https://dx.doi.org/10.22161/ijaers.4.4.1 ISSN: 2349-6495(P) | 2456-1908(O)

Eco-Efficiency of Drinking Water Treatment

M. Farhaoui

National Office of Electricity and Drinking Water, Meknes, Morocco

Abstract*— *Problem statement: *In the water treatment processes, the chemicals (aluminum sulfate AS, chlorine, and polyelectrolyte) are required in the different steps of treatment (coagulation, flocculation, settling, disinfection…). The chemicals residues can affect the human healthy and the environment. The treatment process produces sludge according to the level of the water turbidity. However, the sludge management increases the monitoring expenses. Moreover, this water treatment sub-product constitutes a threat for the environment and the downstream water users.* ***Approach:*** *In this study, the effectiveness of chemicals uses and sludge reuse was evaluatedin order to find optimal operational conditions and reduce its residues. The influence of the chemicals consumption on the cost of treated water was also studied. A set of jar test experiments was conducted to find the sludge and aluminum sulfate dosages in order to improve the produced water quality for different turbidity levels.* ***Results:*** *Results demonstrated that the consumption of chemicals could be reduced by 10 to 15%. The sludge reuse improve the water quality and decrease the AS consumption by 50 to 60%. The turbidity removal is increasing and the aluminum residues is decreasing by 50%.* ***Conclusions/Recommendations:*** *Results show that the sludge reuse plays a very important role in reducing the aluminum sulfate dosage, improving the treated water quality and reducing water cost. The AS control and modeling reduce the chemicals consumption. This approach contributes in preserving the environment and opens income-earning opportunities for local population by promoting local products made from water treatment sludge.*

Keywords*— *Efficiency, water treatment, water quality, chemicalsresidues, sludge, environment, beneficiaries.

I. INTRODUCTION

The demand on water supply is increasing over the last century due to improved lifestyle, industrial development and population growth. This increased demand is facing a paradox to produce treated water with high quality at lower cost. In order to reduce the water cost, it is very important to optimize the operating expenses in the water treatment plant (power, chemicals, operator's expenses…) and many measures should be taken in this vision [1].

The treatment of drinking water comprises the aeration, coagulation, sedimentation, filtration and disinfection of raw water produced by the springs. During the rainfall period, the water's turbidity increases, colloidal particles are separated in the treatment plant by means of a chemical coagulation process: consisting in the charge destabilization of the suspended particles by adding coagulant. The coagulant used is aluminum sulfate; it is the most widely used coagulant in Morocco as well as many other countries in the drinking water industry. It is mainly used because of its effectiveness, accessibility and low price. As a common practice, aluminum sulfate is applied according to the jars test results. The main difficulty is how to reduce the treated water cost and improve the water quality in the same time. Also, le sludge management is a real problem in water treatment plant, it is increasing the both investment and operating costs. optimize the aluminum sulfate dosage related to raw water characteristics by using other cheaper products. Some attempts have been made to improve the effectiveness of the aluminum sulfate or to substitute this coagulant by another natural, available and cheaper [2].Finding of various coagulation processes have been reported in literature. Some of these include; studying the effect of using the bentonite, MoringaOleifera, Date seeds, Pollen Sheath,Mesquite Bean and Cactus Latifariaon the coagulation in the treatment of low turbidity [3],[4],[5]. Those natural products have coagulating activity in the treatment of turbid water and can be used as coagulant or as coagulant aid with other synthetic and industrial coagulants (aluminum sulfate…) in order to reduce the coagulant consumption in the water treatment plant. However, Studies have demonstrated that sludge produced by the water treatment plant can improve the coagulation process and reduce the aluminum sulfate consumption [6].

This paper addresses the problem of improving water quality by decreasing the chemicals use in water treatment plant and the possibility to reuse sludge in the water production chain. This paper is organized as fellows. After an introduction of the objective of this study, the experimental section is described in section II, also,the methodology used to assess the approach impacts is explained. In section III, the results are presented and discussed.

https://dx.doi.org/10.22161/ijaers.4.4.1 ISSN: 2349-6495(P) | 2456-1908(O)

II. EXPERIMENTAL SECTION

a) Water treatment operation

This study was developed in a water treatment plant located in Meknes in the middle of Moroccan Kingdom, whose source is two big springs Bittit (630 l/s) and Ribaa (400l/s). The quality of water produced by the springs changes according to the rainfall in the region. Sometimes, it can be affected by the snow in the Atlas Mountain. The treatment water plant, as part of other water resources, water to more than 700.000 inhabiatnts of Meknes city, Morocco and has a nominal capacity of 600 l/s of treated water. Figure 1 presents a schematic overview of the various operations necessary to treat the water.

