

EFFECT OF FLOCCULATION-ADSORPTION COMBINATION ON THE PURIFICATION OF SURFACE WATER: A CASE STUDY OF SIDYACOUB DAM WATER, ALGERIA

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ABSTRACT

An increase in the amount of Natural organic matter (NOM) was observed over the last 10 to 20 years in raw water supplies, which has a significant effect on the treatment of drinking water. The most common and most profitable disposal methods of the NOM are coagulation and flocculation followed by sedimentation and sand filtration. Nevertheless, there are some organic compounds, which cannot be removed completely in a coagulation step. An alternative for better elimination of NOM was studied in this work. The use of adsorbents such as activated carbon and bentonite as additives for flocculation significantly reduced the organic matter content.

KEY WORDS : Aluminum sulphate, Bentonite, Coagulation-flocculation, Powdered activated carbon, Turbidity

INTRODUCTION

Natural organic matter (NOM) is defined as a complex matrix of organic matter in natural waters (Matilainen *et al.*, 2010; Papageorgiou *et al.*, 2016). Aquatic NOM consists of a wide variety of organic compounds which are primarily derived from the plants residue and animals decomposition (Summers and Roberts, 1988; Joseph *et al.*, 2012; Papageorgiou *et al.*, 2016). In addition to this, a recent study showed that the concentrations of NOM have increased over the past decade in many rivers, including drinking water sources (Hruška *et al.*, 2009). As a result, the water sources used for drinking water production usually contain NOM (Matilainen *et al.*, 2010).

The presence of NOM in various sources of water is a major concern for scientists and environmental engineers, especially in the treatment of water (Kozyatnik *et al.*, 2010; Khaouane *et al.*, 2017). The NOM often contributes to unpleasant taste and odors in potential sources of drinking water (Matilainen *et al.*, 2005; Yan *et al.*, 2008; Zhan *et al.*,

2010; John C. Crittenden, 2012; Joseph *et al.*, 2012) and acts as a support for metals and various harmful organic chemicals (Jacangelo *et al.*, 1995). In addition, NOM can disrupt various processes in a conventional water treatment installation (Joseph *et al.*, 2012; Ivanèev-Tumbas, 2014). It affects floc formation during the coagulation process, which often generates small flakes (Parsons *et al.*, 2004). NOM is considered a precursor of by-products of the carcinogenic disinfection such as trihalomethanes and haloacetic acids that can be formed during chlorination (Rook, 1977; Weinberg *et al.*, 2002; Singer, 2006; Chowdhury *et al.*, 2009; American Water Works Association, 2011; Kristiana *et al.*, 2011; Mahdavi *et al.*, 2017) and contribute to bacterial regrowth and biofilm formation in water distribution networks (Jacangelo *et al.*, 1995; Lu and Chu, 2005; Qaiser *et al.*, 2014).

The removal of organic matter from aqueous environment has been widely studied (Choo *et al.*, 2008) and the development of technologies for the removal of NOM from water is of great importance (Wang *et al.*, 2011; Mahdavi *et al.*, 2017).

Conventional water treatment processes are mainly composed of coagulation, sedimentation and filtration by gravity. Coagulation is an essential process for the removal of various particles and organic matter (Tomaszewska *et al.*, 2004; Zouboulis *et al.*, 2007; Zhan *et al.*, 2010; Mahdavi *et al.*, 2017). Nevertheless, there are some organic compounds, which cannot be removed completely in a coagulation step (Zhan *et al.*, 2010). In addition, conventional treatment processes are primarily designed for the reduction of turbidity and inactivation of pathogenic microorganisms (Parsons *et al.*, 2004). These processes are regularly faced with difficult water conditions so that the removal of the NOM may be compromised (Jarvis *et al.*, 2005).

In such cases, other methods are required (Zhan *et al.*, 2010). The adsorption on activated carbon and anion exchange are two recommended technologies for the removal of the NOM from water (Graf *et al.*, 2014). A wide variety of adsorbents were studied to eliminate NOM from water, including activated carbon (Bjelopavlic *et al.*, 1999), as well as some new nanoparticles such as carbon nanotubes (Lu and Su, 2007). The use of activated carbon as adsorbent is an effective method to eliminate NOM and has been widespread used (Najm *et al.*, 1998; Jarvis *et al.*, 2005).

