Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23552

143 (2019) 229–234
March

Performance of bentonite clay as a coagulation aid on water quality

M'hamed Ahari[a,*], Hassan Ddahim[b], Rachid Ramadane[c]

[a]*Department of Chemistry, Faculty of Sciences and Techniques, Abdelmalek Essaâdi University, 32000 Al Hoceima, Morocco, Tel. +212539807172; Fax: +212539807173; email: ahari.mhamed@gmail.com*
[b]*Department of Chemistry, Faculty of Sciences, Ibn Zohr University, 80000 Agadir, Morocco, email: ddahim.hassan@gmail.com*
[c]*Laboratory of ONEE-Water Branch, Treatment station, 87000 Chtouka-Ait-baha, Morocco, email: ramdane.rachid@gmail.com*

Received 4 August 2018; Accepted 29 November 2018

ABSTRACT

The objective of this work is to observe the effectiveness of bentonite as a coagulation adjuvant on water treatment quality at Ait Baha station. In our case, bentonite is used as a source of turbidity and is not an adsorbent. Jar tests were performed on raw water samples of low turbidity according to the approach applied in the laboratory. The performance of the bentonite was tested in mixtures: raw water/bentonite, raw water/coagulant and coagulant/bentonite. The main objectives of this study are to verify whether bentonite acts as a coagulation aid for water treatment, and then to minimize the dose of aluminum sulfate while respecting the treatment yield of the station. Indeed, the results obtained showed that the addition of bentonite doses of 20 mg/L can eliminate 96.72% of the turbidity and 60% of the oxidizable material. Also the increase of the dose of bentonite decreases the pH more than the use of aluminum sulfate alone, which makes the water pH optimal for coagulation–flocculation, but also to improve the coagulation and flocculation processes to obtain a good quality effluent and the rapid sedimentation of the flocs formed.

Keywords: Coagulation/flocculation; Turbidity; Jar test; Bentonite; Water treatment

1. Introduction

In Morocco, rural areas and semi-urban areas are experiencing a drastic decline in terms of drinking water, at the same time, the situation of water supply for a rural population, which represent half of the total population, is also considerable delay. These dam reservoirs considered as a first settling of the raw water, in fact a large part of the pollution (suspended solids and the colloidal matter) was eliminated by the precipitation toward the bottom of the reservoirs which make the water less turbid and influence in the direct way to the treatment process. The water contains a quantity of substances composed of suspended solids, colloids and the dissolved matter of mineral salts and very fine organic molecules difficult to decant, even after the treatment, which cause a real problem in the process [1]. To ensure good water solubility of the dam water, several conventional methods for clarifying its waters exist and the most common are based on the coagulation–flocculation process using aluminum sulfate as a coagulant [2–5]. Several studies have inspired some authors who advocated as an adjunct mixed clay–chitosan or hybrid materials [6–8] to ensure the formation of larger and heavier flocs to facilitate settling. The general objective of this work is the study of the performance of clay bentonite as a coagulation aid on the quality of water produced at the Ait Baha treatment plant, in other words, to verify if bentonite acts as a coagulation aid for water treatment, and also the optimization of the dose of coagulant used. The choice of bentonite as a clay mineral makes it possible to give the water a colloidal charge and consequently to increase the turbidity of the water. According to Ofir et al. [9], the optimal concentration of the clay material is, therefore, 20 mg/L because it creates a turbidity of 17.3.

The coagulant/bentonite mixture in the clarification of surface water gives very important results; the pH increases

* Corresponding author.

with the increase of the dose of the bentonite on the other hand it decreases for aluminum sulfate [10,11] and the turbidity increases with the concentration of bentonite [12,13].

2. Materials and methods

2.1. Location Ait Baha treatment plant

The National Office of Electricity and Drinking Water – Water Branch provides 65% of its production of drinking water from surface water, whose mobilization is mainly ensured by the implementation of dam reservoirs. The Ait Baha drinking water plant is located 80 km southeast of Agadir (Morocco), it provides drinking water to the city of Ait Baha and neighboring douars from the dam Ahl-Souss. The commissioning of the station was on July 28, 2010. It has a maximum processing capacity of 40 L/s, a production capacity of 3,456 m^3/d for a factory operation of 24 h (Fig. 1).