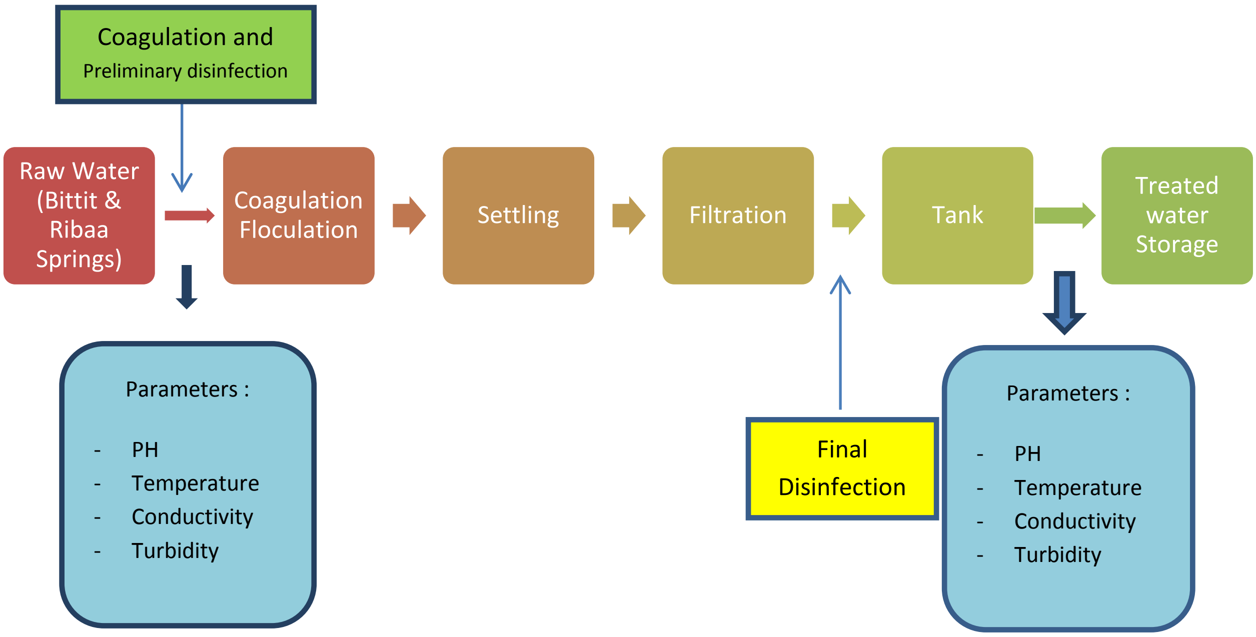

Fig.1: simplified synopsis of the water treatment plant.

Many measurements of variables such as turbidity level, PH, conductivity, temperatureis needed to carry out the jars test in order to determine the optimal dose of the aluminum sulfate. The raw water variables used in this study present the following variation intervals:

Table.1: statistical summary of raw water conditions from 01/01/2013 to 31/12/2016 (ONEE, 2016)

Variables	**Min**	**Max**
Turbidity: Bittit (NTU)	**1.7**	**850**
Turbidity: Ribaa (NTU)	**1.62**	**960**
PH	**6.80**	**7.74**
Temperature: (°C)	**14**	**24.70**
Conductivity micro s/cm	**509**	**624**

In the rainfall period, the turbidity of raw water changes from time to time as shown in the figure 2:

