's surface and constitutes the hydrosphere. It is synonymous with life and in particular that of human populations whose history it has influenced and conditioned development [1]. It is also one of the main vectors of disease transmission via pollutants. These pollutants are either naturally present in the environment or the result of human activities [2]. Either way, the availability of good quality water, essential for human well-being, is far from a given [3]. Groundwater once was sufficient and unpolluted to meet the needs of populations, is nowadays sometimes contaminated with the advent of the industrial revolution [4]. The use of surface water is becoming essential and necessary in order to provide populations with water. To make surface water drinkable, it would have to undergo some physicochemical and sometimes biological treatments [5]. The flocculation coagulation technique that uses chemicals is proven to be effective and by far the most widely used process in the industry due to its simplicity, low cost and ease of pH control [6-7]. In this process, chemicals react with ions in the water to form insoluble precipitates which are separated from the water by sedimentation or filtration. The flocculation coagulation technique is the process used at the Djoué River water treatment plant by the Djoué plant for clarifying water before disinfection. Our work constitutes a study by experimental approach of the optimization of coagulation flocculation by aluminum sulfate as a coagulant in the clarification of surface water of the Djoué River.

2. Materials and methods

2.1. Location of the study area

Located on the right bank of the Congo River, Brazzaville is the capital of Congo. It has nine districs and its geographical position is 4°16'04" South Latitude and 15°16'31" East Longitude. In this city are located two water treatment plants, the Djoué plant in south of the city located in the district 1 Makélékélé and the Djiri plant in north of the city located in the district 9 Djiri. Each of the two plants processes 122,400 m^3/day and 163,200 m^3/day, respectively.

2.2. Sampling

The sampling covered three months (January, February and March). The samples were taken at the water catchment of the Djoué river for raw water (EB) for analysis in the laboratory and in the various points of the treatment station for the settled water (ED), filtered water (EF) and treated water (ET) respectively. Bottles of 1000 ml glasses were used. Before use, these vials were thoroughly washed and rinsed. They were then dried and then wrapped in aluminum foil and sterilized by autoclaving (125°C) for 15 minutes.

2.3. Analytical methods

The following parameters were determined in the water samples taken: temperature (T), pH, turbidity (Turb.), residual chlorine (Cl2-res.), total organic carbon (TOC), ammonium ion ($NH4^+$), bromide ion (Br^-) and absorbance 254 nm (Abs. UV), color, suspended matter (MES), conductivity, total dissolved solids (TDS), Alkalimetric Titer (TA), Complete Alkalimetric Titer (TAC), Total Hydrotimetric Titer (THt), sulfate ion ($SO4^{2-}$), nitrate ion ($NO3^-$), magnesium ion (Mg^{2+}) and aluminum ion (Al^{3+}). The temperature was measured using a WTW brand thermometer, EU, HACH. The pH was measured using a pH-meter AR25 type, Fischer scientific. Turbidity was measured using an HACH Lange Nephelometric Infrared Light Turbidimeter (Model 2100P IS, Range 0.001 to 1000NTU, Noisy Le Grand, France). Residual chlorine was determined using the DPD method (diethyl-p-phenyldiamine) using a TestpaK apparatus (Comparator 2000+ Lovibond, Tintometer-Group, France). The bromide ion was determined using SpectroDirect / PC spectro II-3 O4/2008 using the pellet method (DPD n°1). Ammonium ($NH4^+$) ions were measured using a SpectroDirect / PC spectro II-3 O4 / 2008 using the 2-3 indophenol method. The TOC contents were determined using a SpectroDirect / PC spectro II-3 O4 / 2008 brand analyzer using the MERCK Spectroquant (R) method, cuvette test No.1.14879.0001, Persulfate method. UV absorbance was measured at 254 nm using SpectroDirect / PC spectro II-3. Color was measured with a color comparator, MES was measured with a photometer (HACH), conductivity was measured using a conductivity meter (WTW, UE, HACH), ions ($SO4^{2-}$), nitrate ion (NO_3^-), magnesium ion (Mg^{2+}) and aluminum ion (Al^{3+}) were measured with a Colorimeter DR850 DR890 (HACH). Total water hardness (THt) were determined by volumetric titration with 0.01M EDTA. The complete alkalinity (TAC) was determined by field titrimetry using 0.01N H_2SO_4 solution.Alumina [$Al_2(SO4)_3$ $18H_2O$ (MW = 666 g)] is the flocculant used at the Djoué plant. The percentage of reduction in turbidity during the jar-test tests is evaluated by the yield which is equivalent:

$$A\% = \frac{To-T}{To} \times 100 \quad (1)$$

To and T respectively represent the initial and final turbidities of each beaker after settling, expressed in NTU [8].