2.2. Sampling

The clay materials used in our study, come from the Nador deposit (North-East of Morocco) is a sodium bentonite, gray color. External studies by X-ray diffraction, infrared spectroscopy and thermal analysis show that the raw Nador bentonite is a type of montmorillonite [14]. The clay samples were separately subjected to crushing, grinding and dry sieving purification operations at the laboratory [15]. A stock solution of 10 g/L is prepared by dissolving the bentonite in distilled water with stirring for 24 h. The coagulant used is aluminum sulfate. A stock solution of 10 g/L is prepared periodically by dissolving the aluminum sulfate [$Al_2(SO_4)_3$ $18(H_2O)$] in distilled water.

2.3. Physicochemical analysis

A sample of raw water fed to the station is taken at the level of the distribution structure. Several parameters are analyzed to get a general idea about the quality of this water. Table 1 summarizes the different parameters analyzed, method and technique used.

2.4. Coagulation–flocculation test (jar test)

A coagulation–flocculation process application is performed on raw water samples using a jar test (JLT6), with six 1-L beakers and an individual rotation speed between 40 and 120 rpm, this unit allows you to mix the water at the same time.

In this study, the performance of bentonite was tested in raw water/coagulant and coagulant/bentonite mixtures. The purpose of the tests is to determine the optimal doses of coagulant and bentonite to clarify the water in the treatment plant.

In this case, in order to determine the optimal dose of coagulant, the coagulant was introduced into the sample of raw water studied in different amounts increasing from 30 to 80 mg/L, taking into consideration the study performed by Hecini and Achour [16] who found an optimal

Fig. 1. Geographical situation of the Ait Baha treatment plant and the Ahl-Souss dam.

Table 1
Methods and techniques used for the chemical characterization of raw water

Parameter	Method and technique
pH	Electrometric measurement (Hach HQ40d Dual-Input Multiparameter)
Turbidity, NTU	Nephelometry (turbidity meters Turb 430 IR)
Conductivity, ms cm^{-1}	Electrical conductivity (Hach HQ40d Dual-Input Multiparameter)
Oxidation, $mg(O_2)\ L^{-1}$	Hot acid oxidation by $KMnO_4$
Dissolved oxygen, mg L^{-1}	Odometry (Winkler Method)
Nitrate, mg L^{-1}	Molecular absorption spectrometry
Ammonium, mg L^{-1}	Molecular absorption spectrometry
Chloride (Cl^-), mg L^{-1}	Determination by mercuric nitrate (Mohr method)

dose at 50 mg/L. The coagulant used is aluminum sulfate and the stirring conditions are 120 rpm for 2 min (rapid stirring) and 40 rpm for 20 min (slow stirring) and 30 min decantation.

Numerous studies have shown that turbidity increases with the concentration of bentonite, so the pH increases in parallel with the concentration [13,17,18]. Regarding the optimal dose of coagulant and bentonite which corresponds to the lowest value of turbidity, they found an average value of 65 mg/L of coagulant with 1 g/L of bentonite. This study aims to improve the quality of these waters to an acceptable level taking into account the standards.

Using jar test assays to determine optimal doses of coagulant and adjuvant, for aluminum sulfate/bentonite mixing tests, the adjuvant dose (bentonite) was fixed in each test with an increasing dose of coagulant, to determine the adjuvant dose that gives good elimination performance turbidity and minimize the optimal dose of coagulant.

3. Results and discussion

3.1. Characterization of the water supplying Ait Baha station

The Ait Baha drinking water station is fed by surface water from the Ahl-Souss dam, two operational sluices. The analysis of the physicochemical parameters of the water supplying the treatment station gave the results which are summarized in Table 2 as follows:

According to the analyzes carried out, the following points on the quality of the water studied were noticed: (i) rate of organic matter quite important following the algal proliferation at the level of the reservoir; (ii) A pH value that varies with the season; it increases as it approaches the summer period; (iii) Very low turbidity which makes the removal of colloids by settling more difficult.

3.2. Influence of the dose of aluminum sulfate alone

The jar test was carried out on raw Ahl-Souss Dam water. The test is performed with aluminum sulfate to determine the optimal dose of coagulant. After 30 min a certain amount of water decanted was taken while avoiding a possible resuspension of the floc to determine the various parameters most influenced.

From the results of Table 3 obtained during the coagulation–flocculation test; it is noted that the pH decrease with the increase of the dose of aluminum sulfate, because when using the latter, the Al^{3+} ions bind with the ions $3OH^-$ from the bicarbonates to go to the state $Al(OH)_3$, protons H^+ are released in the medium and the pH is lowered accordingly.