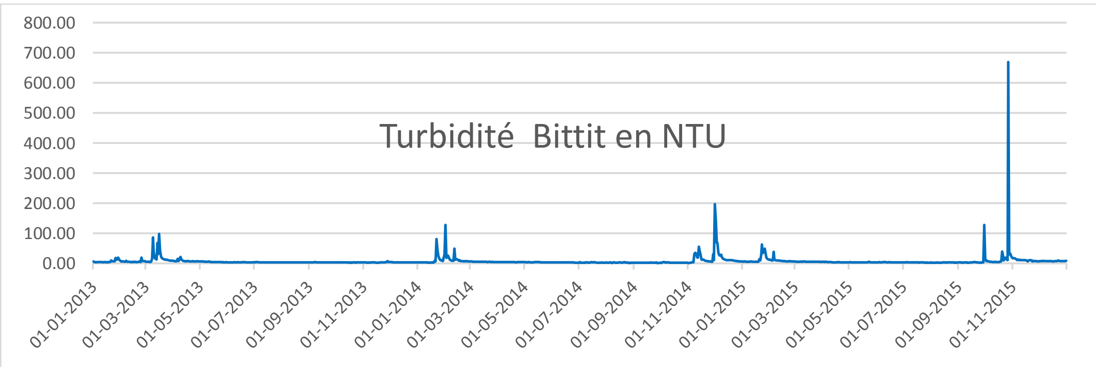

Fig.2: statistical data of turbidity level of the spring's water from 01/01/2013 to 31/12/2015 (ONEE, 2016).

The chemicals used in the water treatment process consume about 50% the total operating expenses of the water treatment. The energy cost is between 10 to 15% related to the total cost in 2013, 2014 and 2015 as shown in the Figure 3.

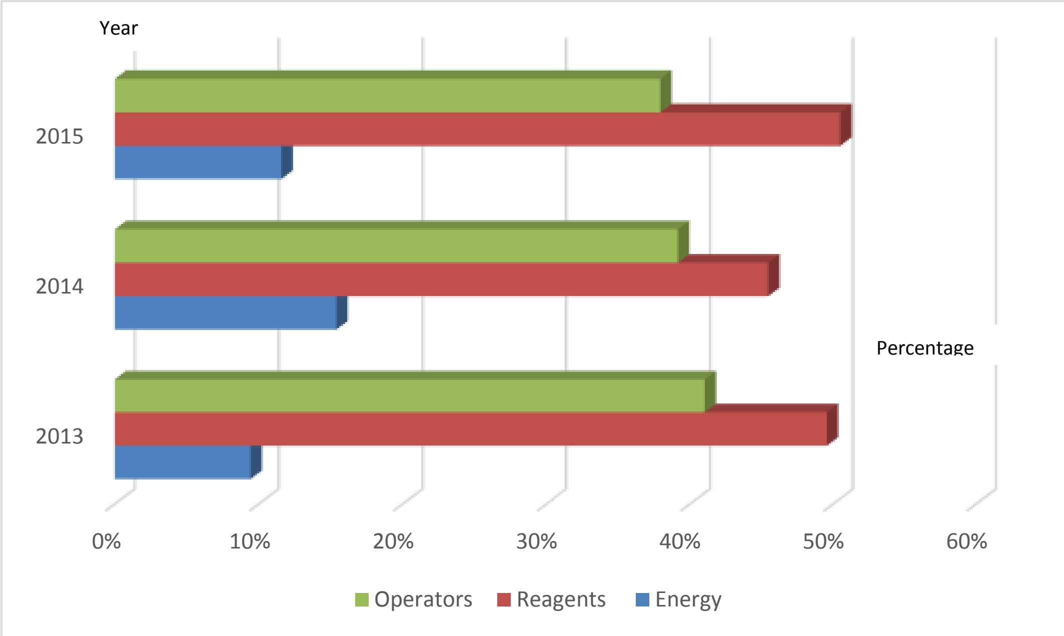

Fig.3: Operations expenses of the water treatment plant in 2013, 2014 and 2015 (National Office of Electricity and Drinking Water ONEE, 2015).

In addition, used as coagulant, the aluminum sulfate (Alum) consumption is more than 70% of the total chemicals consumption in the water treatment plant. Le polyelectrolyte (Poly) consumption is less than 10% and the chlorine is between 16 and 26% of the total chemicals used in the water treatment plant according to the water quality as shown by the figure below:

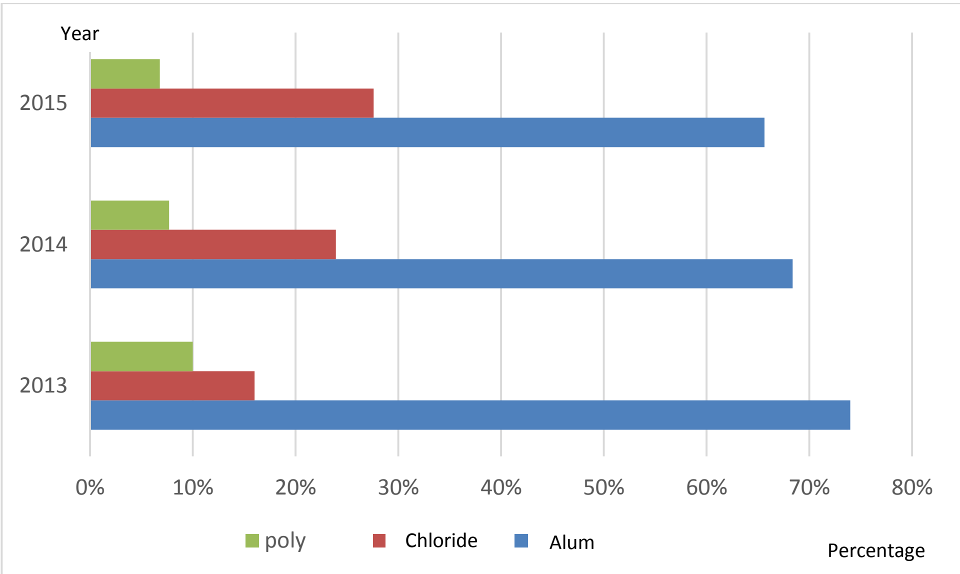

Fig.4: Percentage of chemicals expenses consumed by the water treatment plant in 2013, 2014 and 2015 (National Office of Electricity and Drinking Water ONEE, 2015).

The table 2 show the volume of the treated water and sludge produced by the water treatment plant between 2013 and 2015.

Table.2: Volume of treated water and sludge produced by the WTP in 2013, 2014 and 2015 per month (National Office of Electricity and Drinking Water ONEE, 2016)

Year	Volume of treated water (m^3)	Consumption of aluminum sulfate (kg)	Volume of sludge produced in the WTP (m^3)
2013	15098736	242850	9559
2014	15508924	203820	14021
2015	15214486	149330	10810

b) Materials and methods

b.1 Modeling of the aluminum sulfate dose:

The prediction of optimal coagulant dose from raw water characteristics is a nonlinear regression problem. The identification aims at modeling and parameter estimation. It consists of constructing a mathematical model that can describe the behavior "-Input-output" of the system [17]. The problem is to determine the model parameters from input and output data. The analysis of experimental data for different periods of the year in the water treatment plant allow obtain mathematical models describing the changes in dose of Alum based on the input parameters of the raw water using Statgraphics software [7].

The model to develop will be based on the data available in the plant from 01/06/2014 to 31/12/2015 (495 data). The data validation, processing and modeling of the coagulant dosage rate are the main steps to construct the model as presented by the figure 5.

