JOURNAL OF APPLIED SCIENCES AND ENVIRONMENTAL STUDIES

Journal of Applied Science and Environmental Studies
JASES
http://revues.imist.ma/index.php?journal=jases
https://doi.org/10.48393/IMIST.PRSM/jases-v5i2.45694

Université Sidi Mohamed Ben Abdellah

Original Paper

Optimization of coagulant presence in the natural raw water at the Ain Nokbi station in Fez

D. Azzouni, S. Alaoui Mrani and E. M. Saoudi Hassani

Engineering Electrochemistry, Modeling and Environment Laboratory, Department of Chemistry, Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco

Received 12 June 2022; Revised 30 June 2022, Accepted 11 July 2022

Keywords
Coagulation;
Flocculation;
Liquid reject;
Optimization.

Abstract

An optimization study of the coagulation-flocculation chemical treatment process was carried out at the Ain Nokbi station in Fez in order to identify the problems associated with liquid rejects. The purpose of the study involved optimizing three key factors in the coagulation-flocculation process: the pH of the raw water, the coagulant amount (aluminum sulphate) and the flocculent amount (sodium alginate solution or polyelectrolyte at 0.1 mg/l). This demonstrated how acidification can improve treatment performance, particularly in terms of pH. Specifically, reducing the pH to 7 revealed advantages during disinfection, boosting the efficiency of the process. In addition, the optimum dosage of coagulant (aluminum sulphate) has been determined to be around 50 mg/l instead of 60 mg/l, saving 10 mg/l and reducing annual costs by MAD 240,000.

1. Introduction

The global increase in population inherently leads to a substantial surge in overall consumption, subsequently causing a marked escalation in the volume of waste generated by human activities. Various industrial sectors and consumers on a global scale generate vast quantities of waste, which could potentially serve as a readily available and abundant energy and chemical bioresource due to its rich organic composition. This presents an opportunity for a wide array of applications within a circular economic framework **[1]**.

The need for safe drinking water is growing all the time as a result of population growth and industrialization, particularly in many emerging countries **[2]**. Previously associated mainly with Third World regions, the issue of access to drinking water has become so wide-spread that even developed countries such as the United States and Australia are beginning to pay more attention to preserving this natural resource **[3]**. The biggest challenge to providing access of drinking water is the unequal distribution of water around the world and the ongoing pollution of water resources caused by industry, agriculture and urban run-off **[4]**. Dams, rivers, lakes and groundwater are increasingly polluted, with worrying repercussions for aquatic fauna **[5]**. In addition to these anthropogenic influences, the impact of which can hopefully be progressively mitigated by a rapid increase in public and official awareness, natural geochemical processes have also contributed to the contamination of groundwater by pollutants naturally present in the soil **[6]**. Organic water treatment is often an effective and economical process. It is applied both to the treatment of urban wastewater and to certain wastewater from the agri-food sector or other industries **[7]**. However, the main limitation to the systematic use of this method relates to the difficulty of adapting bacteria to certain effluents, as well as their inhibition by certain chemical components **[8-13]**. Mechanical and physical processes including screening, filtering and biological treatment using activated wastewater sludge have eliminated a significant proportion of the substances present in the water **[14-17]**. However, even after these operations, the water retains a quantity of substances composed of suspended matter, colloids and very fine particles that are difficult to settle **[18-20]**.

The general purpose of this study is to explore the optimum parameters for the optimization of the coagulation-flocculation process applied in the chemical treatment of water at the station. In addition, the study will analyze the effect of pH and turbidity on the coagulation, flocculation and decantation steps. In this approach, the optimum concentration of the coagulant used (aluminum sulphate) will be determined by means of a Jar-Test experiment.

2. Experimental details

The coagulant quantity is determined by means of an experimental test known as the "Jar-test". This test consists of the addition of increasing amounts of coagulant to containers holding the same raw water. After a specific time, essential measurements to assess water quality are taken on the settled water. The most appropriate coagulant amount is then determined on the basis of the comparative quality of the different waters **[21-23].**

The experimental process requires a flocculator fitted with 6 stirrers powered by an electric motor operating at a rate of around 120 rpm. Each of the 6 beakers is filled with one liter of the water sample to be analyzed. The beakers are then placed in the flocculator. Chlorine is introduced at a breaking point amount, as well as a solution of aluminum sulphate (coagulant) and a solution of sodium alginate or polyelectrolyte at a concentration of 0.1 mg/l (flocculent) **[24].** Through this experimental process, the effect of different amounts of coagulant on the raw water can be assessed. The flocculator is used to stimulate flock formation, and the stirrer velocity is adjusted to ensure homogeneous mixing. The chlorine breakpoint measurement also helps to determine the optimum dose of coagulant for water treatment.

After a two-minute preparation period, the following steps were executed in a series of Jar-test coagulation-flocculation experiments:

1. A consistent amount of flocculent (polyelectrolyte) equivalent to 0.1 mg/l was introduced into separate beakers.
2. The stirring rate was decreased to 40 rpm and maintained for 20 minutes.
3. The appearance and shape of the flocks were observed at the commencement of agitation.