The further development of the adsorbents was studied. Many researchers have used materials such as cane bagasse, peanut shell, apple pomace, wheat straw, sawdust, coconut, orange zest, soft banana and pine bark, as adsorbents to remove dyes, heavy metals, nitrate, etc ... (Zhan *et al.*, 2010). These materials showed a good adsorption capacity for different dyes organic acids (Orlando *et al.*, 2002).

Experimental procedures carried on combined treatment (coagulation and adsorption) have shown that this technique can be effective in eliminating NOM from various types of water sources as well as the elimination of other organic contaminants from potential sources of drinking water, and also acts on improving the settling of flocs formed (Zhan *et al.*, 2010; Joseph *et al.*, 2012). Removal percentages obtained with the process of combined treatment vary from 45 to 80% (Najm *et al.*, 1998; Uyak *et al.*, 2007; Álvarez-Uriarte *et al.*, 2010).

In Algeria, the city of Chlef supplies drinking water primarily from a conventional treatment plant which proceeds in the following stages: pre-chlorination, coagulation, flocculation, sedimentation, gravity filtration through granular bed, and disinfection. Yet a growing number of

consumers prefer drinking spring water delivered by tankers or bottled water. The reasons for this are mainly aesthetic and closely related to tastes and smells. Tests carried on water for consumption showed the presence of significant amounts of organic matter.

This work focuses on improving the quality of feed water from the city of Chlef, through a combination of coagulation with aluminum sulphate and adsorption by one of the two materials, activated carbon and bentonite.

Water samples were taken on arrival at the station throughout the study period and transported to the analytical laboratory. Some measurements were taken on site.

MATERIALS AND METHODS

Quality of the raw water

Waters object of this study were extracted on arrival at the treatment plant to provide a range of physical and chemical characteristics of the raw water. Turbidity, pH, electrical conductivity, mineralization, nitrogen compounds, chemical oxygen demand, absorbance UV_{254} , total organic carbon (TOC) and oxidizability to $KMnO_4$ in water were measured (Table 1).

Table 1. Summary of physico - chemical quality parameters of the raw water from the dam at the time of the experiment

Parameter	unit	Max - Min
Turbidity	NTU	75.4-7.88
pH	-	8.30 - 7.25
Electric Conductivity	$\mu\text{s/cm}$	1520 - 1184
TDS	mg/l	1394 - 1193
NO_3^-	mg/l	2 - 0
NH_4^+	mg/l	0.1 - 0
COD	mg O_2 /l	68.0-13.0
absorbance UV_{254}	cm^{-1}	1.847 -0.308
SUVA	l/m.mg C	3.81 - 2.55
Oxidizability to $KMnO_4$	mg O_2 /l	47.0-9.0

SUVA is the ratio of the UV absorbance at 254 nm to the total organic carbon (TOC) content of the sample (Rodier, 2009; American Water Works Association, 2011; Klymenko *et al.*, 2014). Water with high SUVA values of 4 or greater indicate that the NOM is composed mainly of aquatic humic matter. Raw waters with SUVA of 2 to 4 contain a mixture of aquatic humic matter and non-humic NOM. Raw waters with $SUVA < 2$ contain mainly non-humic

material (American Water Works Association, 2011).

Preparation of Solutions

The aluminum sulphate stock solution 10 g/l of $Al_2(SO_4)_3 \cdot 18H_2O$, was prepared from powdered commercial aluminum sulphate, used for water treatment. This solution is produced by adding 10g of aluminum sulphate to 1 liter of ultrapure deionized water, and stirred for overnight. The solution was renewed and stored in the refrigerator for the duration of the study.

The adsorbents used, powdered activated carbon (inert microporous carbon, trademark Fluka, where 75% of the particles have diameters ≤ 40 μm) and bentonite (pretreated local powder gray clay) were prepared from adding 100 mg of each adsorbent in 1000 ml of deionized water and stirring the solution on a magnetic stirrer at 600 rotations per minute (r.p.m).