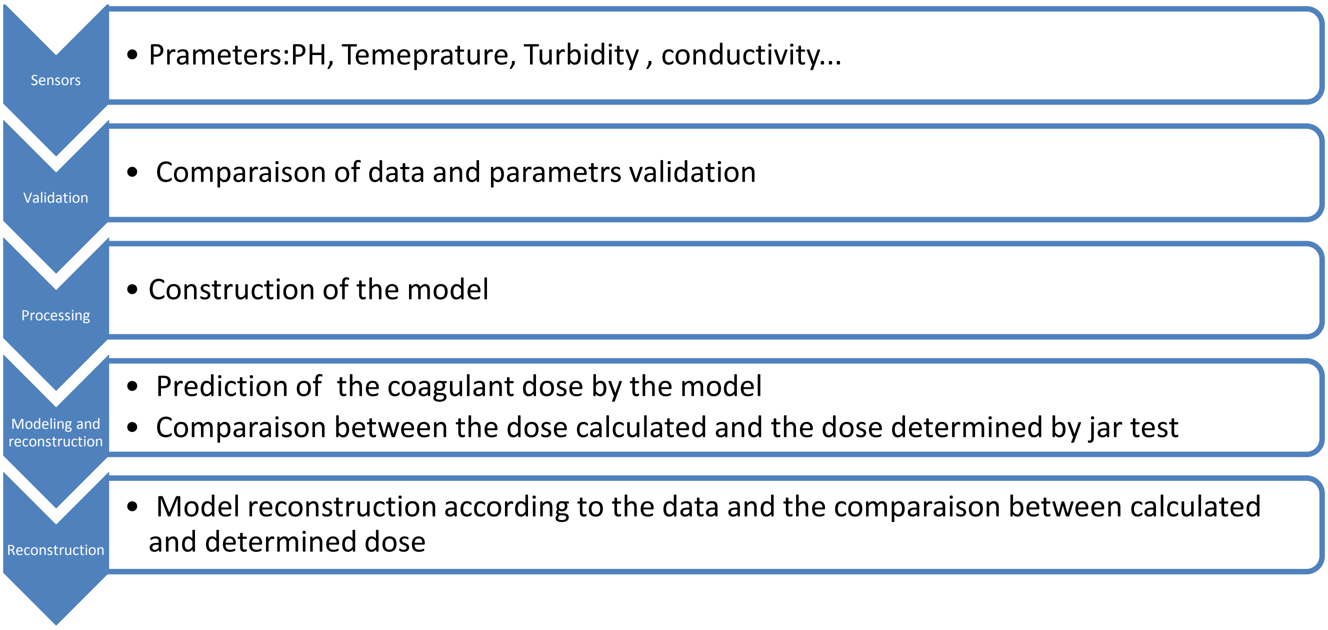

Fig.5: structure of the model for the prediction of the coagulant dosage rate.

According to the data recorded in the water treatment plant, many models are identified and analyzed using Statgraphics software which indicates the relationship between the Aluminum doses measured and calculated by different models. Only eleven models from the simplest to a complex one are exanimated below regarding to the output (aluminum sulfate dose calculated).

After the construction of the models, they are compared each one to the other. Two statistical tests are performed on models in order to choose the model fitted with the observed data. First, an ANOVA test is performed on models to determine if there is a significant difference between models and observed data. Finally, the Euclidian distance method is applied to models in order to choose the more representative of the observed data.

b.2 Reusing sludge in the water treatment process:

1/ Preparation of synthetic turbid water:

The turbid water is prepared by adding different weights of sludge in mg into 1 liter of raw water from the spring for the medium (20 NTU) and high (40 NTU) turbidity levels. However, the low turbidity (10 NTU) water is obtained directly from the spring.

2/ Preparation of Aluminum solution:

The Aluminum solution was prepared by dissolving 1 g of AS ($Al_2(SO4)_3$) in distilled water (PH = 7 ± 0.1) and the solution volume is increased to 1 liter. Each 1 ml of prepared stock solution is equal to 10 mg/l when it is added to 1 liter of turbid water to be tested.

3/ Preparation of sludge solution:

https://dx.doi.org/10.22161/ijaers.4.4.1 ISSN: 2349-6495(P) | 2456-1908(O)

The sludge produced in the settling step of the treatment process is used to prepare the sludge solution. A certain volume of raw water is added to the blend and stirred for 5 minutes at 300 rpm using magnetic stirrer. The volume of obtained suspension is increased to 1 liter and the gravity filtered through a 1um filter paper to separate residual particles from the prepared solution. The filtrate solution is referred to a sludge coagulant in this study.

4/Research methodology:

A standard jar test apparatus equipped with six paddles rotating in a set of six beakers is used to simulate coagulation, flocculation and sedimentation processes.At the first, Control experiments for coagulation tests are performed in order to determine the optimal dose of the aluminum sulfate in normal conditions. The selected level of turbid water (1L) is filled into the beakers and various doses in the range from 10 to 100 mg/l of sludge and the aluminum sulfate according to the results of the first jar test determining the optimal dose of the inorganic coagulant in normal conditions are separately added in the beakers and mixed rapidly (300 rpm) for one minute. The mixing speed was then reduced to 40 rpm for 20 minutes. Then thestirrer is turned off and the suspensions are allowed to settle for different periods of time ranging from 30 to 120 minutes under quiescent conditions.After each period of settling time, supernatant samples of each beaker in the jar test is withdrawn from located 10 cm below the water level and residual turbidity is measured.

III. RESULTS AND DISCUSSIONS

3.1. Evaluation of experiments impacts:

1/ Modeling of the aluminum sulfate dose:

According to this study, the coagulant dose modeling can reduce the aluminum sulfate consumption by 10 to 15% [7].