4. Propellers were deactivated, allowing the settled water to stand undisturbed for 30 minutes.
5. The settling rate was estimated at the conclusion of the slow agitation.
6. Subsequently, the pH, turbidity, oxidability, and residual chlorine of the supernatant were determined for each beaker.
7. The supernatant underwent filtration through a clean white band filter (similar to a sand filter), and measurements of turbidity and alkalinity were taken.
8. The decanted water, yielding the most favorable results after treatment, underwent evaluation for aggressiveness.

The criteria for optimal dose selection were established based on the beaker demonstrating the best flocculation and turbidity reduction, with the following requirements:

- Turbidity of settled water < 5 NTU
- Turbidity of filtered water < 0.5 NTU
- Oxidability < 2 mg/l
- Flock size equal to or greater than 06 ("medium" or "best" size)
- 7 < pH < 7.4

Six Jar-test coagulation-flocculation experiments were conducted on different days, with varying pH values, to determine the optimal doses of coagulant and assess the pH's impact on dose variation and the overall coagulation-flocculation process. The experiments involved the following detailed steps:

a. The initial **3 tests** involved conducting the Jar-test on three distinct raw water samples, comparing the results to determine the optimum coagulant dose while considering the characteristics of the raw water used.
b. In the **4th test**, a Jar-test was performed on the same raw water with and without flocculent.
c. The **5th test** involved conducting a Jar-test on the same raw water with increasing doses of flocculent (polymer) and a fixed dose of coagulant (aluminum sulfate).
d. The **6th test** utilized three different raw water samples to conduct three "Jar-tests" A, B, and C at three different pH levels. Acidifications were achieved by adding sulfuric acid H_2SO_4 (0.5 mol/l), and the results obtained for the different pH conditions were compared.

3. Results and discussion

The purpose of the jar test is to determine the optimum doses of reagents to be injected on an industrial basis. This step, carried out as part of primary treatment processes, requires the same conditions to be reproduced and the same protocol used in the station to carry out these analyses to be applied. Before initiating the injections into the flocculator, it is necessary to determine the quantity of chlorine to be injected for each raw water used.

3.1. Determination of the chlorine injection amount (break point method)

As soon as we have determined the bleach concentration, we prepare a solution with a concentration of 1 g/L, then a diluted solution of 0.1 g/L. Progressive injections are then performed in the raw water containers and the residual chlorine is measured after 30 minutes. The results obtained for each raw water are summarized in the table below.

Table 1. Titration of bleach water

Test number	1	2	3
Titration of bleach water (mg/l)	41.18	46	49.7

Table 2. Chlorine residual results

	1	2	3	4	5	6	7	8	9	10	11	12
Cl_2 injected (mg/l)	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
Cl_2 residual test 1 (mg/l)	0.2	0.2	0.1	1.4	2	2.5	1.8	2	5	4	4.5	4.5
Cl_2 residual test 2 (mg/l)	2	2	2.5	3	4	4	4.5	4.5	4	4	4	4
Cl_2 residual test 3 (mg/l)	0.1	0.6	0.8	2	2.5	3	4	3.5	4	4.5	4.5	4.5

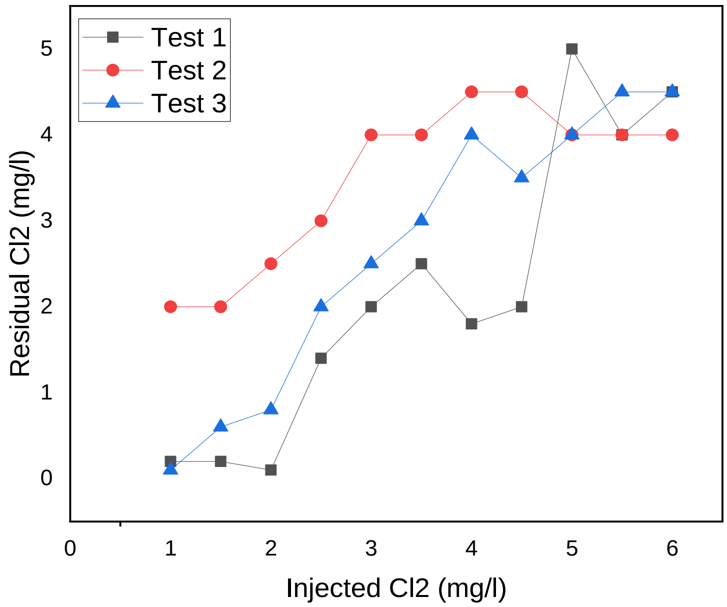

Figure 1. Critical point curve

The chlorine dosage to be injected, corresponding to the breakpoint, is crucial for effective water treatment. Table 3 outlines the specified chlorine amounts for injection in three distinct tests.

Table 3. Chlorine amount to be injected

	Test 1	Test 2	Test 3
Pre-chlorination	4.5	4.5	4

3.2. Raw water analysis

For each experiment, it is necessary to carry out an analysis of the raw water to determine not only the pH but also the physico-chemical characteristics.

Table 4. Raw water analysis

Test number	pH	TA	TAC	Turbidity (NTU)	Temperature (°C)
Test 1	8.30	0	5.6	95	18
Test 2	8.35	0.6	6	101	23
Test 3	8.29	0	6.2	128	21.8

When the pH has been determined for the raw water and the chlorine injection amount has been calculated, the chlorine was added during the Jar-test experiments. All the Jar-test experiments were performed for different samples under the same conditions described in the table below.