3. Results and discussion

There is not enough surface water to drink. The presence in these waters of organic and mineral substances is the cause of many problems during drinking water treatment. Their composition will make it possible to make an effective diagnosis which will serve as a basis for the choice of the steps to recommend for the treatment and to monitor the quality parameters to avoid any risk of deterioration of this quality [9-10].

3.1. Physicochemical characterization of raw water from the Djoué River

Table VII presents the physicochemical characteristics of raw water from the Djoué River following five samples and the average for each parameter analyzed was estimated. The analyses were carried out at the Central Laboratory of the National Water Distribution Company (LCDE).

- The pH of the water varied between 7.25 and 7.80. pH represents the intensity of acidity or alkalinity and measures the concentration of hydronium ions in water. The range of pH values recommended by the WHO is 6.5 - 8.5. The pH of the water analyzed was in all cases within the limit required by WHO.

Table 1: Results of physicochemical analyzes of raw water from the Djoué River

Parameter	Unit	Raw Water (EB)	Guidance (WHO)
pH		7.42	6.5-8.5
Temperature	°C	20	
Turbidity	NTU	11.18	2
TOC	mg/L	7.83	2
Abs. UV (254 nm)	cm^{-1}	0.016	
Color	mg/L	0	15
MES	mg/L	2.6	<1
Conductivity	µS/Cm	21.31	277
TDS	mg/L	9.6	340
TA	mg/L	0	30
TAC	mg/L	7.3	30
THt	mg/L	10.32	50
NO_3	mg/L	0.8	50
Ammonium	mg/L	0.18	0.5
Phosphate	mg/L	0.36	5
Magnesium	mg/L	0.5	0.5
Sulfide	mg/L	0.8	250
Aluminum	mg/L	0.14	0.2
Bicarbonate	mg/L	11.1	-

- Turbidity is a very important physical parameter for water quality control. Very high values are found at the level of raw water collection and in the treatment chain at the Station, varying between 7.7 and 15.3 NTU. These recorded turbidity levels greatly exceed the acceptable limit value for water intended for human consumption, which is 2 NTU [11]. Perhaps the most important health effect that characterizes turbidity is its ability to protect bacteria and viruses from disinfection [12].

- Suspended matter represents all the mineral and organic particles contained in the water. They depend on the nature of the land crossed, the season, rainfall, water flow regime, the nature of the discharges, etc. [13]. The measurement of SS content in samples taken from the water varied between 1 and 5 mg / L. The high levels of suspended solids can be considered as a form of pollution. The limit recommended by WHO is less than 1 mg / L [14]. Such an increase can also lead to warming of the water, which will have the effect of reducing the quality of habitat for cold-water organisms [15].

- Total organic carbon (TOC) varied between 7.24 and 7.83 mg/L. These values are greater than the guideline value authorized by WHO. The TOC is a characteristic of natural organic matter. It is an indicator of the precursors of THMT [16]. Monitoring this indicator is interesting because it is more linked to humic acids, precursors that are more reactive than fulvic acids with respect to chlorine. Likewise, the 254 nm UV absorbance indicator is also used to characterize the reactivity of organic matter to chlorine and its potential to form chlorination byproducts (SPC) like trihalomethanes (THMT). The TOC parameter also makes it possible to assess the quality of the physicochemical treatment carried out at the plant [17]. All other parameters have values below the limit required by WHO.

3.2. Evaluation of analyzes of some physicochemical parameters in the treatment sector (treatment station)

The results of the analyses carried out at the Potabloc of Djoué are represented in figures (graphs) 1, 2 and 3. To make a general reading of the evolving trends of the concentrations of some parameters (pH, Conductivity, SS, $NO3^-$, Turbidity ...) on the one hand, the TOC and UV absorbance 254 nm on the other hand, we proceeded to the plots of their evolution in graphs 1 to 3. These graphs show the steps of the process applied at the level of the Djoué potabloc.