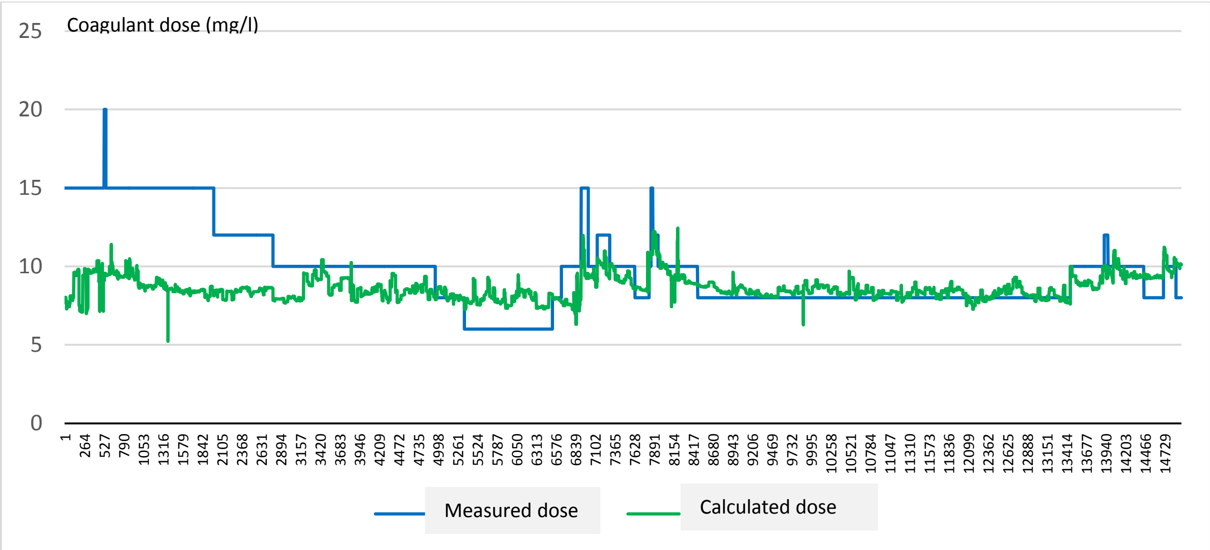

Fig.6: Comparison between the calculated and measured dose of the coagulant.

2/ Sludge reusing:

According to the jar test experiments, the sludge can play a very interesting role the improvement of settling activities in the water treatment process. The sludge reusing can reduce the aluminum sulfate consumption by 40 to 50% according to the water turbidity level [6].

The table 3 shows the results of coagulant consumption reduction after using sludge as aid coagulant with aluminum sulfate:

Table.3: AS consumption reduction for different levels of turbidity using AS and sludge

	Low Turbidity	Medium turbidity	High turbidity
Initial turbidity	9.34	21	39.4
Optimal dose of Aluminum sulfate (mg/l) (1)	10	20	20
Optimal dose of sludge (mg/l) used within AS (2)	35	50	60
Dose of AS (mg/l) proposed to be used with optimal dose of sludge (3).	6	10	12
% of AS reduction	**40%**	**50%**	**40%**

https://dx.doi.org/10.22161/ijaers.4.4.1 ISSN: 2349-6495(P) | 2456-1908(O)

3.2. Evaluation of operational impacts:

1/ Improvement of water quality:

Both modeling of coagulant dose and reusing of sludge in coagulation process improve the water quality produced by the water treatment plant. Concerning the dose modeling, the calculated dose based on real time parameters is just the dose that the process requires and many problems of over or under dose are avoid. Thus, the quality of water is improved. In addition, the sludge reusing improves the water quality by increasing the turbidity removal.

The table 4 shows the results of turbidity removal percentage using aluminum sulfate only, optimal dose of AS and sludge and the optimal dose of sludge and the proposed dose of AS :

Table.4: Turbidity removal percentage for different levels of turbidity using AS and sludge

	Low Turbidity	Medium turbidity	High turbidity
Initial turbidity	9.34	21	39.4
Turbidity removal percentage using only AS (1)	**96.71%**	**98.05%**	**98.98%**
Turbidity removal percentage using AS and sludge as coagulant aid (1)+(2)	**97.14%**	**98.33%**	**99.34%**
Turbidity removal percentage using optimal dose of sludge and AS (2)+(3)	**97.56%**	**98.96%**	**99.47%**

The results show that the sludge used as coagulant aid with the AS improves not only the water quality produced by the treatment plant (turbidity removal percentage from 96.71 to 97.56%, from 98.05 to 98.96% and from 98.98 to 99.47% for low, medium and high turbid water respectively).In addition, it can be used to reduce the AS dose in the coagulation process.