Table 5. Jar test conditions

	1	2	3	4	5	6
Coagulant (mg/l)	20	30	40	50	60	70
Flocculent (mg/l)	0.1	0.1	0.1	0.1	0.1	0.1

3.3. Jar-test results

After stirring and settling for 30 minutes to allow sediment to settle, analyses are carried out on both the settled water and the water after filtration. In order to simplify comparison between the different samples and to make it easier to determine which gives the best results, the results obtained are recorded in tables.

3.3.1. Calculated parameters after settling

3.3.1.1. Water turbidity

The requirement that the turbidity level of the settled water should not exceed 5 NTU is necessary to ensure clarity throughout the process. The results of turbidity measurements after the settling process are shown in Table 6, allowing for a full assessment of the efficiency of the water treatment.

Table 6. Turbidity results after settling

Samples	1	2	3	4	5	6
Test 1	0.46	0.74	0.92	0.87	1.04	1.24
Test 2	0.56	0.62	0.77	1.48	1.19	1.43
Test 3	1.67	2.17	1.74	1.96	1.78	1.02

Within each conducted test, the sample exhibiting the lowest turbidity level is identified as the optimal outcome, emphasizing superior water clarity. The quantity of coagulant injected into this particular sample is regarded as the correct result, signifying the most effective dose for achieving optimal settling and turbidity reduction. Figure 2 graphically illustrates the evolution of turbidity after the settling process, presenting a dynamic representation of its impact on water quality measured in Nephelometric turbidity units (NTU).

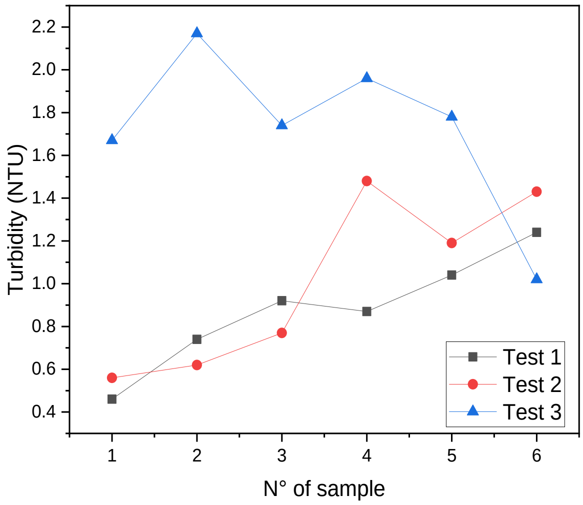

Figure 2. Turbidity evolution after settling (NTU)

3.3.1.2. pH

In the preliminary selection process, samples with pH values within the specified range are chosen for further analysis to ensure suitability for subsequent steps in the water treatment process. Samples with pH values below 6.5 or above 7.4 are excluded from the analysis, as their measurement is deemed inappropriate. The variation in pH values throughout the analysis process is detailed in Table 7, offering a comprehensive understanding of the pH fluctuations during the experimental steps.

Table 7. pH evolution

Samples	1	2	3	4	5	6
Test 1	7.86	7.75	7.6	7.51	7.39	7.41
Test 2	8.04	7.8	7.81	7.69	7.62	7.53
Test 3	7.93	7.88	7.71	7.64	7.59	7.44

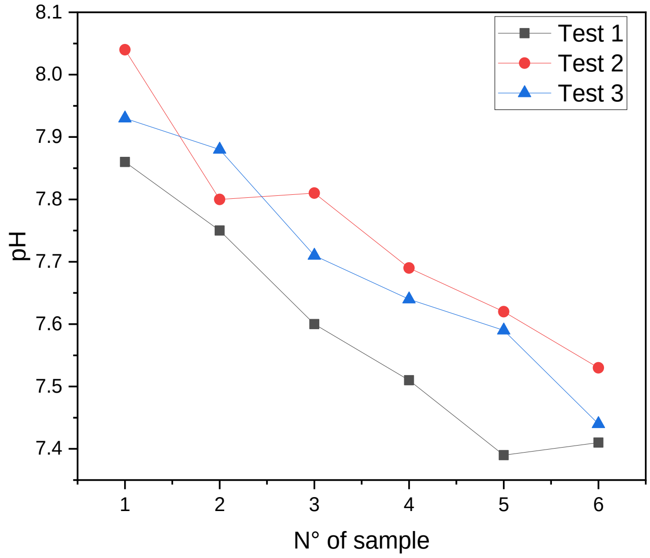

Figure 3. pH evolution after settling

3.3.2. Calculated parameters after filtration

3.3.2.1. Water turbidity

The turbidity measurement is crucial to ensure that the filtered water maintains a maximum level of 0.5 NTU, preserving water clarity. The results of turbidity measurements obtained after filtration are presented in Table 8.