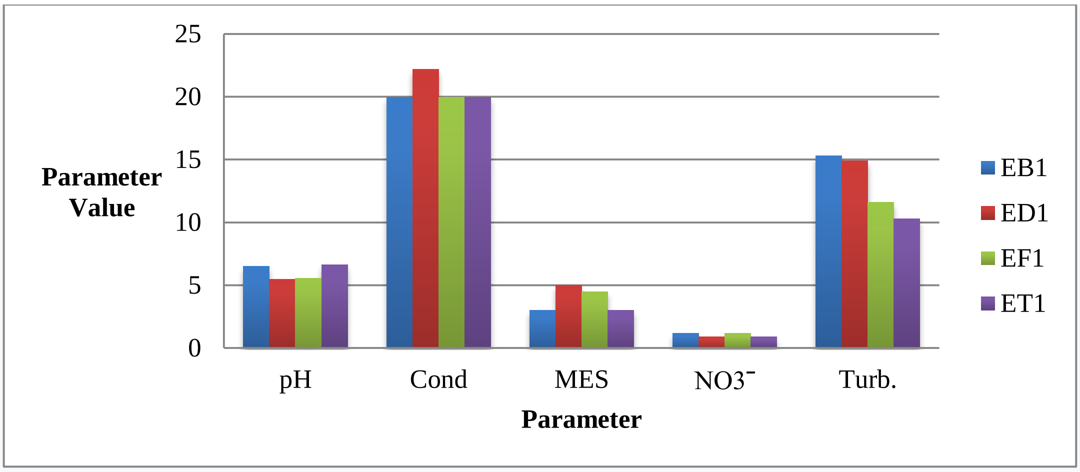

Figure 1: Evolution of the parameters according to the processing steps

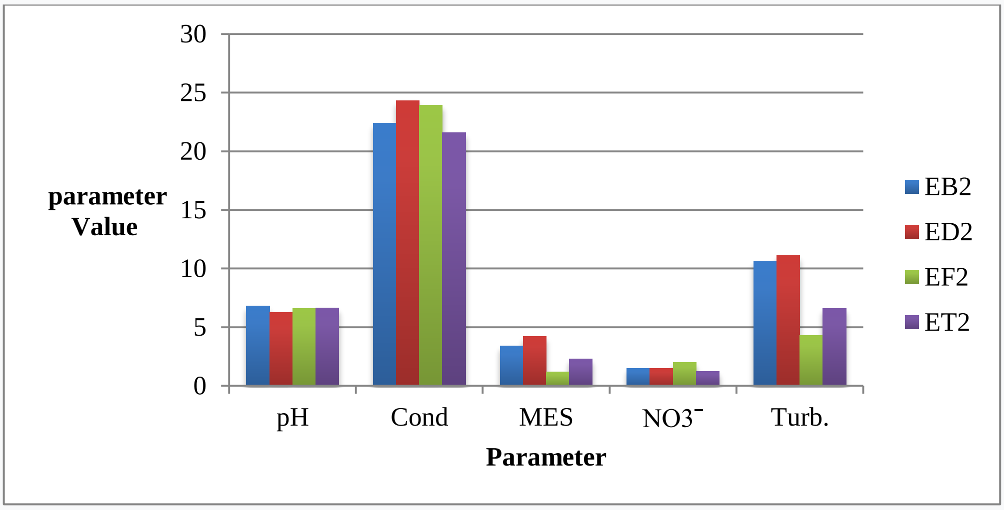

Figure 2: Evolution of the parameters according to the processing steps

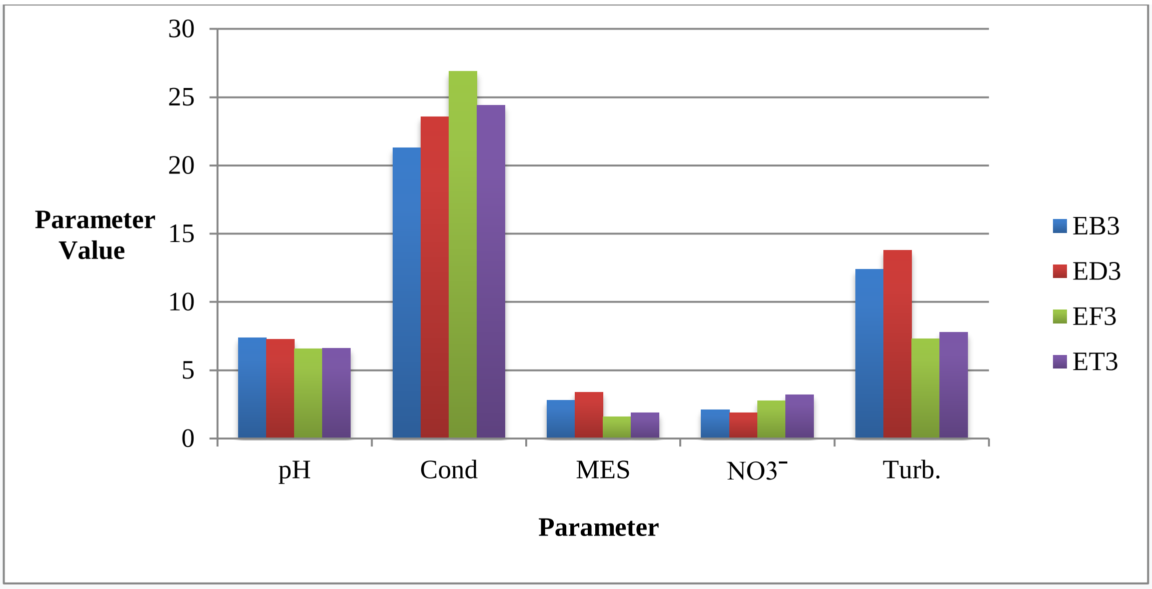

Figure 3: Evolution of the parameters according to the processing steps

For the pH (graphs 1 to 3), it is interesting to note that the treatment steps are accompanied by a slight drop in pH, as we advance through the treatment process, then increase slightly. The decrease in pH could be explained by the addition of the coagulant to the medium. Aluminum sulfate (AS) dissociated in water produces H_3O^+ ions responsible for lowering the pH, according to equation [18].

$$Al^{3+} + 3H_2O \leftrightarrow Al(OH)_3 + 3H^+ \qquad (2)$$

The increase in pH is more marked when exiting the equalisation tank. This could be explained by the use of hypochlorite which has basic properties.

$$Ca(ClO)_2 \rightarrow Ca^{2+} + 2ClO^- \qquad (3)$$

$$ClO^- + H_2O \rightarrow HClO + OH^- \qquad (4)$$

The conductivity values observed at each processing step are all below the WHO guideline value. This reflects the low mineralisation of the water in the Djoué River. Small amplitudes of variation are observed for suspended solids (SS) which vary according to the treatment steps. Higher values are observed at the stages of decantation, filtration and water equalization. Treatment applied at the plant may contribute to the increase in suspending solids (SS). The treatment steps do not seem to have an impact on the variations in nitrate ($NO3^-$) concentrations. Turbidity changes distinctly from one graph to another. In figure 1, the turbidity decreases steadily between raw water and treated water, while it increases between EB and ED, decreases between ED and EF then increases between EF and ET in figures 2 and 3. This could can be explained on the one hand by the effectiveness of the treatment applied and on the other hand by the state of the plant's installations. To allow an evaluation by the organic matter at the levels of each treatment step, curves have been represented in figures (4, 5 and 6). These curves show the evolution of organic matter indicators (TOC and Abs. UV). Figure 4 shows a decrease in TOC between EB and ET. This could be explained by the use of the coagulant (SA) when clarifying the water at the plant. Likewise, a decrease in absorbance is also observed with a peak at the EF level. This could reflect the presence of more important aromatic compounds at this stage of treatment.

