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EFFECTIVENESS OF TREATMENT OF WATER SURFACE WITH FERRIC CHLORIDE AND ALUMINIUM SULPHATE

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ABSTRACT

The municipality of M'rirt located in the eastern part of central Morocco, in response to the scarcity of water resources in food, the national Office of Drinking Water has used the coagulation-flocculation for water treatment of Oum Errabia River, process of removing the most delicate phase in suspension by the addition of a body chemical called coagulant. The application of coagulation flocculation process for the treatment of surface water is an interesting alternative as the treatment is fast, cheap and allows obtaining perfectly clear water can fill the deficit in water. In the case of our study, we chose the coagulation-flocculation with aluminum sulphate and ferric chloride in order to compare their effectiveness in the elimination or reduction of turbidity on the one hand, and On the other hand see the effectiveness of aluminum sulfate in an acid pH range. The tests are performed in the laboratory and were conducted using a jar test. Ferric chloride showed an effective reduction of the turbidity of water from the aluminum sulfate at low concentrations. The reduction in turbidity of the water by the aluminum sulphate is higher in acid pH (pH 5.5) according to the results obtained from the tests.

Keywords: Coagulation- floculation, Water treatment, Ferric chloride, Aluminium sulphate, Jar-test, Turbidity.

1. INTRODUCTION

With the development of urbanization and changing consumption patterns, the demand for potable water is changing dramatically in terms of quantity and quality. Located in the eastern part of central Morocco, near the western edge of the Middle Atlas Causse M'rirt, a small town located at 1113 m above sea level, is halfway between Azrou and Khenifra; it is also connected to Meknes by road from Adarouch.

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The municipality of M'rirt had in 2004 a total population of 35,196 inhabitants. The population grew from 13,856 inhabitants in 1982 to 25942 residents in 1994, the relatively rapid increase in population has led to think of a source of drinking water due to insufficient amounts of water supplied to it the national Office of water and Electricity (ONEE-MOROCCO) constructed a water treatment station of Oum Errabia River to supply the city with drinking water M'rirt.

The water we have in nature, is not used directly for human consumption because it is not always safe to drink. By crossing the different soil layers, or by casting on the surface of the earth or even in the air, the water load of suspended solids: clay particles, waste vegetation, live microorganisms (plankton, bacteria, viruses, parasites), various salts (chlorides, sulfates, carbonates, sodium carbonates of calcium, iron, manganese ...), organic matter (humic acid, fulvic acid ...) or other impurities.

The treatment monitoring at the treatment plant of M'rirt is conventional treatment which includes: Screening-settling-prechlorination-Coagulation / Flocculation- decantation and Filtration. This treatment is based on the physico-chemical technique that is coagulation / flocculation.

The coagulation-flocculation method may be used to remove many types of organic and inorganic materials: fats, oils, phosphorus, matter in suspension (MES), heavy metals, etc. [1]

The coagulation-flocculation is a process widely used in water treatment plants to be made drinkable. The salts used are salts of either aluminium or iron salts or many authors have focused their research on the use of either of these salts in water treatment. [2, 3]

The principle of coagulation-flocculation technique is based on the destabilization of suspended particles by injecting and rapid dispersion of chemicals to promote their agglomeration and allow their sedimentation. Suspended particles more difficult to remove in the water to be treated are those with a very small (colloidal particles causing turbidity) and those that are dissolved (organic matter causing staining). These colloids usually carry a negative electrical charge, which prevents the particles from agglomerating each other to form larger particles (flocks) and to facilitate their removal by sedimentation and filtration [4]. Recall that the aluminium ion has strong capabilities complexation with organic molecules. [5, 6]

The objective of the coagulation is to neutralize the charges of these particles to promote the formation of an agglomerate. To do this, salts of aluminium or iron is usually introduced into the water to treat a chemical called "coagulant". [4]

The definitions of coagulant and flocculent are presented below; these two terms are often confused in the literature. Coagulant: This is a chemical such as alum that causes the agglomeration of fine particles and can form a gelatinous precipitate in the waste water which can then be removed. Flocculent: It is a polymer that traps colloidal agglomerated and forms large flakes that settle by gravity. Is added after coagulation to further increase the size and cohesion of the flock. [1]. The mechanisms leading to the destabilization of colloids have been extensively studied and can be summarized as follows: charge neutralization based on the addition of sufficient cations to neutralize the negatively charged stable particles. The clotting mechanism is found only in acidic pH (<5.5) where the dominant species are positively charged coagulant ($Al(OH)^{2+}$, $Al(OH)_2^{+}$, $Al_{13}(OH)_{34}^{5+}$). As against, overdose coagulant cation source may cause an excessive adsorption of cations and reversing the charge of the particles becomes positive. The particles would then destabilize. Imprisonment and adsorption of colloids on aluminium flock are when sufficient amounts of ($Al_2(SO_4)_3$, $18H_2O$) are added. It thus forms, depending on the pH, a precipitate $Al(OH)_3$, the shape of the coagulant flocculent, typically having adsorption properties of interest. The pH of the water to be treated must be within a range of optimum pH where there is coexistence between coagulant forms and flock shape. The precipitate formed, called flock, comes into contact with negatively charged particles and traps. The particles are then entrained in the decantation. [4]

The objective of this study is first, to make a complete characterization of raw water (water of Oum Errabia River) and decanted, and secondly, to look for the optimum conditions to implement two different chemical coagulants (ferric chloride, aluminium sulfate) at the laboratory of M'rirt city treatment plant by tests of jar test.