According to the results obtained, it is noted that the turbidity and the organic matter decrease with the increase of the dose of aluminum sulfate. This is predicted by the works of literature [5,19]. We can notice the amount of coagulant necessary to have a good coagulation whose values of quality parameters (turbidity, oxidability, aluminum, etc.) respecting the standards of purification.

Table 2
Results of raw water analyzes in the station

Parameters	Raw water			
	Sampling 1	Sampling 2	Sampling 3	Average
Temperature, °C	12.00	15.00	17.10	14.70
pH	7.42	7.71	7.90	7.67
Turbidity, NTU	3.24	4.29	2.60	3.38
Conductivity, µs/cm	112.00	200.00	122.00	144.67
Oxidability, mg (O_2)/L	4.00	6.50	5.50	5.33
O_2 dissous, mg (O_2)/L	5.50	6.00	5.80	5.77
Nitrite, mg/L	0.02	0.01	0.01	0.01
Ammonium, mg/L	0.55	0.50	0.40	0.48
Chloride, mg/L	18.46	26.98	21.30	22.25

Table 3
Coagulation–flocculation test results by aluminum sulfate

Parameters		Raw water	Injected dose of aluminum sulfate (mg/L)					
			30	40	50	60	70	80
Time (of appearance of the flocks)		–	90s	90s	60s	**60s**	30s	30s
Floc appearance		–	06	06	06	**06**	08	08
Cl_2 residual (mg/L)		0.00	1.1	1.1	1.1	**1.1**	1.1	1.1
pH		7.90	7.75	7.60	7.52	**7.42**	7.29	7.12
Turbidity	Decanted water	3.12	0.90	0.83	0.72	**0.61**	0.50	0.33
	Filtered water		0.38	0.33	0.25	**0.20**	0.22	0.10
Turbidity removal efficiency %		–	87.82	89.42	91.98	**93.58**	92.94	96.67
Oxydability (At $KMnO_4$)		5.0	2.90	2.4	2.00	**1.7**	1.45	1.4
Elimination yield of the ox. material %		–	42	52	60	**66**	71	72
Aluminium		0.00	0.35	0.25	0.20	**0.18**	0.15	0.10

The analysis of the appearance of the flocks and their settling speed shows the incorrect settling of flocs formed with low doses. The appearance of the flocs becomes better with the increase of the dose of aluminum sulfate.

Also, good water quality is observed for all doses with respect to turbidity and oxidability. The parameter that makes the difference between the doses and allows choosing the optimal dose is aluminum. Then the optimal dose of aluminum sulfate is 60 mg/L because it is the point where the curve is less than 0.2 mg/L in aluminum.

3.3. Influence of bentonite doses on the coagulation-flocculation process

The jar test was carried out on raw water from Ahl-Souss Dam. The test is carried out with aluminum sulfate and bentonite to determine the optimum dose of the adjuvant that ensures the proper treatment. After 30 min a certain amount of water decanted was taken while avoiding a possible resuspension of the floc to determine the various parameters most influenced.

The set of results obtained during coupling coagulation tests coagulant/adjuvant, gives us the variation of the parameters (turbidity, oxidability, pH, etc.) according to the different doses of aluminum sulfate and bentonite added. Through these graphs we can see the dose of bentonite needed to have good coagulation. The dose of bentonite is fixed in each test, the dose of aluminum sulfate varies from 30 to 80 mg/L. The results obtained are shown in Table 4, and Figs. 2 and 3.

The interpretation of this clarification with the coagulant/adjuvant coupling is done in this case by comparison with the first clarification test (the use of aluminum sulfate alone) which gave the optimal dose at 60 mg/L that

Table 4
Results of the treatment test performed using aluminum sulfate and bentonite