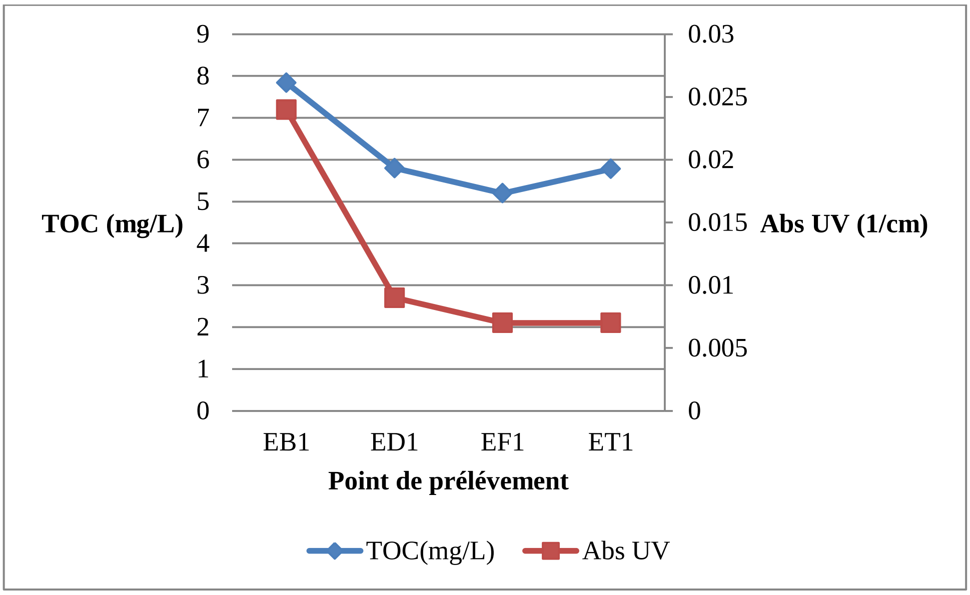

Figure 4: Evolution of TOC and UV Absorbance

Figure 5 shows the evolution of TOC and Abs. UV. The two parameters look the same between EB and EF. At the exit of the equalization tank (ET), the figure shows a high TOC concentration compared to ED and EF, similarly a high value of UV absorbance is also observed. This could be attributed to a release of organic matter into the environment by the installations [19].

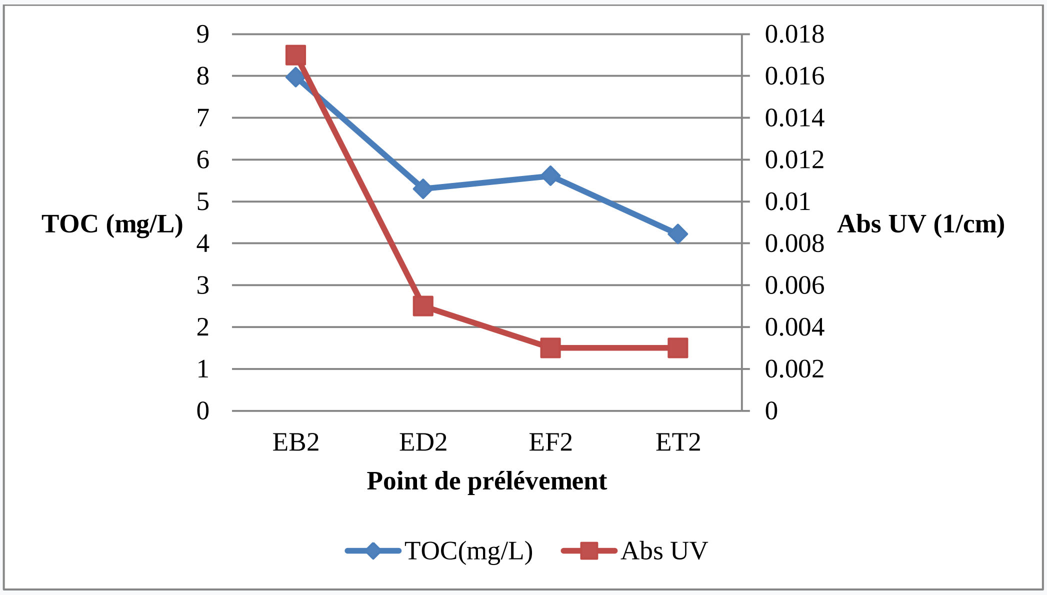

Figure 5: Evolution of TOC and UV Absorbance

Figure 6, shows a decrease in TOC from EB to ET, as the absorbance decreases between EB and EF and then increases slightly between at exit (ET).