Furthermore, the sludge reuse in coagulation process decrease the aluminum residues in produced water. The figure 7 show the aluminum residues before and after reusing sludge in water treatment process.

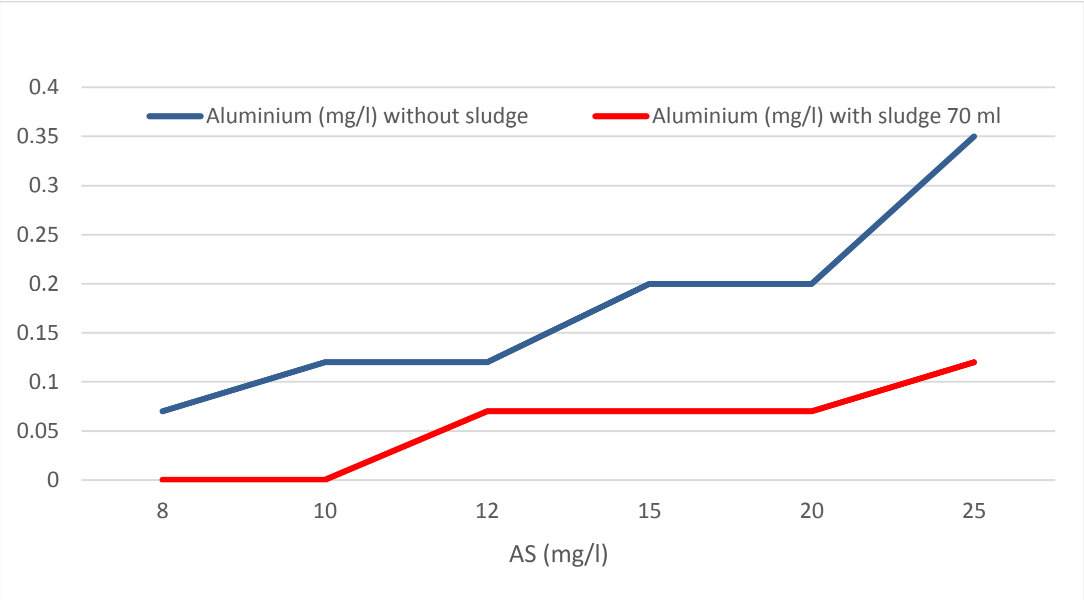

Fig.7: Impact of sludge reusing on aluminum residues in treated water.

2/ Reduction of waste streams:

The sludge reusing in the coagulation process reduce the volume of waste streams and plays a great role in the environment preservation.Properties of the sludge produced by the water treatment plant depends on the raw water quality and the WTP process [8]. Moreover, the sludge can play very interesting role in removing phosphorus as various species of phosphate by means of its aluminum components [9].A model has been elaborated to predict the sludge volume [10]. The model contributes to master the sub-products produced by the WTP in order to manage the plant performances.

3/Improvement of the local population income:

Several studies have been performed in order to treasure the sludge produced by both drinking water treatment plants (WTP) and wastewater treatment plants (WWTP) [11]. Although the reuse of sludge from WWTP is of crucial importance according to the organic matter it contain. In fact, the reuse of sludge have been studied in different sectors especially in the field of construction and civil engineering.

As in construction field, WTP sludge is very important in the pottery sector. Indeed, the use of a mixture consisting of sludge (85%) and sand (silicon dioxide) 15% in pottery manufacturingis proposed [12].Then, sludge produced by the water treatment plant contributes in the development of handcraft activities in the region. It can create more than 10000 handcraft items (each item needs 1.5 kg of sludge and costs more than five $). Thus, the sludge will become an asset for the local population not an obstacle for WTP managers.

3.3. Evaluation of approach impacts:

The approach based on modeling of the coagulant dose and the sludge reusing in water treatment plant can be widespread. The relevance of these approach findings for the challenge is appreciated at three levels:

1/ The environmental level:

The application of this approach contributes to enhance and protect the environment and improve the water quality. The treated water quality is improved by increasing the turbidity removal percentage and decreasing the aluminium residues. However, the rejected water quality is improved by decreasing all of the chemicals residues. In addition, this approach play a very important role in reducing waste streams (sludge). Thus, the agricultural activities in the plant downstream are not affected by the WTP streams.