Dose of bentonite	Dose of AS	pH	Tur.		Tur. rate	Al	Ox.	Ox. rate
			DW	FW				
10 mg/L	0.00 (R.W)	7.80	3.50		0.00	0.00	6.00	0.00
	30	7.56	0.48	0.14	86.28	0.15	2.08	65.33
	40	7.52	0.32	0.17	90.85	0.14	2	66.66
	50	**7.42**	**0.30**	**0.12**	**91.42**	**0.12**	**1.5**	**75**
	60	7.32	0.13	0.10	96.28	0.10	1.12	81.33
	70	7.23	0.26	0.12	92.57	0.08	1.04	82.66
	80	7.11	0.31	0.04	91.14	0.08	1.6	73.33
20 mg/L	0.00 (R.W)	8.02	3.66		0.00	0.00	4.00	0.00
	30	7.50	0.23	0.16	93.71	0.20	2.4	40
	40	7.43	0.20	0.16	94.53	0.18	2.16	46
	50	**7.26**	**0.14**	**0.10**	**96.17**	**0.16**	**1.75**	**56.25**
	60	7.24	0.12	0.09	96.72	0.14	1.6	60
	70	7.20	0.14	0.13	96.17	0.12	2.16	46
	80	7.15	0.10	0.10	97.26	0.11	2.16	46
30 mg/L	0.00 (R.W)	8.00	3.17		0.00	0.00	3.76	0.00
	30	7.65	0.80	0.29	74.76	0.18	2,08	44.68
	40	7.46	0.68	0.18	78.54	0.15	2,08	44.68
	50	7.34	0.52	0.11	83.59	0.13	2	46.80
	60	7.25	0.51	0.07	83.91	0.12	2	46.80
	70	**7.17**	**0.31**	**0.09**	**90.22**	**0.12**	**1,76**	**53.19**
	80	7.12	0.30	0.09	90.53	0.12	1,52	59.57
40 mg/L	0.00 (R.W)	7.90	3.00		0.00	0.00	4.00	0.00
	30	7.79	0.94	0.19	68.66	0.19	2,88	28
	40	7.69	0.72	0.16	76	0.17	2,4	40
	50	7.50	0.66	0.12	78	0.14	2,32	42
	60	7.48	0.50	0.09	83.33	0.12	2,14	46.5
	70	**7.45**	**0.58**	**0.05**	**80.66**	**0.12**	**1,84**	**54**
	80	7.39	0.76	0.13	74.66	0.10	2,64	34

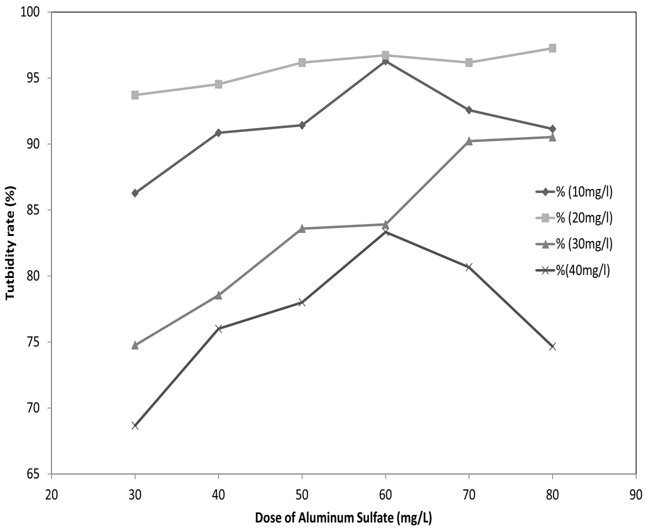

Fig. 2. Evolution of the rate of elimination of turbidity as a function of AS dose.

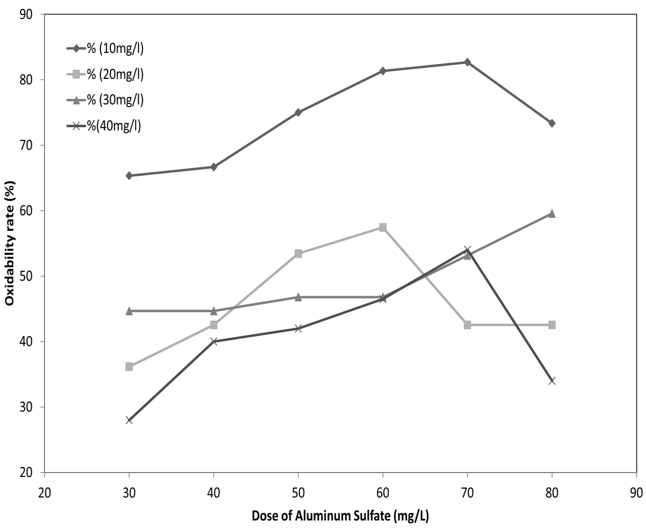

Fig. 3. Evolution of the rate of elimination of the oxidizable material as a function of AS dose.

means the optimal coupling dose which must be chosen, is obliged to be less than 60 mg/L to have an optimization of the dose of coagulant by the adjuvant dose.