Table 8. Water turbidity after filtration

Samples	1	2	3	4	5	6
Test 1	0.28	0.34	0.29	0.34	0.34	0.36
Test 2	0.41	0.43	0.53	0.33	0.42	0.57
Test 3	0.51	0.44	0.45	0.54	0.60	0.60

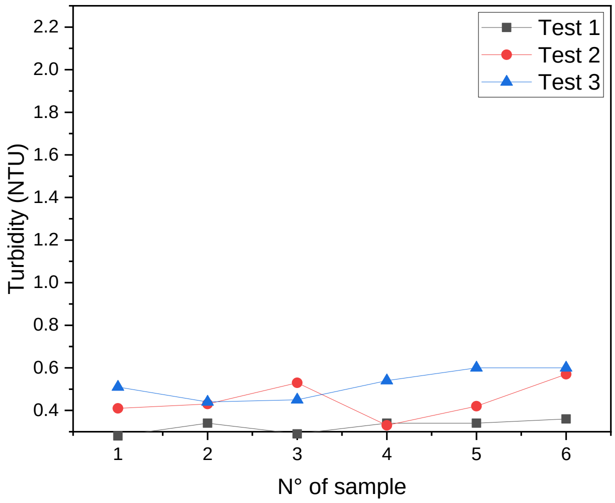

Figure 4 : Turbidity evolution after filtration

After filtration, assessing the water's turbidity becomes crucial to determine the optimum amount of coagulant. The primary goal is to pinpoint the ideal coagulant dosage for sedimentation, effectively eliminating suspended solids and minimizing turbidity. As a result, samples with turbidity levels exceeding 0.5 are excluded from the analysis.

3.3.2.2. TAC

The variation in total alkalinity concentration results is displayed in Table 9, offering an overview of the changes and fluctuations observed in total alkalinity concentrations throughout the experimental tests. Figure 5 illustrates the evolution of total alkalinity (TAC) after the filtration process. The plot provides a graphical representation of the observed changes and patterns in total alkalinity concentration corresponding to each filtration step.

Table 9. Variation of complete alkalimetric concentration results

Samples	1	2	3	4	5	6
Test 1	5	5.3	5.3	5.1	5.5	4.8
Test 2	5.4	5.3	5.6	5.3	5	5.5
Test 3	5.5	5.47	5.3	5.4	5.22	5.15

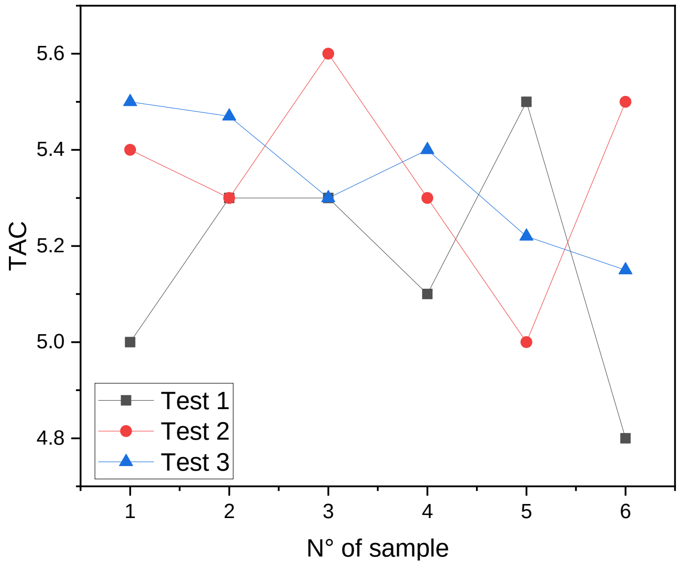

Figure 5. Evolution of TAC After filtration process

3.3.2.3. Presence and absence of flocculent

Using aluminum sulphate, the objective of this experiment is to optimize the optimal amount of coagulant both in the absence and presence of flocculent by injecting increasing quantities of aluminum sulphate. The physical and chemical parameters examined under decantation and filtration conditions are graphically presented in Figure 6. Serving as a comprehensive illustration, it facilitates an easy comparison of the effects of experimental conditions on the specified parameters.

Table 10. Analysis of some physicochemical parameters

Samples	1	2	3	4	5	6
Pre-chlorination (mg/l)	4	4	4	4	4	4
Coagulant (mg/l)	30	40	50	30	40	50
Flocculent (mg/l)	-	-	-	0.1	0.1	0.1
Flock appearance	02	04	04	06	06	06
After settling pH	7.88	7.74	7.63	7.86	7.12	7.64
After settling turbidity (NTU)	3.81	3.7	1.51	1.84	1.70	0.97
Residual Chlorine	2.5	2	2	1.4	1.9	1.8
After filtration turbidity (NTU)	1.75	1.56	1.88	0.79	0.5	0.61
TAC	5.3	5.5	5.4	5.5	5.5	5.2