2. EXPERIMENTAL

2.1. Water to be treated

Water to be treated in these trials is water of Oum Errabia River.

2.2. Testing Water Treatment of Oum Errabia River

2.2.1. Methods of Jar-Test

The tests are performed according to the protocol of the "Jar-test" using a flocculator which results in six beakers of a liter of raw water, strictly identical and adjustable stirring period through a central control. This method comprises introducing a coagulant into a series of six one-liter beakers containing raw water with stirring for a short time (2 min), but with a very high speed (120 tr/min) and to ensure a very good dispersion of the reactants and a good chemical destabilization of colloids. Rapid stirring is followed by a slow stirring (20 rev / min) for 18 minutes with a stirrer blades in order to promote contacting contiguous particles and avoid breaking the flocks formed. After 30 minutes of decantation, the supernatant was siphoned to be analyzed; the decanted water is filtered through a filter of porosity of 0.45 microns. The pH adjustment was done by the addition of dilute sulfuric acid.

The influence of the dose of the coagulant introduced and the effect of pH on the Coagulation-Flocculation was carried out according to the following tests:

- Comparison of coagulants of aluminium sulphate ferric chloride;
- Effect of dose of aluminium sulphate at pH= 7.6;
- Effect of pH with increasing doses of sulfuric acid and a constant concentration of aluminium sulphate.

Treatment efficacy was assessed visually and analytically by monitoring the rate of reduction of turbidity. The calculation of the reduction of X as a percentage rate parameter is based on the following formula:

$$\% \text{ Dejection } (X) = \frac{Ci\,(X) - Cf\,(X)}{Ci\,(X)} * 100 \qquad [7]$$

Ci: Initial concentration of X in the raw water.

Cf: Final concentration in water decanted or filtered.

2.2. Methods used to Assay

All solutions were prepared from distilled water having the following characteristics: pH ranging from 4.8 to 5.5, conductivity 2µS.cm^{-1}.

- The pH of water is an indication of its tendency to be acidic or alkaline; it is based on the activity of hydrogen ions H^+ present in the water. The pH measurement was carried out by using potentiometer glass electrode. This method can be used for the pH measurement of all types of water.
- The conductivity is measured using a conductimeter of Tacussel type and expressed as microsiemens per cm (µS.cm $^{-1}$).
- The measurement of the turbidity of the water was determined by using a turbidimeter using the effect of Opacimeter. The elements in suspension in a liquid absorbing some radiations. This absorption depends mainly on the number of particles in suspension, their constitutions, the thickness of the liquid and the wave length of the incident radiation. The unit is NTU (Nephelometric turbidity unit).
- The temperature measurement was made with a thermometer. It is expressed in degrees Celsius. It is important to know the temperature of the water precisely, given its role in the solubility of the salts and especially of the gases as well as in the separation of dissolved salts (electrical conductivity).
- The residual chlorine content was determined by the method orthotolidine.
- The Chlorides are determined by the acid medium in the presence of mercuric nitrate and diphenylcarbazone as indicator dye.
- The content of aluminium ions (Al^{3+}) and iron (Fe^{3+}) was determined by the method of kits.
- The alkalinity was determined according the standard (AFNOR T90-036).

3. RESULTS AND DISCUSSION

3.1. Comparison of the Two Coagulants: Aluminium Sulphate and Ferric Chloride

During these tests; we added increasing concentrations of aluminium sulphate (5mg/l - 30mg/l) from the mother solution of 10g/l and increasing concentrations (5mg/l-30mg/l) of ferric chloride from mother solution of 1g/l. The tests were conducted by adding 1.5 mg/l of sodium hypochlorite (NaClO) as an oxidant in the stage of pre-chlorination and this after determining chlorine demand. The physical and chemical quality of raw water varies depending on rainfall conditions, in this part mean physico-chemical characteristics of the raw water (water of Oum Errabia River), decanted water and water filtered are shown in tables 1 and 2.