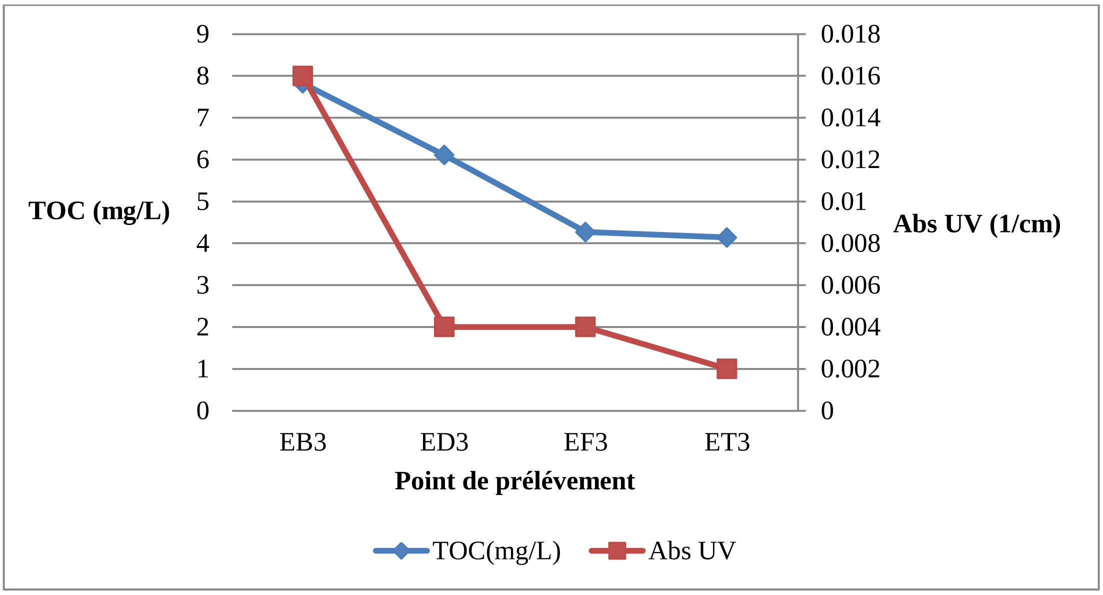

Figure 6: Evolution of TOC and UV Absorbance

3.3. Optimization of the stages of clarification

Determination of the optimal dose of aluminum salt

A simple decantation would not be sufficient for an efficient separation of the solid and liquid phases, because the sedimentation rate of the colloids (2 to 200 years for one meter) is low. Coagulation-floculation is then necessary. To destabilize the colloids and thus cause them to agglomerate into flocs, the ionic strength of the medium can be increased by the introduction of an electrolyte such as aluminum sulfate. This has the effect of reducing the thickness of the electrochemical double layer by lowering the potential barrier existing around the colloid and facilitating this agglomeration [20]. The parameter such as turbidity was retained to optimise the optimal dose of the coagulant. To show the importance of jar-tests in determining the optimal dose of aluminum sulfate (AS). The tests were carried out on raw water samples during the period January, February and March 2018. The effect of the dose of SA on each beaker is studied by adjusting the pH of the suspension to 7 before each test. To deduce the SA dose for each beaker, the presentation of the turbidities of the samples after 30 min of settling at different doses and for all the raw water samples is shown in Figures 7, 8 and 9.

The analysis of the turbidity evolution curves with the quantities of SA ranging from 0.01 to 0.1 g/L, shows:

For all the samples, a strong drop in turbidity is observed in the first three beakers for doses ranging from 0.06 to 0.08 g/L of SA. The decrease in turbidity results in the destabilization of the organic matter thanks to the Al^{3+} ions, allowing the elimination of suspended matter (SS) in the form of flocs of hydroxides [$Al(OH)_3$] or in the form of a complex with organic matter (OM) according to equation [21]:

$$Al^{3+} + n\,MO \leftrightarrow Al(MO)_n^{3+} \qquad (5)$$

The resulting turbidity after 30 minutes of settling varies between (reductions of 25 to 81 %) depending on the dose and the sample:

- A very good elimination of turbidity is observed with the dose of SA equal to 0.08 g/L (reduction in the order of 67.31 to 81.06 %).