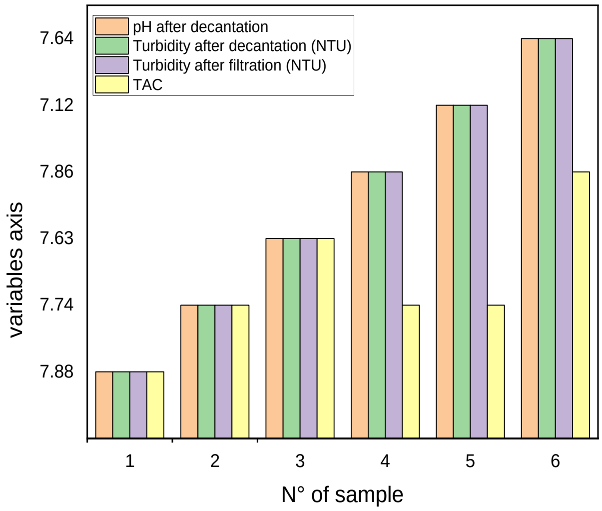

Figure 6. Physical and chemical parameters in the settled and filtered conditions

The flock appearance is lower than 6 in beakers 1, 2 and 3, so they must be eliminated. After settling, turbidity should be less than 5 NTU and after filtration less than 0.5 NTU. The selection of sample No. 5 is based mainly on the reduced coagulant concentration and the quality requirements established for physico-chemical analysis.

3.3.2.4. Increasing amounts of flocculent (polymer) and fixed amount of coagulant (aluminum sulphate)

In order to optimize the polyelectrolyte dosage, a fixed amount of aluminum sulfate was applied along with varying quantities of polyelectrolyte. This evaluation aimed to assess the impact of different polyelectrolyte concentrations on the treatment process. A thorough analysis of selected physicochemical parameters is presented in Table 11, offering insight into the observed changes with increasing polyelectrolyte amounts while maintaining a constant coagulant dosage. These results contribute significantly to understanding the interaction between coagulant and flocculent, crucial for achieving optimal water treatment results.

Table 11. Analysis of some physicochemical parameters

Samples	1	2	3	4	5	6
Pre-chlorination (mg/l)	3	3	3	3	3	3
Coagulant (mg/l)	60	60	60	60	60	60
Flocculent (mg/l)	0.05	0.1	0.15	0.2	0.25	0.3
Flock appearance	04	04	06	06	06	06
After settling pH	7.47	7.52	7.51	7.56	7.52	7.52
After settling turbidity (NTU)	2.56	1.29	0.93	1.80	1.15	1.22
Residual Chlorine	0.8	0.9	0.55	0.65	0.5	0.5
After filtration turbidity (NTU)	0.55	0.50	0.49	0.74	0.55	0.53
TAC	4.92	5	5.2	5.3	5.3	5.4

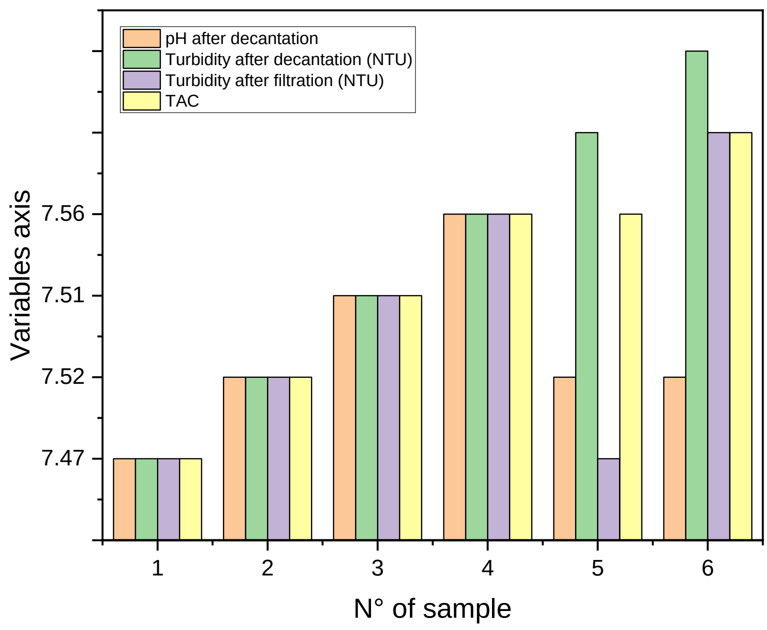

Figure 7. Physical and chemical parameters in the settled and filtered conditions

In beakers 1 and 2, the flock aspect is less than 6, so they must be eliminated. After settling, turbidity should be less than 5 NTU, and after filtration less than 0.5 NTU. Sample No. 3 will therefore be chosen because the optimum polymer quantity is 0.15 mg/l (between 0.1 and 0.15 mg/l), which is equivalent to the amount of product injected into the station during normal periods.

3.3.2.5. Acidification

To achieve optimal results in water treatment, the acidification process is employed to optimize the pH value. Adjusting acidity enhances the efficiency of the treatment process. Furthermore, the amount of chlorine injected corresponds to the breakpoint, ensuring precise proportioning of chlorine to meet the specific requirements of the treatment. The quantities of chlorine injected during the acidification process are detailed in Table 12, providing a comprehensive reference for maintaining the required pH conditions and facilitating the attainment of more achievable water treatment results

Table 12. Injected chlorine dose

	Test A	**Test B**	**Test C**
Pre-chlorination	3.5	4	3

3.4. Raw water analysis

The raw water used in each test had to be analyzed in order to determine both the pH and the physico-chemical properties of the water. The results of the analysis of selected physico-chemical parameters are shown in Table 13, providing an outline of the basic conditions of the raw water used in the experiment.