Table-1. Conditions and physicochemical characteristics of the raw and decanted water

Parameters	Units	Raw water	Decanted water											
			Alum (mg/l)						Ferric chloride (mg/l)					
			5	10	15	20	25	30	5	10	15	20	25	30
pH	-	8.15	7.99	7.88	7.79	7.70	7.64	7.6	7.83	7.59	7.43	7.32	7.17	7.08
Turbidity	NTU	13.2	9.9	7.80	2.8	1.6	1.19	0.97	1.93	0.78	0.72	0.68	0.58	0.74
Dejection	%	-	25.0	40.9	78.78	87.87	90.98	92.65	85.37	94.09	94.54	94.84	95.60	94.39
Alcalinity	°F	24.25	23.5	23.25	23.0	23.0	22.5	22.5	23.2	23.0	22.5	22.2	21.7	21.0
Dejection	%	-	3.09	4.12	5.15	5.15	7.22	7.22	4.33	5.15	7.22	8.45	10.51	13.40
Residual aluminum	mg/l	0	0.12	0.2	0.2	0.2	0.2	0.2	-	-	-	-	-	-
Residual Fer	mg/l	0	-	-	-	-	-	-	0	0	0	0	0	0

Table-2. Conditions and physicochemical characteristics of the raw water and filtered water

Parameters	Units	Raw water	Decanted water											
			Alumina sulphate (mg/l)						Ferric chloride (mg/l)					
			5	10	15	20	25	30	5	10	15	20	25	30
pH	-	8.15	7.99	7.88	7.79	7.70	7.64	7.60	7.83	7.59	7.43	7.32	7.17	7.08
Turbidity	NTU	13.2	1.4	0.33	0.20	0.19	0.18	0.17	0.23	0.19	0.18	0.17	0.17	0.15
Reduction	%	-	89.39	97.5	98.84	98.56	98.63	98.71	98.25	98.56	98.63	98.71	98.71	98.86
Alcalinity	°F	24.25	23.5	23.25	23.0	23.0	22.5	22.5	23.2	23.0	22.5	22.2	21.7	21.0
Reduction	%	-	3.09	4.12	5.15	5.15	7.22	7.22	4.33	5.15	7.22	8.45	10.51	13.40
Residual aluminum	mg/l	0	0.12	0.2	0.2	0.2	0.2	0.2	-	-	-	-	-	-
Residual Fer	mg/l	0	-	-	-	-	-	-	0	0	0	0	0	0

The results of the coagulation-flocculation tests are illustrated in Figures 1, 2,3,4,5 and 6. Figures 1 and 2 show the variation of turbidity and reduction of turbidity of the decanted water versus the concentration of both coagulants (alumina sulfate and ferric chloride), and Figures 3 and 4 represent the variation of turbidity and reduction of turbidity of the filtered water versus the concentration of both coagulants (aluminium sulphate and ferric chloride).The figure 5 represents the variation of the pH of decanted water versus the concentration of both coagulants and Figure 6 shows the variation of the decanted water alkalinity versus the concentration of both coagulants.

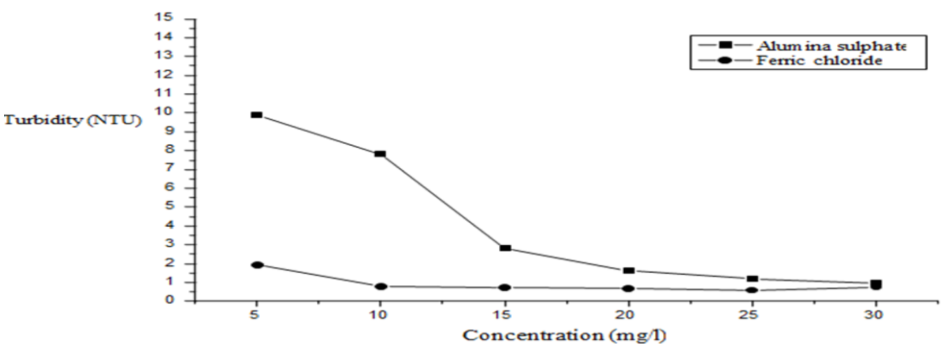

Fig-1. Variation of the decanted water turbidity versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