Analytical Methods

General parameters of water quality

The sampled pH was measured using a pH-meter with a combination pH-electrode (WTW pH inoLab LEVEL1). The calibration was performed with two buffer solutions having respectively a pH of 6.86 and pH 9.18. A Turbid-meter (2100N model Hach) was used for a direct reading of the turbidity of a sample in nephelometric turbidity unit (NTU).

The electrical conductivity was measured by means of conductivity meter (salt meter conductivity meter LF 197) that measures directly micro Siemens/centimeter ($\mu s/cm$). We also use the conductivity meter to measure the sum solids dissolved in water (TDS). The determination of the nitrogen compounds were carried out by the molecular absorption spectrometric method (Rodier, 2009).

Measuring the organic material was evaluated on the basis of the oxidizability to potassium permanganate ($KMnO_4$) which consists of a hot-chemical oxidation in an acid medium (Rodier, 2009), absorbance UV_{254} analyzed using 9200UV/VS Spectrophotometer, TOC was determined by BioTector B7000-HACH and the chemical demand of oxygen (COD) using the reflux method in an open system. Some matters contained in the water oxidize to 150 °C boiling due to an excess of potassium dichromate in an acidic medium (Rodier, 2009).

Jar test

A "JAR TEST pro LABO" variable speed, with six

flat blades agitator was used and which results in six beakers 01 liter of water to be examined, strictly identical and adjustable stirring during the same duration through a central control.

During the experiments, the raw water and coagulant are subjected for 2 min at rapid stirring to 170 r.p.m. The speed is subsequently reduced to 40 r.p.m for a period of 20 min. After, a 30 min settling (a phase during which destabilized floc is driven towards the bottom of the beaker).

Afterwards, a sample was taken from each beaker for measurements and subsequent trials. The turbidity measurement is made on the water surface fringe at 2 cm.

RESULTS AND DISCUSSION

Coagulation treatment without additives

Three jar tests with aluminum sulphate alone were carried out on raw water arriving at the SidiYacoub treatment plant for different periods of time. The results of the measurement of Turbidity, COD, UV_{254} and oxidizability to $KMnO_4$ before and after treatment are shown in Table 2 and presented in Figures 1 and 2.

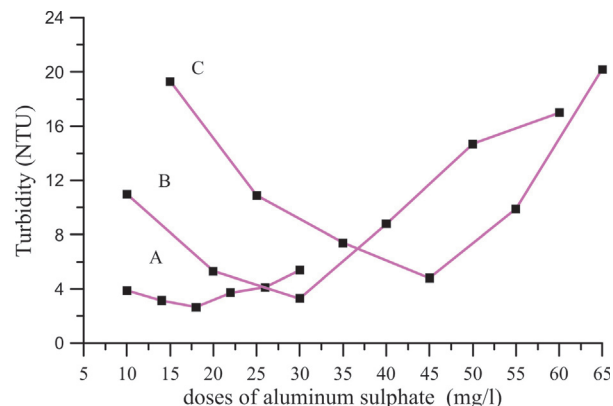


Fig. 1. Turbidity variation according to the aluminum sulphate dose (A : Trial 1 , B : Trial 2 , C : Trial 3)

La Figure 1 montre l'effet de la dose de sulfate d'aluminium sur le traitement de l'eau. Une élimination maximale de la turbidité est obtenue pour différentes doses de sulfate d'aluminium. Turbidity is reduced with increasing dose of flocculant, reaching a minimum where the removal rate reaches 66.24%, 83.50 and 85.50% for the three respective trials. Beyond that it increases, because of exceeding the corresponding optimal dose.