Table 13. Analysis of some physicochemical parameters

	pH	TA	TAC	Turbidity (NTU)	Temperature (°C)
Test 1	8.31	1.2	6.2	124	21
Test 2	8.35	1.1	6.4	200	20.6
Test 3	8.3	0.7	6.6	240	20.2

3.4.1. Test A

Table 14 presents a detailed analysis of the physico-chemical parameters, offering a comprehensive insight into the quality of the raw water for this test. The comparison between physical and chemical parameters after decantation and filtration is illustrated in Figure 8. Which is also carried out for tests B and C.

Table 14: Analysis of some physicochemical parameters

Samples	1	2	3	4	5	6
pH after acidification	8.31	7.22	6.90	6.33	6	5.5
Pre-chlorination (mg/l)	3.5	3.5	3.5	3.5	3.5	3.5
Coagulant (mg/l)	60	60	60	60	60	60
Flocculent (mg/l)	0.1	0.1	0.1	0.1	0.1	0.1
Flock appearance	06	06	06	06	06	06
After settling pH	7.54	7.12	6.93	6.46	5.95	5.65
After settling turbidity (NTU)	0.84	1.18	1.09	2.73	1.21	1.62
Residual Chlorine	1.6	0.1	0.4	0.5	1	1
After filtration turbidity (NTU)	0.66	0.50	0.46	0.47	0.57	0.50
TAC	5.2	4.8	4.2	3	1.5	0.9

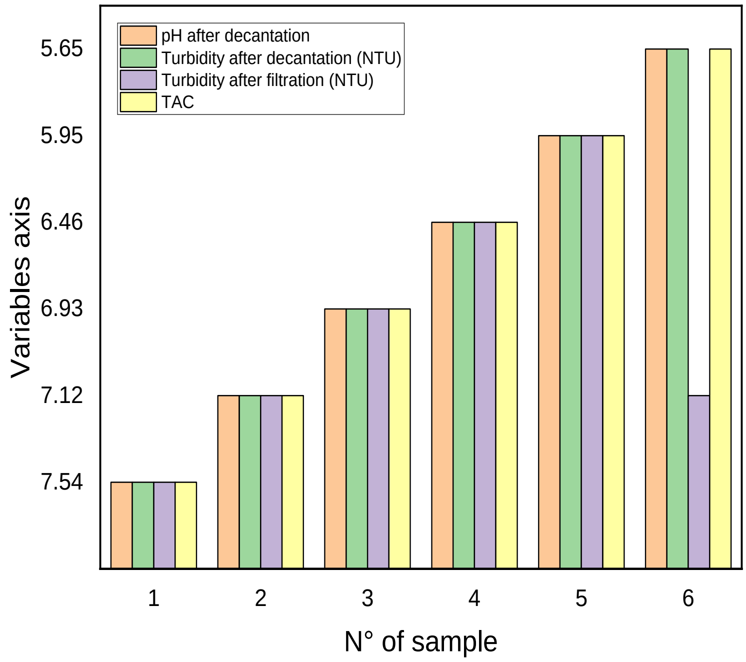

Figure 8. Physical and chemical parameters in the settled and filtered conditions

3.4.2. Test B

Table 15. Analysis of some physicochemical parameters

Samples	1	2	3	4	5	6
pH after acidification	8.35	7.42	6.95	6.71	6	5.68
Pre-chlorination (mg/l)	4	4	4	4	4	4
Coagulant (mg/l)	50	50	50	50	50	50
Flocculent (mg/l)	0.1	0.1	0.1	0.1	0.1	0.1
Flock appearance	06	06	06	06	06	06
After settling pH	7.68	7.29	7.04	6.83	6.30	5.83
After settling turbidity (NTU)	1.32	1.39	1.69	2.56	2.07	6.06
Residual Chlorine	0.8	0.8	1	0.7	0.5	0.7
After filtration turbidity (NTU)	0.51	0.47	0.34	0.32	0.27	1.46
TAC	5.3	4.9	4.5	3.9	2.1	1.1

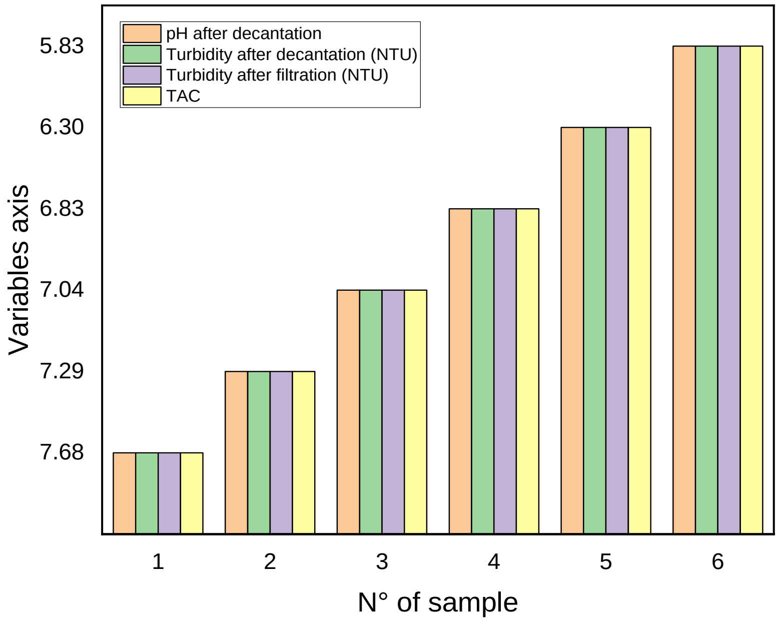

Figure 9 : Physical and chemical parameters in the settled and filtered conditions