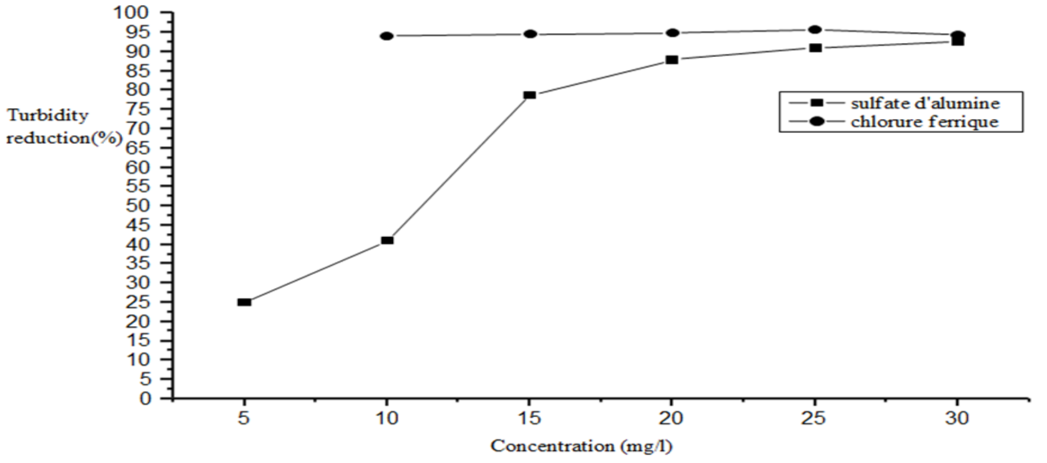

Fig-2. Variation of reduction of turbidity of the decanted water versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

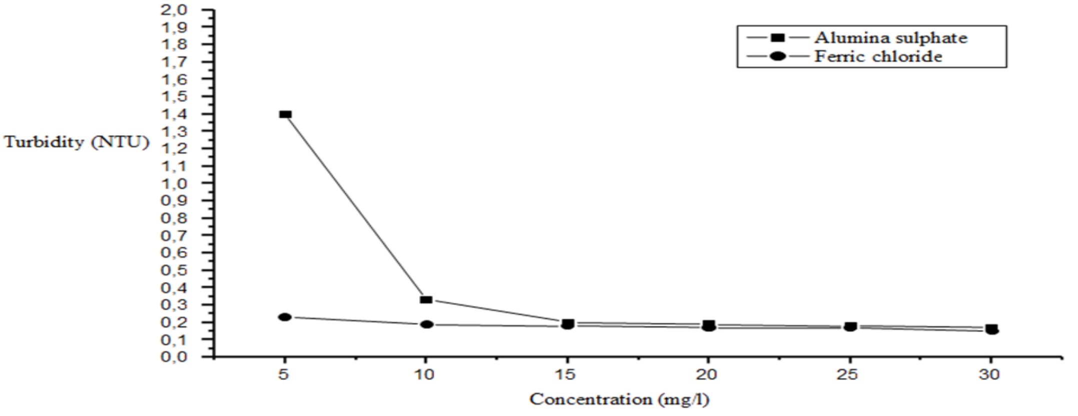

Fig-3. Variation of the filtered water turbidity versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

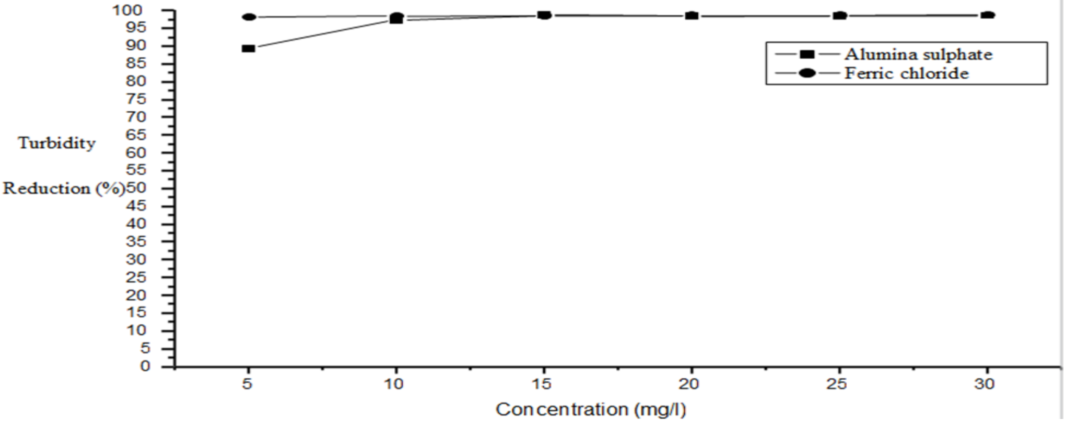

Fig-4. Variation of reduction of turbidity of the filtered water versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

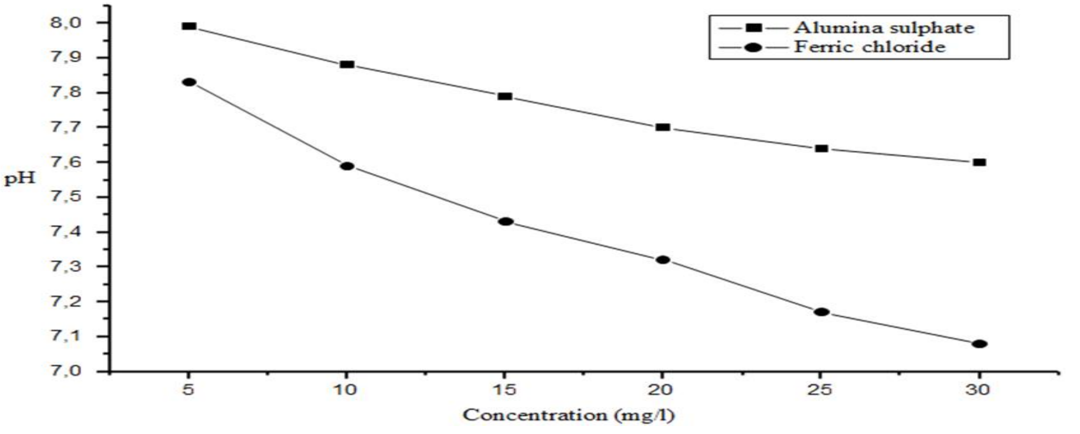

Fig-5. Variation of the decanted water pH versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