From the results obtained, it was found that the addition of bentonite in parallel with aluminum sulfate significantly increases the rate of elimination of turbidity for all doses, and for the oxidized material, it is noted that only the dose of 10 mg/L gave good results. And it is interesting to note that this coagulant/adjuvant combination also makes it possible to improve the appearance of the flocks and their consequent eliminations with a fast settling speed.

Bentonite has a low negative charge, in which the flocks are grouped together to produce larger, heavier, and stronger flocs that decant faster. Furthermore, bentonite-based hydrophobic media has the capacity to absorb up to 60% of its weight in organic contaminants [20,21].

It is thus noted that the comparison of the curves of Figs. 2 and 3, show that the doses of 10 and 20 mg/L are the most effective, they, respectively, lead to a reduction of 96.28% and 96.72% of the turbidity and 81.33% and 60% of the oxidizable material, this compared with the results found using aluminum sulfate alone.

According to comparable studies, on the effectiveness of concentration of bentonite on the quality of coagulation–flocculation; the turbidity increases with the concentration of bentonite, so the pH increases in parallel with the concentration [22,23].

Beyond these two adjuvant values (10 and 20 mg/L), non-standard parameters of potabilization are obtained, a dose greater than 60 mg/L of coagulant is given, for example, test number three and four (30 and 40 mg/L of bentonite) have better qualities at the dose of 80 and 70 mg/L of aluminum sulfate, respectively.

The aluminum sulfate alone test gave an acceptable amount of aluminum in the treated water from the 60 mg/L dose. On the other hand, when the bentonite is added to the sulfate of aluminum, the quantity of aluminum in the treated water has been reduced from 30 mg/L. Increasing the dose of bentonite reduces pH and aluminum sulfate alone, which gives an optimal pH of coagulation–flocculation and makes the appearance of the floc bigger and heavier.

4. Conclusion

The present research had two main objectives, the first is the study of the influence of bentonite on the elimination of turbidity and oxidizable matter in the raw water studied. The second objective of this research is to optimize the optimal dose of coagulant used.

The characterization of the raw water supplying the Ait Baha station shows that this water contains a low turbidity (2.60 NTU). It is characterized by a low alkalinity (2°f) and a pH slightly neutral (7.40) with a high content of organic matter (6.5 mg(O_2)/L). The coagulation–flocculation study with aluminum sulfate makes it possible to determine the optimal dose of coagulant (60 mg/L) to have a good coagulation whose values of the quality parameters (turbidity, pH, oxidation, aluminum) respect the drinking water standards.

With regard to the coagulation–flocculation study with aluminum sulfate/bentonite coupling, it has been shown that 96.72% of the turbidity can be eliminated with a dose of 20 mg/L of bentonite and 60% of the oxidizable material. Beyond this dose (20 mg/L), we obtain non-standard parameters of potabilization. Also the increase of the dose of bentonite decreases the pH, more than the use of aluminum sulfate alone, that make the water pH optimal for coagulation–flocculation, as a result of the formation of very heavy flocs with a bigger appearance.

Acknowledgments

The authors wish to thank ELQOUQI Said Chef du secteur de la production Agadir, Taroudant, Tiznit, Ait Baha, OURRAIS Abdellah Chef de la station de traitement Ait-Baha, Morocco, for their support during the realization of the research.

References

[1] A. Koohestanian, M. Hosseini, Z. Abbasian, The separation method for removing of colloidal particles from raw water, American-Eurasian J. Agric. Environ. Sci., 4 (2008) 266–273.

[2] A. Bazer-Bachi, E. Puech-Coste, R. Ben Aim, J. L. Probst, Mathematical modeling of optimal coagulant dose in water treatment plant, Revue des Sciences de l'Eau, 3 (1990) 377–397.

[3] T.K.F.S. Freitas, V.M. Oliveira, M.T.F. De Souza, H.C.L. Geraldino, V.C. Almeida, S.L. Favaro, J.C Garcia, Optimization of coagulation-flocculation process for treatment of industrial textile wastewater using okra (*A. esculentus*) mucilage as natural coagulant, Ind. Crops Prod., 76 (2015) 538–544.

[4] Y. Wei, X. Dong, A. Ding, D. Xie, Characterization and coagulation-flocculation behavior of an inorganic polymer coagulant-poly-ferric-zinc-sulfate, J. Taiwan Inst. Chem. Eng., 58 (2016) 351–356.