The measure of oxidability to $KMnO_4$ and COD

Table 2. Results of coagulation treatment alone with Aluminium Sulphate

Trial N°	Turbidity		Natural organic matter (NOM)					
	R. W.	T. W.	COD (mg O ₂ /L)		UV ₂₅₄ (cm ⁻¹)		Oxidizability to KMnO ₄ (mg O ₂ /L)	
			R. W.	T. W.	R. W.	T. W.	R. W.	T. W.
1	7.88	2.66	25.0	19.0	0.677	0.545	16.2	11.3
2	20.0	3.3	35.0	24.5	0.935	0.733	22.0	17.5
3	33.1	4.8	43.5	31.0	1,202	0,841	28.0	21.4

R. W. : Raw water ; T.W.: Treated water

expresses the content of dissolved organic matter. The UV₂₅₄ absorbance makes it possible to characterize the presence of organic molecules (aromatic nuclei in particular) which absorb ultraviolet light (Figure 2).

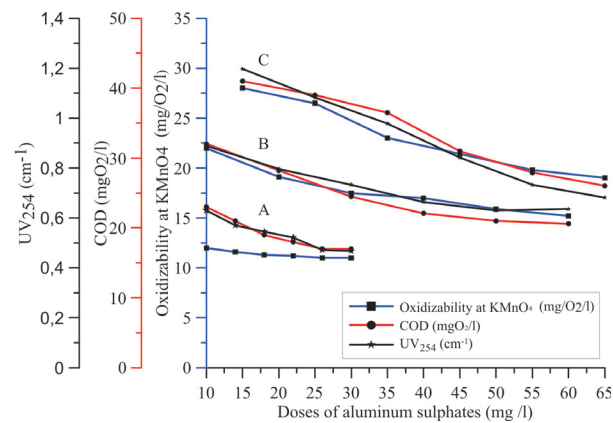


Fig. 2. Variation of the oxidizability to KMnO₄, COD and UV₂₅₄ according to aluminum sulphate dose (A : Trial 1, B : Trial 2, C : Trial 3)

These three parameters follow similar paces and show a slight decrease as a function of the dose of aluminum sulphate. They were reduced with rates ranging from 20 to 30% depending on the maximum reduction in turbidity.

It is thus noted that the results of the measurements show that there is a strong correlation between the COD, UV₂₅₄ and the oxidizability to KMnO₄ in the treated water.

Finally, we deduce that the coagulation-flocculation process with aluminum sulphate achieves a good performance turbidity removal but still not enough to reduce organic matter.

Combined coagulation and adsorption using activated carbon and bentonite for NOM removal

Raw water samples taken regularly during the study period are first subjected to coagulation tests with aluminum sulphate, and then to coagulation

treatments associated with adsorption: after having optimized the dose of coagulant for each sample following the jar test protocol, a second jar test is performed in order to determine the optimal dose of the adsorbent.

The results obtained are shown in Table 3.

Turbidity elimination rate by coagulation associated with adsorption

The evolution of the turbidity is practically identical for the two adsorbents: By using the coagulant alone, the turbidity of the raw water has been considerably reduced. Levels ranging from 75.74 to 86.73% are recorded depending on the increase in the dose of the coagulant. After the addition of the adsorbents, a marked increase in the turbidity removal rates was observed for both adjuvants which reached 12.43%, except that the lowest turbidity after treatment was obtained for lower doses of activated carbon and this for all the tests carried out (Figures 3 and 4).

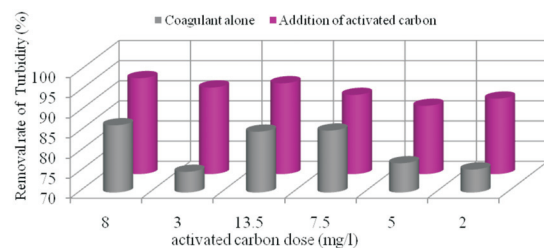


Fig. 3. Variation of the rate of elimination of turbidity as a function of the dose of activated carbon.