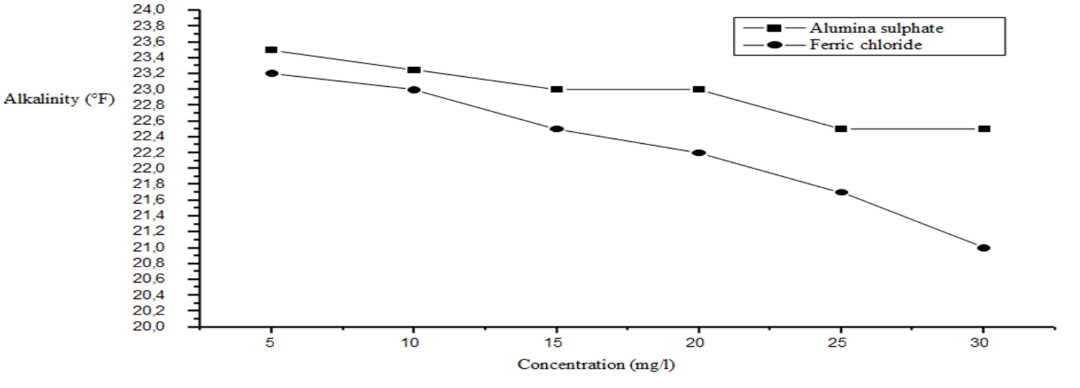

Fig-6. Variation of the decanted water alkalinity versus the concentration of both coagulants (aluminium sulphate and ferric chloride)

According to tables 1 and 2 and figures 1,2,3 and 4 above and the requirements of drinking water treatment that is a decanted and filtered turbidity respectively lower than 5 NTU and 0.5 NTU, it is clear from evaluation of the results obtained for the two coagulants that after the injection of 10 mg/l of ferric chloride, the reduction of turbidity is 95.53% unlike aluminium sulphate which gives us a reduction of 87.87% for a dose of 20 mg/l of coagulant which allow to produce quality water meets the requirements of treatment.

Table 1 and figures 5 and 6 show that the pH and alkalinity of the water decanted decrease remarkably as the concentration of ferric chloride is increased ferric unlike aluminium sulphate where the decrease is progressive. Turbidity of filtered water varies slightly as the concentration is increased.

It is also found that ferric chloride is most efficient in terms of reduction of turbidity at lower doses in comparison with aluminum sulphate. This may be due to physical or physico-chemical effects, the forces of repulsion and Van der Waal forces's are important in coagulation.

Alkalinity is another chemical parameter influenced by both reagents. These reagents act on bicarbonates in the water and there is a continual decrease in alkalinity when the dose of the two reagents increases.

The use of these two reagents in the coagulation-flocculation tests led to a significant decrease in the pH of the water after treatment .However, the pH remains in the range of allowable pH (6.5 to 8.5).

3.2. Effect of dose of Aluminum Sulfate at pH = 7.6

The effect of the dose of aluminium sulphate on the treatment was carried out at pH = 7.6. This pH is selected so to see the effect of aluminium sulphate in slightly alkaline water. The pH adjustment was made by adding dilute sulfuric acid to the raw water after completing the 6 beakers. During these tests; we added increasing concentrations of aluminium sulphate (5 mg/l-30 mg/l) from the mother solution of 10g/l. The tests were conducted by adding 1.5 mg/l of sodium hypochlorite (NaClO) as an oxidant in the stage of pre-chlorination and this after determining chlorine demand. The physico-chemical characteristics of the raw water (water of Oum Errabia River), the decanted water and filtered water are presented in tables 3 and 4.