- We notice for each sample that the residual turbidity differs according to the amount of SA added. Thus, for doses that are too high, the effectiveness of SA clearly decreases with the decrease in the pH of the medium. The ability of the aluminum ion to condense and precipitate depends on the physicochemical conditions of the medium. Thus, at acidic pH pH <4 aluminum hydroxide dissolves and gives rise to hydrolyzed aluminum ions according to the equation:

$$Al(OH)_3 \rightarrow Al^{3+} + 3OH^- \quad (6)$$

In fact, the structure of the floc, consisting mainly of aluminum hydroxide, dissolves totally at very acidic pH. At this pH, dissolved aluminum is almost completely in the Al^{3+} form. This is immediately solvated with water, according to the reactions below [22]:

$$mAl^{3+} + qH_2O \rightarrow Alm(OH)_q^{(3m-q)+} + qH^+ \qquad (7)$$

The release of H^+ ions causes a decrease in pH. There can also be have $Al(OH)_2^+$ ion formation depending on the reaction:

$$Al(OH)_3 + H^+ \rightarrow Al(OH)_2^+ + H_2O \qquad (8)$$

Aluminum in the cationic state, complexed by soluble organic matter (reaction 5) subsequently undergoes an exchange reaction with OH- ions (reaction 9) [23 - 24]:

$$[Al(MO)_n]^{3+}\ 3\,OH^- \leftrightarrow [Al(OH)_m(MO)_{n-m}]^{(3-m)+} + (3-m)\,OH^- + m\,MO \qquad (9)$$

This results in an increase in turbidity, due to soluble organic matter, and by inversion of the potential by excess Al^{3+} ions in solution [25- 26 - 27]. Laboratory treatment could only remove 67.31 %, 81.06 % and 78.84 % for Figures 7, 8 and 9, respectively. The mean laboratory elimination during the jar test is estimated to be 75.73 %, while the mean elimination at the processing plant is estimated to be 35.83 %. At the factory, the average obtained is significantly lower than that obtained by jar-test. The optimal doses of aluminum sulfate vary according to the quality of the raw water, which would require the treatment plant to continuously monitor this quality (especially turbidity and organic matter) [28].

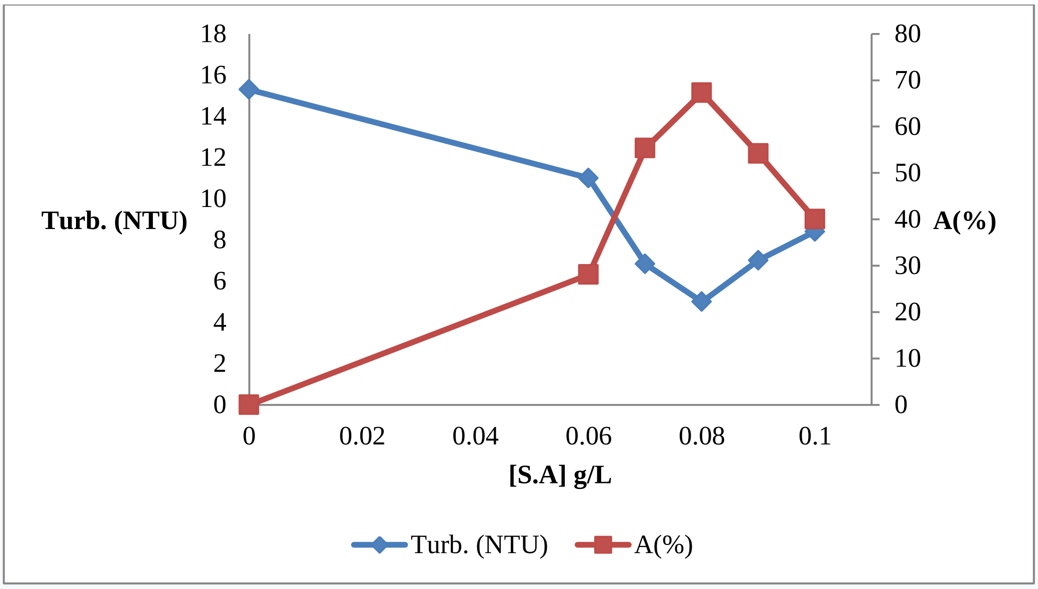

Figure 7: Evolution of the turbidity (15.3 NTU) and the reduction rate as a function of the concentrations of the coagulant