3.4.3. Test C

Following an extensive comparison between the three tests, combined with the results obtained and the selection factors, it was established that the best sample was number 3 from the third test, which satisfied all the requirements. As regards physico-chemical quality, water treatment optimization with a pH of 6.80 (pH after acidification) yielded higher results, with settled water turbidity of 1.11 NTU (< 5 NTU) and filtered water turbidity of 0.36 NTU (< 0.5 NTU).

From an economic standpoint, the use of aluminum sulfate at an optimal quantity of 50 mg/l instead of 60 mg/l led to a reduction of 10 mg/l, resulting in an annual cost savings of MAD 240,000. Therefore, acidification emerged as a beneficial treatment method, particularly advantageous for decontamination, where pH reduction towards 7 enhanced the efficiency of the decontamination process.

Table 16. Analysis of some physicochemical parameters

Samples	1	2	3	4	5	6
pH after acidification	8.3	7.27	6.73	6.14	5.5	4
Pre-chlorination (mg/l)	3	3	3	3	3	3
Coagulant (mg/l)	50	50	50	50	50	50
Flocculent (mg/l)	0.1	0.1	0.1	0.1	0.1	0.1
Flock appearance	06	06	06	06	06	06
After settling pH	7.64	7.27	6.89	6.45	5.92	4.82
After settling turbidity (NTU)	0.90	1.36	1.11	1.62	0.98	6.71
Residual Chlorine	0.3	0.1	0.2	0.3	0.4	0.1
After filtration turbidity (NTU)	0.49	0.40	0.36	0.63	0.51	2.22
TAC	5.2	4.8	4.2	2.7	1.4	0.3

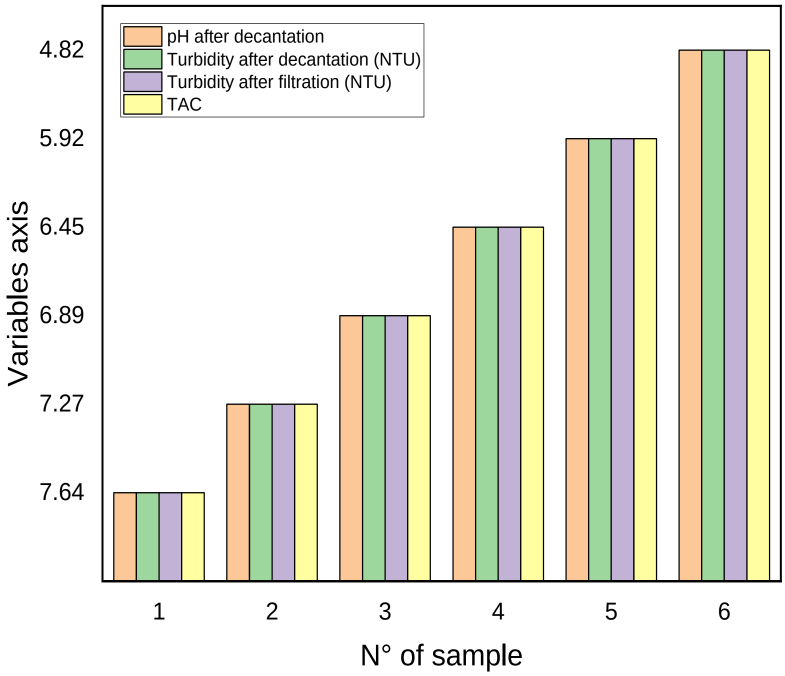

Figure 10. Physical and chemical parameters in the settled and filtered conditions

4. Conclusion

In fact, the purpose is to deal with the treatment process at the Ain Nokbi station, focusing on coagulation-flocculation given its importance within the process. In order to determine the optimum dose of coagulant to inject into the raw water and to establish the most suitable conditions, we carried out several tests using aluminum sulphate in the water. Various parameters that could affect the effectiveness of this reagent were also examined. Monitoring of this phase showed that the doses of coagulant determined using the Jar-test method gave satisfactory results when applied, with the treated water complying with Moroccan drinking water guidelines. The research also demonstrated that a mild acidification of the water can reduce the amount of coagulant required. This represents not only a cost-effective advantage, but also a health benefit, as higher quantities would give significant amounts of aluminum residue, which could constitute a potential health hazard.