Table-3. Conditions and physicochemical characteristics of the raw and decanted water

Parameters	Units	Raw water	Decanted water					
			Aliminum sulphate (mg/l)					
			5	10	15	20	25	30
pH	-	8.30	7.57	7.55	7.53	7.48	7.44	7.41
Turbidity	NTU	57.1	9.49	4.28	1.90	1.11	1.05	1.28
Reduction	%	-	83.38	92.50	96.67	98.05	98.16	97.75
Alkalinity	°F	24.0	23.0	22.5	22.0	21.75	21.5	21.0
Reduction	%	-	4.16	6.25	8.33	9.38	10.42	12.5
Residual aluminium	mg/l	0	0.12	0.12	0.12	0.12	0.12	0.12

Table-4. Conditions and physicochemical characteristics of the raw and filtered water

Parameters	Units	Raw water	Filtered water					
			Aliminum sulphate (mg/l)					
			5	10	15	20	25	30
pH 7.41	-	8.30		7.57	7.55	7.53	7.48	7.44
Turbidity	NTU	57.1	0.22	0.18	0.17	0.17	0.16	0.15
Reduction	%	-	99.61	99.68	99.70	99.70	99.72	99.73
Alkalinity	°F	24.0	23.0	22.5	22.0	21.75	21.5	21.0
Reduction	%	-	4.16	6.25	8.33	9.38	10.42	12.5
Residual aluminum	mg/l	0	0.12	0.12	0.12	0.12	0.12	0.12

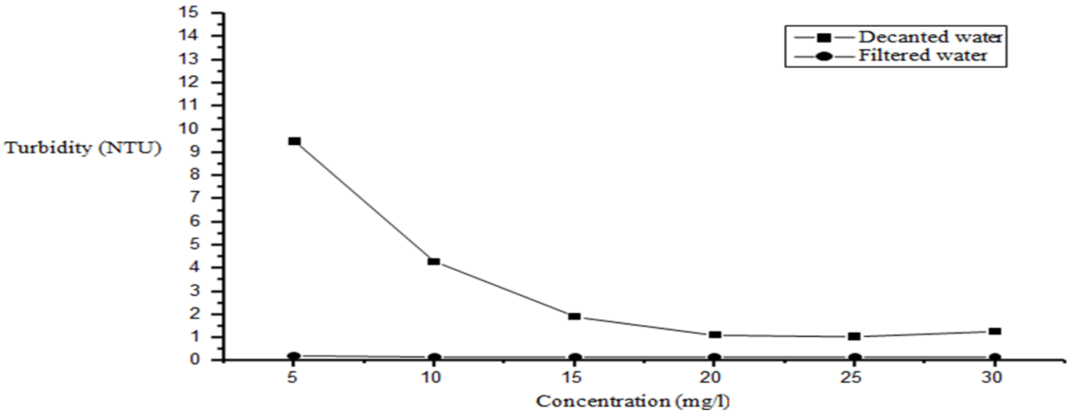

Fig-7. Variation of turbidity of decanted water versus the concentration of aluminum sulphate

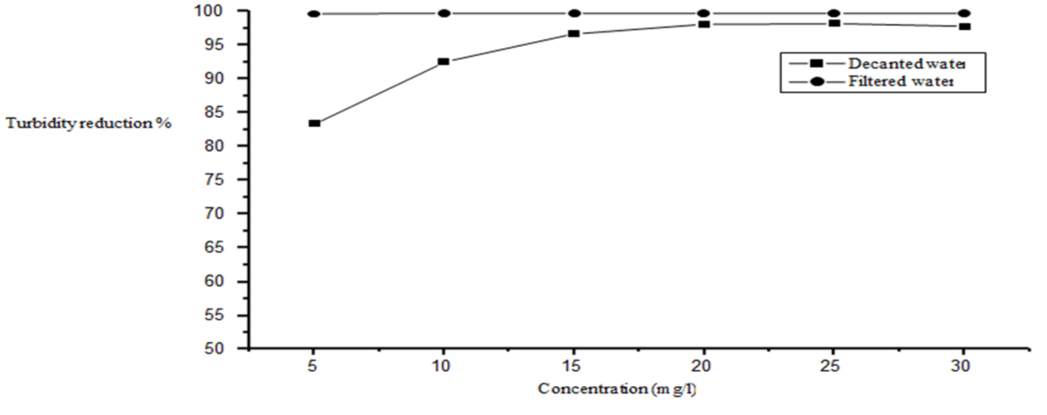

Fig-8. Variation of turbidity reduction of decanted water versus the concentration of aluminium sulphate