NOM elimination rate by coagulation associated with adsorption

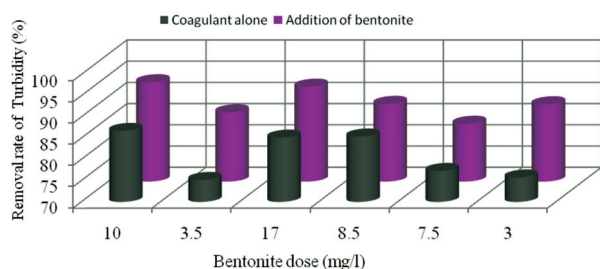
Activated carbon Employment

Figure 5 shows NOM removal rates as a function of activated carbon doses associated with aluminum sulfate coagulation.

The test jars used resulted in doses of activated carbon varying between 2 and 13.5 mg/l, depending

Table 3. NOM removal and turbidity from various dam water samples using coagulation and combined adsorption using activated carbon and bentonite.

Samples			1	2	3	4	5	6			
Raw water	Turbidity		NTU	63.3	15.3	75.4	28.1	20.7	16.9		
	COD		mg O ₂ /l	44.0	17.5	68.0	36.5	32.0	13.0		
	absorbance UV ₂₅₄		cm ⁻¹	1.314	0.543	1.847	0.988	0.781	0.308		
	Oxidizability to KMnO ₄		mg O ₂ /l	30.0	11.5	47.0	28.0	24.5	9.0		
	SUVA		l/mg.m	-	3.81	-	-	2.9	2.55		
Treated water	first jar test	Optimal dose of Al. S.		mg/l	40	20	45	30	25	16	
		Optimal Turbidity		NTU	8.4	3.8	11.2	4.1	4.7	4.1	
		SUVA		l/mg.m	-	3.76	-	-	2.78	2.33	
	second Jar test	Association of activated carbon		optimal dose of activated carbon	mg/l	8	3	13.5	7.5	5	2
		Association of Bentonite		optimal dose of bentonite	mg/l	10	3.5	17	8.5	7.5	3
		COD		mg O ₂ /l	11	6.5	15	9.5	11	5.5	
		absorbance UV ₂₅₄		cm ⁻¹	0.381	0.218	0.419	0.301	0.285	0.130	
		Oxidizability to KMnO ₄		mg O ₂ /l	9.0	4.6	12.2	9.0	9.8	4.1	
		SUVA		l/mg.m	-	2.66	-	-	2.11	2.09	
		Turbidity		NTU	3.9	1.3	5.6	2.9	2.7	1.9	
		COD		mg O ₂ /l	16.28	8.40	22.44	14.24	12.80	6.76	
		absorbance UV ₂₅₄		cm ⁻¹	0.533	0.270	0.583	0.450	0.367	0.169	
		Oxidizability to KMnO ₄		mg O ₂ /l	12.6	6.2	16.9	13.4	11.8	5.0	
		SUVA		l/mg.m	-	2.9	-	-	2.3	2.18	
		Turbidity		NTU	4.2	2.1	5.8	3.3	3.4	2.0	

**Fig. 4.** Variation of the rate of elimination of turbidity as a function of the dose of bentonite.

on the amount of organic matter in the raw water. By going further from optimal doses, the elimination of NOM is reduced due to desorption.

The combined technique of coagulation-adsorption with activated carbon led to a considerable elimination of NOM with rates ranging from 55 to 78%.

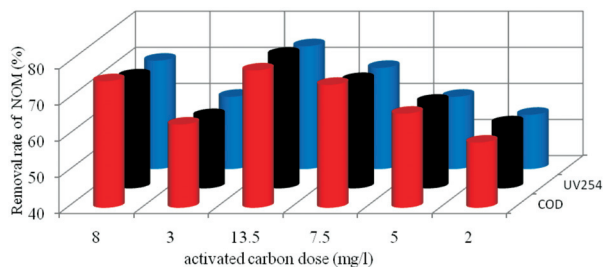
Slight increases in NOM elimination with increasing doses of activated carbon were observed.

The bentonite Employment

Figure 6 shows NOM removal rates as a function of bentonite doses associated with aluminum sulfate coagulation.

The test jars used resulted in doses of bentonite varying between 3 and 17 mg/l.

The NOM removal percentages were low in this case. They vary between 44 and 67%. Likewise, an increased rate of NOM removal was observed with increasing doses of bentonite.