[5] F. Fiessinger, J.L. Bersillon, Prépolymérisation de l'hydroxyde d'aluminium pour la coagulation des eaux, Tribune du Cebedeau, 399 (1977) 51–68.

[6] M. Jansson-Chariuer, E. Guibal, J. Roussy, B. Delanghe, P. Le Cloirec, Vanadium (IV) sorption by chitosan: kinetics and equilibrium, Water Res., 30 (1995) 465–475.

[7] E. Assaad, A. Azzouz, D. Nistor, A.V. Ursu, T. Sajin, D.N. Miron, F. Monette, P. Niquette, R. Hausler, Metal removal through synergic coagulation-flocculation using an optimized chitosan–montmorillonite system, Appl. Clay Sci., 37 (2007) 258–274.

[8] K.E. Lee, N. Morad, T. Teng, B.T. Poh, Development, characterization and the application of hybrid materials, in coagulation/flocculation of wastewater: a review, Chem. Eng. J., 203 (2012) 370–386.

[9] E. Ofir, Y. Oren, A. Adin, Comparing pretreatment by iron of electro-flocculation and chemical flocculation, Desalination, 204 (2007) 87–93.

[10] V. Tomar, Dinesh Kumar, A critical study on efficiency of different materials for fluoride removal from aqueous media, Chem. Cent. J., 7 (2013) 51–66.

[11] B. Akbar, A. Daryabeigi Zand, N. Mehrdadi, A. Karbassi, Optimizing coagulation process for low to high turbidity waters using aluminum and iron salts, Am. J. Environ. Sci., 6 (2010) 442–448.

[12] N. Levy, S. Magdassi, Y. Bar-Or, Physico-chemical aspects in flocculation of bentonite suspensions by a cyanobacterial bioflocculant, Water Res., 26 (1992) 249–254.

[13] A. Syafalni, Rohana, I. Abustan, A.N.M. Ibrahim, Wastewater treatment using bentonite, the combinations of bentonite-zeolite, bentonite-alum, and bentonite-limestone as adsorbent and coagulant, Int. J. Environ. Sci., 4 (2013) 379–391.

[14] M. El Miz, H. Akichoh, D. Berraaouan, S. Salhi, A. Tahani, Chemical and physical characterization of Moroccan bentonite taken from Nador, Am. J. Chem., 7 (2017) 105–112.

[15] Z. Zhongguo, L. Dan, H. Dandan, L. Duo, R. Xiaojing, C. Yanjun, L. Zhaokun, Effects of slow-mixing on the coagulation performance of polyaluminum chloride, Chin. J. Chem. Eng., 21 (2013) 318–323.

[16] L. Hecini, S. Achour, Coagulation-flocculation by aluminum sulfate of organic phenolic compounds and effect of calcium and magnesium salts, J. Water Sci., 27 (2017) 271–280.

[17] J. León-Luque, C.L. Barajas, C.A. Peña-Guzmán, Determination of the optimal dosage of aluminum sulfate in the coagulation-flocculation process using an artificial neural network, Int. J. Environ. Sci. Dev., 7 (2016) 346–350.

[18] G. Apostol, R. Kouachi, I. Constantinescu, Optimization of coagulation-flocculation process with aluminum sulfate based on response surface methodology, U.P.B. Sci. Bull., Series B, 73 (2011) 77–84.

[19] M. Benaichata, A. Boukerroui, M. Assouli, Coagulation flocculation test of djorf torba's water dam using clay and lime: a comparative study, Larhyss J., 28 (2016) 39–53.

[20] Q.H. Hu, F. Qiao, S.Z. Haghseresht, M.A. Wilson, G.Q. Lu, Adsorption study for removal of basic red dye using bentonite, Ind. Eng. Chem. Res., 45 (2006) 733–738.

[21] B. Healy, Colloid Environmental Technology Company Arlington Heights, Illinois. Surface Modified Clay: An Innovative Technology for Groundwater Remediation, 2010. Available from: http://info.ugwa.org/gwol/pdf/930158293.PDF.

[22] F. Sher, A. Malik, H. Liu, Industrial polymer effluent treatment by chemical coagulation and flocculation, J. Environ. Chem. Eng., 1 (2013) 684–689.

[23] S. Syafalni, I. Abustan, F. Zakaria, M. Zawawi, R. Abd Rahim, Raw water treatment using bentonite-chitosan as a coagulant, Water Supply, 12 (2012) 480–488.