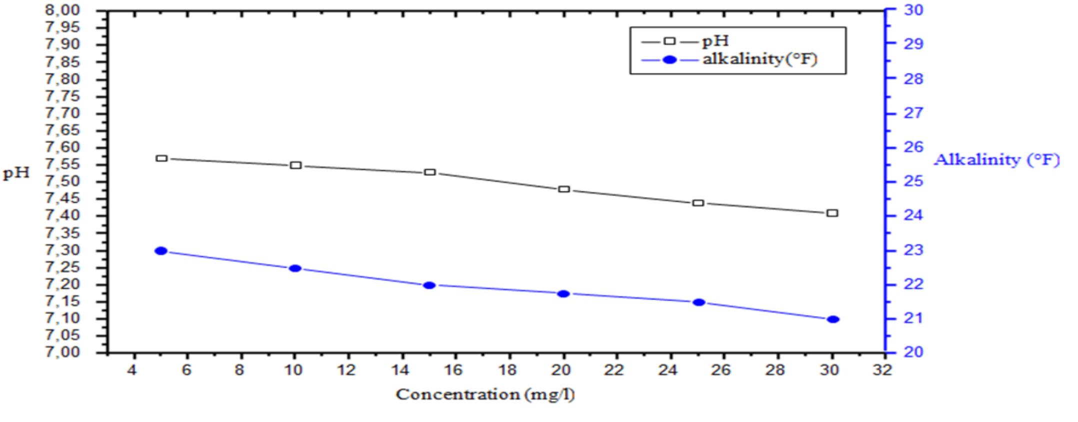

Fig-9. Variation of the pH and alkalinity of the decanted water versus the concentration of aluminium sulphate

The figure 7 and table 3 show that for the allowable value of turbidity of the decanted water is achieved for a dose of aluminium sulphate of 10 mg/l; whereas the value of 5 mg/l of aluminium sulphate is sufficient to have a drinking water that meets the requirements potability in terms of turbidity (below 0.5NTU).Note that the pH decreases from 7.6 to 7.57 and then 7.41 in the beaker 6, this pH drop is due to increasing doses of injected aluminium sulphate.

3.3. Effect of pH at a Constant Concentration of Aluminium Sulphate

The effect of pH on the tests of coagulation /flocculation was carried out on the raw water of Oum Errabia River, the selected pH range is given in the table 5 according to the use of the 6 beakers. The dose of aluminium sulphate used is 20mg/l prepared from the mother solution of 10g/l. The tests were conducted by adding 1.5 mg/l of sodium hypochlorite (NaClO) as an oxidant in the stage of pre-chlorination and this after determining chlorine demand. Physico-chemical characteristics of the raw water (water of Oum Errabia River), the decanted water and filtered water are presented in tables 5 and 6.

Table-5. Conditions and physic-chemicals characteristics of the raw and decanted water

Parameter	Units	Raw water	Decanted water					
			Initial pH					
			8	7.5	7.0	6.5	6.0	5.5
pH	-	8.10	7.63	7.44	7.35	7.23	7.12	7.02
Turbidity	NTU	31.2	0.32	0.25	0.18	0.22	0.26	0.22
Reduction	%	-	98.97	99.19	99.42	99.29	99.16	99.30
Alkalinity	°F	23.75	22.5	22.0	22.0	21.5	21.0	20.5
Residual	mg/l	0 0.2	0.12	0.12	0.12	0.12	0.07 aluminium	

Table-6. Conditions and physic-chemicals characteristics of the raw and filtered water

Parameters	Units	Raw water	Filtered water					
			Initial pH					
			8	7.5	7.0	6.5	6.0	5.5
pH	-	8.10	7.63	7.44	7.35	7.23	7.12	7.02
Turbidity	NTU	31.2	2.2	2.14	1.13	1.20	1.23	1.24
Reduction	%	-	92.94	93.14	96.38	96.15	96.05	96.02
Alkalinity	°F	23.75	22.5	22.0	22.0	21.5	21.0	20.5
Residuel	mg/l	0 0.2	0.12	0.12	0.12	0.12	0.07 aluminium	

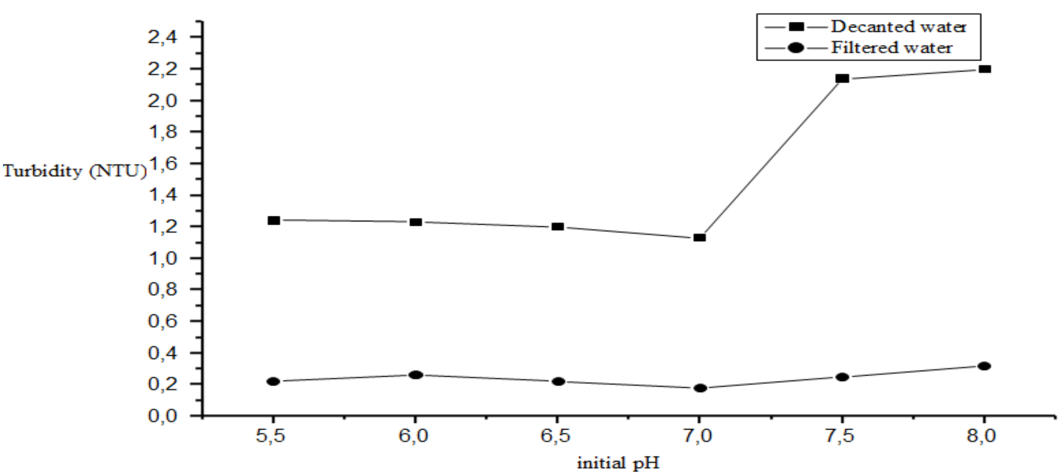

Fig-10. Variation of turbidity of decanted and filtered water versus initial pH of raw water