**Fig. 5.** Variation in the rate of NOM elimination depending on the dose of activated carbon.

CONCLUSION

Experimental procedures were performed to investigate the individual use and the one associated with coagulation adsorption, in order to assess the effectiveness in improving the produced water quality by the drinking water station of Chlef (Algeria) and mainly on the elimination of NOM.

It was found that both treatment methods have high removal efficiency of turbidity (66.24 to 86.73 % in the individual employment and 86.96 to 93.84 % through the associated use with the activated carbon and 83.57 to 93.36 % with Bentonite). This also indicates that the combination of coagulation and adsorption can enhance the removal of the turbidity of the treated water and also acts on the improvement of the flocs formed settling.

In terms of the organic matter removal, we find out that the reduction of the organic material during the use of the individual coagulation was only 20 to 30 %, whereas coagulation combined with the adsorption was more effective. The best results were recorded with activated carbon. The reduction of the organic material was 58 to 78% according to the COD measurement and 55 to 74 % according to the oxidizability to KMnO_4 and this for an activated carbon dosage varying from 2 to 13.5 mg/l. Nevertheless, Bentonite also improves the removal efficiency of the organic material up to 67 % as measured by COD, and 64 % compared to the oxidizability to KMnO_4 for a dose ranging from of 3 to 17 mg/l of bentonite. Beyond these values, there is desorption.

The NOM removal efficiency based on UV_{254} absorbance measurements evolved in almost a similar fashion as that of COD and oxidizability to KMnO_4 for both adsorbents used. The organic matter removal rates were 58 to 77% for activated carbon and 45 to 68% for bentonite.

Another important parameter describes the nature of NOM in the water sample in terms of hydrophobicity and hydrophilicity is the specific

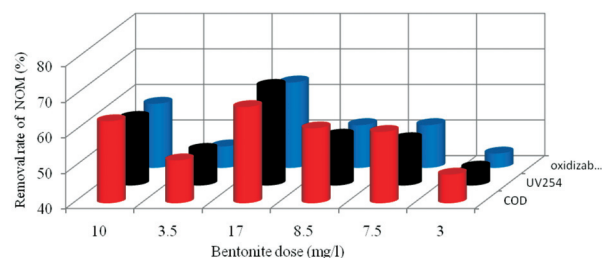


Fig. 6. Variation in the rate of NOM elimination depending on the dose of bentonite

ultraviolet absorption (SUVA). The raw water SUVA average was 3.09 l/m.mg C, reduced to 2.96 after aluminum sulphate coagulation, became 2.29 and 2.46 l/ m.mg C, after combining the activated carbon and the bentonite respectively. This indicates that the raw water was constituted of a varied mixture of hydrophobic (humic) and hydrophilic (non-humic) organic compounds. The treated water is dominated by non humic substances.

We see also a small reduction in SUVA following the coagulation treatment. This is due to the low value of SUVA of the raw water on the one hand and on the other hand; because water treatment processes such as coagulation and adsorption will preferentially suppress aquatic humic matter.

It is also interesting to note that in this study, activated carbon has somewhat higher affinities for hydrophobic humic substances compared to bentonite.

Finally, the combination treatment with activated carbon showed a considerable improvement in the treatment effectiveness. The use of adsorbents characterized by clay properties, such as bentonite, may also be an attractive solution to replace the carbon if required.

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REFERENCES

- Álvarez-Uriarte, J. I., Iriarte-Velasco, U., Chimenó-Alanís, N. and González-Velasco, J. R. 2010. The effect of mixed oxidants and powdered activated carbon on the removal of natural organic matter. *Journal of Hazardous Materials*. 181(1-3) : 426-431.
- American Water Works Association. 2011. *WATER QUALITY & TREATMENT: A handbook on Drinking Water*. sixth Edit. Edited by J. K. Edzwald, Colorado. Pages 218-235.
- Bjelopavlic, M., Newcombe, G. and Hayes, R. 1999. Adsorption of NOM onto activated carbon: Effect of surface charge, ionic strength, and pore volume distribution. *Journal of Colloid and Interface Science*. 210(2) : 271-280.
- Choo, K. H., Tao, R. and Kim, M. J. 2008. Use of a photocatalytic membrane reactor for the removal of natural organic matter in water: Effect of photoinduced desorption and ferrihydrite adsorption. *Journal of Membrane Science*. 322 (2):