2/ The economic level:

The application of this approach contributes:

- Reduce operating costs by mastering the coagulant dose determined by the automatic method instead of manual method and reducing the coagulant consumption after reusing sludge as aid coagulant.
- Improve operator productivity and efficiency and increase operator profits by decreasing the operating expenses. The sludge reusing and modelling contributes to decrease both the investment and operating costs [10].
- Optimize life-cycle economic performance: this approach improve the performances facilities.

3/ The Social level:

The application of this approach contributes to enhancepopulation health and comfort by improving water quality. It can contribute to the socio-economic development of the region by openingincome earning opportunities and promoting local products. Thus, the water plant management enhance local livelihood.

IV. CONCLUSIONS

This paper has presented some results concerning the improvement of the water treatment efficiency and the reduction of its impacts on the environment. It is based on systemic approach that include environmental, economic and social issues and touches all the stakeholders. An innovative solution that reduce environmental impact, optimize water use efficiency and improve the competitiveness of the water supply company. This approach gets the water treatment process more efficient by reducing waste and increasing sub- products recycling and recovery. The study findings show that the water quality is improved while the chemicals consumption is reduced. Thus, the treated water cost is reducing.In addition, this approach touches the social issues, it is based on the idea that improve the local population income and engage the rural community in sustainable economy activities (craft, fertilizers…). Finally, the approach can be generalized for water treatment plants all over the world.

REFERENCES

[1] Farhaoui, M. and Derraz, M. (2016), Review on Optimization of Drinking Water Treatment Process. *Journal of Water Resource and Protection*, Vol.8, pp.777-786. http://dx.doi.org/10.4236/jwarp.2016.88063

[2] Shen, Y.H., Treatment of low turbidity water by sweep coagulation using bentonite. J. Chem. Technol. Biot., 2005, 80: 581-586.

[3] Mukheled A. A Novel Water Pretreatment Approach for Turbidity Removal Using Date Seeds and Pollen Sheath. Journal of Water Resource and Protection, 2012, 4, 79-92

[4] N. A. Eman, A. M. Suleyman, M. S. Hamzah, Md. A. Zahangir and M. R. M. Salleh, Production of Natural Coagulant from MoringaOleifera Seed for Application in Treatment of Low Turbidity Water, *Journal of Water Resource and Protection*, Vol. 2, 2010, No. 3, pp. 259- 266.

[5] Aho, I. M. and Lagasi, J.E., A new water treatment system using MoringaOleifera seed”, American Journal of Scientific and Industrial Research, 3 (6), pp. 487-492. doi:10.5251/ajsir.2012.3.6.487.492.

[6] Farhaoui M. & Derraz M., (2016), Optimizing coagulation process by using sludge produced in the water treatment plant, *Journal of Chemical and Pharmaceutical Research*, V.8(4), pp.749-756.

[7] Farhaoui M., Hasnaoui L., Derraz M., (2016), Optimization of Drinking Water Treatment Process by Modeling the Aluminum Sulfate Dose, *British Journal of Applied Science & Technology*, Vol.17(1), pp.1-14. DOI: 10.9734/BJAST/2016/26840.

[8] Kyncl M., 2008, Opportunities for water treatment sludge reuse, Geo Science Engineering, Vol. LIV 2, No. 1, pp. 11- 22.

[9] Graham-Jones A., 2014, Evaluating reuse of sludge from water treatment for wastewater treatment, An assessement of effects of spent alum sludges on wastewater treatment in Gothenburg, Sweden, MEng degree thesis submitted in Civil and Environmental Engineering with European Studies at the School of Engineering, University of Aberdeen, Sweden, Pp. 67.

[10] FarhaouiM., (2017), “Managing and modeling of the drinking water treatment sludge.” International Journal of Research - Granthaalayah, 5(2), 168-179. https://doi.org/10.5281/zenodo.345636

[11] AeslinaBinti Abdul Kadir, Ahmad Shayuti Bin Abdul Rahim, An Overview of Sludge Utilization into Fired Clay Brick, World Academy of Science, Engineering and Technology, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:8, No:8, 2014.

[12] FarisGorashiFaris, ChoongChoe Earn, A New Approach to Reuse Alum Sludge in Pottery Manufacturing Using Silica and Thermal Curing, International Journal of Chemical, environmental & Biological Sciences (IJCEBS) Volume 2, Issue 3 (2014).