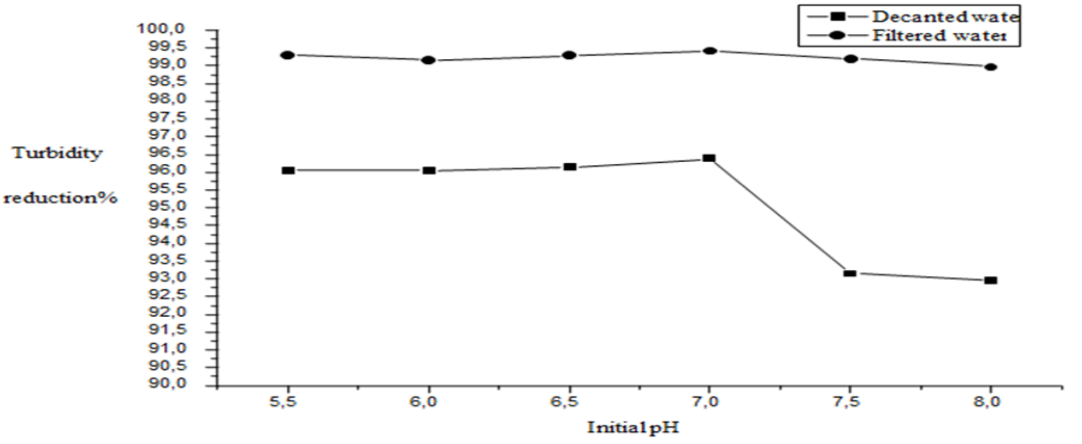

Fig-11. Variation of turbidity reduction of decanted and filtered water versus initial pH of raw water

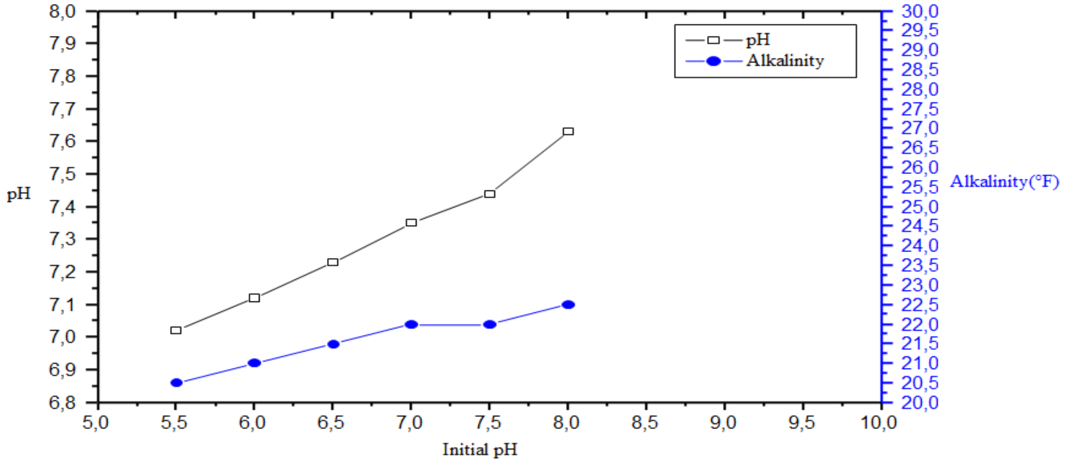

Fig-12. Variation of pH and alkalinity of decanted water versus initial pH of raw water

This test was carried out in order to study the effect of pH variation on the phenomenon of coagulation-flocculation.

According to figure 11 and tables 5 and 6 it can be seen that as the pH is decreased (sulfuric acid injection), the reduction of turbidity after decantation increased from 92.94% (pH = 7.63) to 96.02% (pH = 7.02), so an increase in the allowance of 3.08% to a decrease of 0.61 on the pH value.

When using aluminium sulphate, There are place to ensure that the residual content of Al^{3+} in solution does not exceed 0.2 mg/l (WHO standard) .Or following tables 5 and 6 , the pH = 8 shows a high reduction of turbidity but a high residual in aluminium.

Aluminum sulfate shows its ability to reduce the turbidity of water of Oum Errabia River in acidic pH and again the reduction of the natural alkalinity of the water after the chemical reaction of aluminium sulfate in the water:

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightleftarrows 2Al(OH)_3 + 3CaSO_4 + 6CO_2$$

4. CONCLUSION

A comparison between the results obtained by the two coagulants allowed us to draw the following conclusions:

- The reduction of the turbidity is greater by the use of ferric chloride in comparison with aluminium sulphate and this at lower doses.
- Aluminium sulphate shows a high reduction of turbidity of water at acidic pH and this in the range of investigated pH.
- Increasing the dose of aluminium sulphate leads to a high reduction of the turbidity.

5. ACKNOWLEDGMENTS

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