- 368-374.
- Chowdhury, S., Champagne, P. and McLellan, P. J. 2009. Models for predicting disinfection byproduct (DBP) formation in drinking waters: A chronological review. *Science of the Total Environment*. 407(14) : 4189-4206.
- Graf, K. C., Cornwell, D. A. and Boyer, T. H. 2014. Removal of dissolved organic carbon from surface water by anion exchange and adsorption: Bench-scale testing to simulate a two-stage countercurrent process. *Separation and Purification Technology*. Elsevier B.V. 122 : 523-532.
- Hruska, J., Krařm, P., McDowell, W. H. and Oulehle, F. 2009. Increased Dissolved Organic Carbon (DOC) in central European streams is driven by reductions in ionic strength rather than climate change or decreasing acidity. *Environmental Science and Technology*. 43(12) : 4320-4326.
- Ivaněev-Tumbas, I. 2014. The fate and importance of organics in drinking water treatment: a review. *Environmental Science and Pollution Research*. 21(20) : 11794-11810.
- Jacangelo, J. G., DeMarco, J., Owen, D. M. and Randtke, S. J. 1995. Selected processes for removing NOM: An overview. *Journal / American Water Works Association*. 87(1) : 64-77.
- Jarvis, P., Jefferson, B. and Parsons, S. A. 2005. How the natural organic matter to coagulant ratio impacts on floc structural properties. *Environmental Science and Technology*. 39(22) : 8919-8924.
- John C. Crittenden, 2012. *MWH's Water Treatment: Principles and Design*. Third Edit.
- Joseph, L., Flora, J. R. V., Park, Y.-G., Badawy, M., Saleh, H. and Yoon, Y. 2012. Removal of natural organic matter from potential drinking water sources by combined coagulation and adsorption using carbon nanomaterials. *Separation and Purification Technology*. Elsevier B.V. 95 : 64-72.
- Khaouane, L., Ammi, Y. and Hanini, S. 2017. Modeling the Retention of Organic Compounds by Nanofiltration and Reverse Osmosis Membranes Using Bootstrap Aggregated Neural Networks. *Arabian Journal for Science and Engineering*. 42(4) : 1443-1453.
- Klymenko, N. A., Samsoni-Todorov, E. A. and Savchina, L. A. 2014. Raising the efficiency of coagulation treatment of the Dnieper River water. *Journal of Water Chemistry and Technology*. 36(5) : 230-236.
- Kozyatnik, I. P., Klimenko, N. A. and Savchina, L. A. 2010. The effect of water ozonation on the efficiency of extracting natural organic matter during filtration through biologically activated carbon. *Journal of Water Chemistry and Technology*. 32(3) : 139-144.
- Kristiana, I., Joll, C. and Heitz, A. 2011. Powdered activated carbon coupled with enhanced coagulation for natural organic matter removal and disinfection by-product control: Application in a Western Australian water treatment plant. *Chemosphere*. Elsevier Ltd. 83(5). pp. 661-667.
- Lu, C. and Chu, C. 2005. Effects of acetic acid on the regrowth of heterotrophic bacteria in the drinking water distribution system. *World Journal of Microbiology and Biotechnology*. 21(6-7) : 989-998.
- Lu, C. and Su, F. 2007. Adsorption of natural organic matter by carbon nanotubes. *Separation and Purification Technology*. 58(1) : 113-121.
- Mahdavi, M., Amin, M. M., Hajizadeh, Y., Farrokhzadeh, H. and Ebrahimi, A. 2017. Removal of Different NOM Fractions from Spent Filter Backwash Water by Polyaluminum Ferric Chloride and Ferric Chloride. *Arabian Journal for Science and Engineering*. 42(4) : 1497-1504.
- Matilainen, A., Lindqvist, N. and Tuhkanen, T. 2005. Comparison of the efficiency of aluminium and ferric sulphate in the removal of natural organic matter during drinking water treatment process. *Environmental Technology*. 26(8) : 867-876.
- Matilainen, A., Vepsäläinen, M. and Sillanpää, M. 2010. Natural organic matter removal by coagulation during drinking water treatment: A review. *Advances in Colloid and Interface Science*. Elsevier B.V. 159(2) : 189-197.
- Najm, I., Tate, C. and Selby, D. 1998. Optimizing enhanced coagulation with PAC: A case study. *Journal / American Water Works Association*. 90(10) : 88-95.
- Orlando, U.S., Baes, A.U., Nishijima, W. and Okada, M. 2002. A new procedure to produce lignocellulosic anion exchangers from agricultural waste materials. *Bioresource Technology*. 83(3) : 195-198.
- Papageorgiou, A., Papadakis, N. and Voutsas, D. 2016. Fate of natural organic matter at a full-scale Drinking Water Treatment Plant in Greece. *Environmental Science and Pollution Research*. 23(2) : 1841-1851.
- Parsons, S. A., Jefferson, B., Goslan, E. H., Jarvis, P. R. and Fearing, D. A. 2004. Natural organic matter - The relationship between character and treatability. *Water Science and Technology: Water Supply*. 4(5-6) : 43-48.
- Qaiser, S., Hashmi, I. and Nasir, H. 2014. Chlorination at Treatment Plant and Drinking Water Quality: A Case Study of Different Sectors of Islamabad, Pakistan. *Arabian Journal for Science and Engineering*. 39(7) : 5665-5675.
- Rodier, J. 2009. L'analyse de l'eau. 9e édition. *DUNOD (éditeur.) Paris. Fr.* p. 1600.
- Rook, J. J. 1977. Chlorination Reactions of Fulvic Acids in Natural Waters. *Environmental Science & Technology*. 2 (4).
- Singer, P. C. 2006. DBPs in drinking water: Additional scientific and policy considerations for public health protection. *Journal / American Water Works Association*. 98 (10) : 73-80.
- Summers, R. S. and Roberts, P. V. 1988. Activated