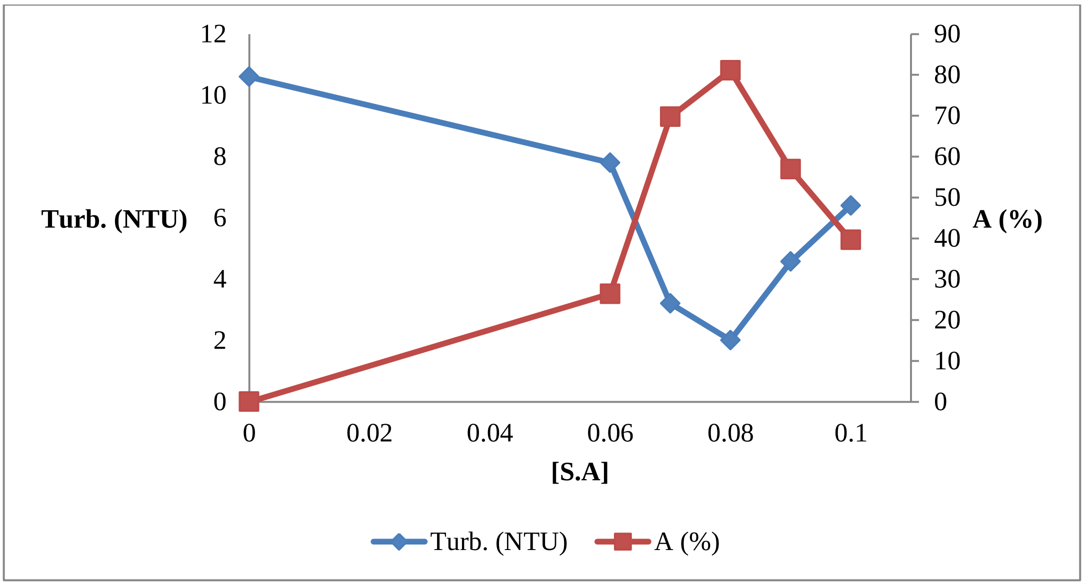

Figure 8: Evolution of the turbidity (10.6 NTU) and the abatement rate as a function of coagulant concentrations

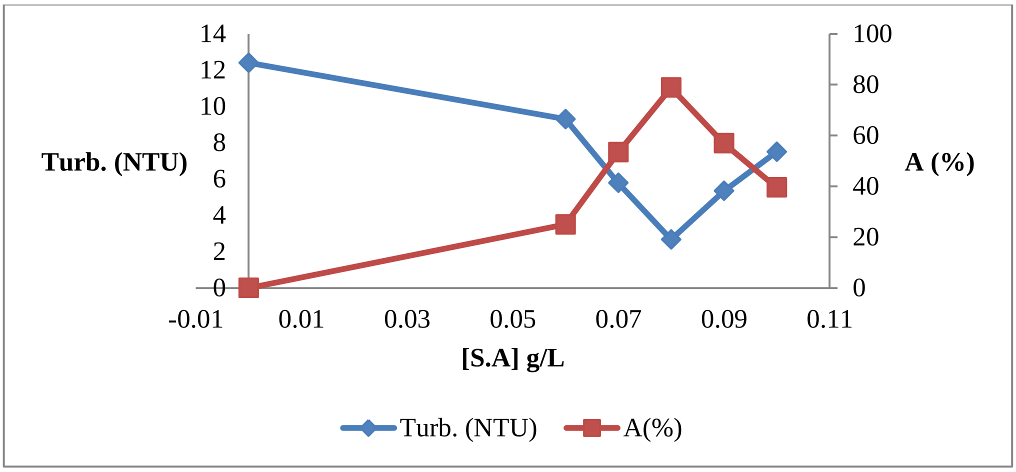

Figure 9: Evolution of the turbidity (12.4 NTU) and the abatement rate as a function of Coagulant concentrations

4. Conclusion

In this study, we observed that surface water is characterized by various physicochemical parameters such as turbidity, pH, TOC, MES, conductivity, or UV absorbance, etc. These parameters are used to estimate the quality of the water. The results of the analyses of the water treated during the clarification show that the in-station treatment is less effective than that carried out by jar-test. The comparison of the results shows that 75.73 % of the turbidity is eliminated by jar-test against only 35.83 % at the factory. The observed deviation must be the subject of continuous monitoring of treatment applied at the plant to allow easy approximation of the organic matter removal yields.

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