References

1. Muthuraj R, Lacoste C, Lacroix P, Bergeret A 2019 Industrial Crops and Products, 135, 238-245.
2. Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. Science, 352(6288), 928-933.
3. Othman, N. H., Alias, N. H., Fuzil, N. S., Marpani, F., Shahruddin, M. Z., Chew, C. M., ... & Ismail, A. F. (2021). A review on the use of membrane technology systems in developing countries. Membranes, 12(1), 30.
4. Khemis, M., Tanguy, G., Leclerc, J. P., Valentin, G., & Lapicque, F. (2005). Electrocoagulation for the treatment of oil suspensions: relation between the rates of electrode reactions and the efficiency of waste removal. Process Safety and Environmental Protection, 83(1), 50-57.
5. Chakraborty, S. K., & Chakraborty, S. K. (2021). River pollution and perturbation: Perspectives and processes. Riverine Ecology Volume 2: Biodiversity Conservation, Conflicts and Resolution, 443-530.
6. Jackson, R. E., Gorody, A. W., Mayer, B., Roy, J. W., Ryan, M. C., & Van Stempvoort, D. R. (2013). Groundwater protection and unconventional gas extraction: The critical need for field-based hydrogeological research. Groundwater, 51(4), 488-510.
7. Tekerlekopoulou, A. G., Economou, C. N., Tatoulis, T. I., Akratos, C. S., & Vayenas, D. V. (2020). Wastewater treatment and water reuse in the food industry. In The Interaction of Food Industry and Environment (pp. 245-280). Academic Press.
8. Kong, Z., Li, L., Xue, Y., Yang, M., & Li, Y. Y. (2019). Challenges and prospects for the anaerobic treatment of chemical-industrial organic wastewater: a review. Journal of cleaner production, 231, 913-927.
9. Azzouni, D., Baragh, F., Mahmoud, A. M., Alanazi, M. M., Rais, Z., & Taleb, M. (2023). Optimization of methylene blue removal from aqueous solutions using activated carbon derived from coffee ground pyrolysis: A response surface methodology (RSM) approach for natural and cost-effective adsorption. Journal of Saudi Chemical Society, 27(5), 101695.
10. Azzouni, D., Saoudi Hassani, E. M., Rais, Z., & Taleb, M. (2022). An Excellent Alternative to Industrial Activated Carbons for the Purification of Textile Water Elaborated from Waste Coffee Grounds. International Journal of Environmental Research, 16(5), 89.
11. Azzouni, D., Lahkimi, A., Louaste, B., Taleb, M., Chaouch, M., & Eloutassi, N. (2019). Performance of Aspergillus Niger and Kluyveromyces marxianus for optimized bioethanol production from dairy waste. In Advanced Intelligent Systems for Sustainable Development (AI2SD'2018) Vol 3: Advanced Intelligent Systems Applied to Environment (pp. 162-175). Springer International Publishing.
12. Azzouni, D., Eloutassi, N., Lahkimi, A., Louasté, B., & Chaouch, M. (2019). Production of the bioenergy from the industrial waste. Materials Today: Proceedings, 13, 607-614.
13. Azzouni, D., Haldhar, R., Salim, R., Ech-chihbi, E., Mrani, S. A., Rais, Z., ... & Taleb, M. (2023). Adsorption treatment residues as novel ecological corrosion inhibitors applied to

mild steel in a molar hydrochloric acid medium: Experimental studies and surface characterization. Materials Today Communications, 35, 106181.

14. Ahansazan, B., Afrashteh, H., Ahansazan, N., & Ahansazan, Z. (2014). Activated sludge process overview. International Journal of Environmental Science and Development, 5(1), 81.
15. Ahmed, S. F., Mofijur, M., Nuzhat, S., Chowdhury, A. T., Rafa, N., Uddin, M. A., ... & Show, P. L. (2021). Recent developments in physical, biological, chemical, and hybrid treatment techniques for removing emerging contaminants from wastewater. Journal of hazardous materials, 416, 125912.
16. Awaleh, M. O., & Soubaneh, Y. D. (2014). Waste water treatment in chemical industries: the concept and current technologies. hydrol current res, 5(1), 1-12.
17. Senthil Kumar, P., & Saravanan, A. (2018). Sustainable waste water treatment technologies. Detox Fashion: Waste Water Treatment, 1-25.
18. Koohestanian, A., Hosseini, M., & Abbasian, Z. (2008). The separation method for removing of colloidal particles from raw water. American-Eurasian J. Agric. & Environ. Sci, 4(2), 266-273.
19. Brostow, W., Lobland, H. H., Pal, S., & Singh, R. P. (2009). Polymeric flocculants for wastewater and industrial effluent treatment. J Mater Educ, 31(3–4), 157-166.
20. Neihof, R. A., & Loeb, G. I. (1972). The surface charge of particulate matter in seawater. Limnology and Oceanography, 17(1), 7-16.
21. Bouyer, D., Escudié, R., & Liné, A. (2005). Experimental analysis of hydrodynamics in a jar-test. Process safety and environmental protection, 83(1), 22-30.
22. Bouyer, D., Line, A., Cockx, A., & Do-Quang, Z. (2001). Experimental analysis of floc size distribution and hydrodynamics in a jar-test. Chemical Engineering Research and Design, 79(8), 1017-1024.
23. Haghiri, S., Daghighi, A., & Moharramzadeh, S. (2018). Optimum coagulant forecasting by modeling jar test experiments using ANNs. Drinking Water Engineering and Science, 11(1), 1-8.
24. Cohen, J. M. (1957). Improved jar test procedure. Journal (American Water Works Association), 49(11), 1425-1431.