- carbon adsorption of humic substances. I. Heterodisperse mixtures and desorption. *Journal of Colloid and Interface Science*. 122(2) : 367-381.
- Tomaszewska, M., Mozia, S. and Morawski, A. W. 2004. Removal of organic matter by coagulation enhanced with adsorption on PAC. *Desalination*. 161(1) : 79-87.
- Uyak, V., Yavuz, S., Toroz, I., Ozaydin, S., and Genceli, E. A. 2007. Disinfection by-products precursors removal by enhanced coagulation and PAC adsorption. *Desalination*. 216 (1-3) : 334-344.
- Wang, H., Keller, A. A. and Clark, K. K. 2011. Natural organic matter removal by adsorption onto magnetic permanently confined micelle arrays. *Journal of Hazardous Materials*. Elsevier B.V., 194 : 156-161.
- Weinberg, H. S., Krasner, S. W., Richardson, S. D. and Thruston Jr., A. D. 2002. The Occurrence of Disinfection By- Products (DBPs) of Health Concern in Drinking Water: Results of a Nationwide DBP Occurrence Study. *National Exposure Research Laboratory*. Athens. Ga. 462p.
- Yan, M., Wang, D., Qu, J., Ni, J. and Chow, C. W. K. 2008. Enhanced coagulation for high alkalinity and micro-polluted water: The third way through coagulant optimization. *Water Research*. 42(8-9) : 2278-2286.
- Zhan, X., Gao, B., Yue, Q., Liu, B., Xu, X. and Li, Q. 2010. Removal natural organic matter by coagulation-adsorption and evaluating the serial effect through a chlorine decay model. *Journal of Hazardous Materials*. Elsevier B.V. 183(1-3) : 279-286.
- Zouboulis, A., Traskas, G. and Samaras, P. 2007. Comparison of single and dual media filtration in a full-scale drinking water treatment plant. *Desalination*. 213 (1-3) : 334-342.
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