

Use of Seawater and *Moringa Oleifera* Seeds for Turbidity Removal in Water Treatment

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Abstract

In the treatment of water purification, one of the most important unit operations is the coagulation-flocculation, because it is responsible for turbidity removal. Aqueous extracts of *Moringa oleifera* seeds prepared in saline solution have demonstrated their effectiveness in coagulation of turbid waters; however, few studies have been reported to seawater as a possible substitute of saline solution. In this work, treatability tests were carried out to verify the behavior of the seeds of *M. Oleifera* when are prepared in different solvents, such as distilled water, saline solution (1% NaCl) and seawater. A factorial design of 3³ was used in this study. The factors considered in the three (3) levels were initial turbidity of the treated samples, the type of solvent, and the coagulant doses. The results showed that the samples treated with extracts prepared with saline solution and seawater had the best removal efficiencies, especially when the initial turbidity of the water is greater than 150 NTU. Similarly, it was demonstrated that seawater is an excellent option as a solvent in the preparation of natural coagulants.

Keywords: *Moringa oleifera*, turbidity, coagulant activity, seawater.

I. INTRODUCTION

To obtain drinking water for human consumption, raw water treatment is needed. Nevertheless, one of the issues with surface water treatment is the large seasonal variation in turbidity [1]. Turbidity elimination in water is possible thanks to use of synthetic products, which are often expensive and require high doses to reduce high turbidity of raw water during rainy seasons; thus, demonstrating low profitability in conventional purification treatment [2]. On the other hand, continuous use of chemical substances in water treatment is currently being associated with public health and environmental problems [3], [4]. In contrast to synthetic coagulants, use of natural coagulants of plant origin for water purification dates to many centuries ago. It is known that *Strychnos potatorum* (Nirmali seeds) was used as a clarifier for murky river waters between the fourteenth and fifteenth

centuries BC; and in India, they were used about 4000 years ago [5]. Recent studies have shown that *Moringa oleifera* seed powder can reduce low and high turbidity values in surface waters [6] - [9]. Generally, natural coagulants are biodegradable, and their use is possible in developing countries, since they can be grown locally and have a wide effective dosage range for treatment of different colloidal suspensions in raw waters [10] without significantly altering pH and alkalinity of samples after coagulation [9], [11], [12]. Even, recent studies consider that coagulant extracts of *M. oleifera* can be a suitable alternative for partial replacement of aluminum sulfate in the raw water treatment of slow bodies such as swamps or reservoirs [13].

Moringa Oleifera Lam (*Moringa Pterygosperma* Gaertn) is the best known and used species from the Moringaceae botanical family. A tree native to the sub-Himalayan regions of northwestern India currently and widely cultivated in countries in Africa, Arabia, Southeast Asia, the Pacific, South America and many Caribbean islands [14].

Moringa oleifera seeds without husks contain proteins (27% to 36.7%), lipids (21% to 34.6%) and carbohydrates (5% to 5.5%) [15], [16] and, their active components responsible for the flocculant processes in murky waters, are basic polypeptides with molecular weights ranging from 6000 to 16000 Daltons, being mainly the amino acids: glutamic acid, proline, methionine and arginine [17]. On the other hand, it has also been reported that in aqueous extracts of *Moringa oleifera* seeds, the active components are protein dimers with molecular weights of approximately 13,000 Daltons and with an isoelectric point between 10 and 11. [18]. [19] found that molecular weight of the active components of the *Moringa oleifera* seed is 6000 Daltons, with a content of 8 amino acids (13.1%), 7 arginines and 1 histidine with positive charges, and only a residue of aspartic acid (1.6%) with negative charge.

Consequently, the protein in aqueous solution has a high positive charge. Equivalent results were reported by [20] mentioning that the active component, responsible for coagulation is not a single homogeneous protein, but a protein mixture with similar physical characteristics. Correspondingly,

it has been reported that turbidity removal in raw water occurs by charge neutralization using the electrostatic patch mechanism [19]. *Moringa oleifera* seeds also have antimicrobial properties capable of eliminating pathogens such as fecal and total coliforms [21], the compound 4- (4'-O-acetyl- α -L-rhamnopyranosyloxy) - Benzyl isothiocyanate has been identified as active antimicrobial agent which is the only currently known mustard oil glycoside. [22].

Extraction of the natural coagulant from *Moringa oleifera* seeds shows a greater coagulant capacity when prepared in 1.0M aqueous solution of NaCl. The above is due to the increase in ionic strength in the solution, which increases solubility of the active components and improves their ability to neutralize surface charges in the particles in solution [23].

The objective of this research study was to examine behavior of the seeds of *Moringa oleifera* prepared with seawater compared to other solvents for the removal of turbidity from shallow raw water.

II. METHODOLOGY

A. Water samples

Samples were prepared by collecting tap water from the aqueduct and artificially clouded it with gray kaolinite, until the three-initial turbidity proposed in the experimental design were reached. Treatability tests were conducted at the water and soil laboratory from Sucre University, in Sincelejo City, Colombia. For the coagulant preparation in seawater, the sample was taken in the Gulf of Morrosquillo, at coordinates: 9°25'36" North and 75°38'16" West.

B. Preparation of Coagulant Extracts

Moringa oleifera seeds were dried outdoors for 12 hours, then ground in an industrial mill and screened in a mesh No. 30 (0.60mm) according to the Tyler series, until reaching a fine powder [9], [12]. Later, 30.0g of *Moringa oleifera* seed powder was dissolved in three 1.0-liter volumetric flasks (10g per flask) with distilled water, 1.0% sodium chloride saline solution (w/v) and seawater (w/v), respectively. Solutions were mixed with magnetic stirring for 1 hour, centrifuged at 3,500 rpm for 10 minutes and filtered under vacuum with cellulose filter paper. Filtrates were labeled as coagulant extract in distilled water, saline solution with a concentration of 10,000 mg/L and solution in seawater. Solutions were kept refrigerated at 4°C until application [12].

C. Jar Testing

To determine percentage of turbidity removal of each coagulant extract, jar testing was performed in an E&Q Flocculator model F6-330-T. Three (3) doses of each extract were applied to each

raw water sample. Rapid mixing process was maintained at 200 rpm for 1 minute, followed by a slow mixture at 40 rpm for 20 minutes, and a 30-minute settling time [24], [25].

Turbidity of all water samples was measured in triplicate before and after the jar testing. This was measured with an ORION AQ3010 turbidimeter. Similarly, salinity and conductivity of coagulant extracts were measured following measurement protocols from the Standardized Methods for the Analysis of Drinking and Residual Water according to the American Public Health Association [26]. In all jar tests, targets were performed to verify activity of coagulant extracts and turbidity removal, estimated with the following equation [27], [28]:

$$\% \text{Removal} = \frac{T_i - T_f}{T_i} * 100 \quad (1)$$

Where T_i represents initial turbidity of sample and T_f the final one.

D. Experimental Design

A 3³ experimental design was carried out; i.e., out of 3 variables in 3 levels: Initial turbidity of raw water (50 NTU, 150 NTU and 300 NTU), Solvent of extracts (distilled water, saline solution and seawater) and applied dose (10mg/L, 20mg/L and 30mg/L). The response variable measured before and after the treatment train was Turbidity. Statgraphics Centurion XVI Software (Version 16.0.07) was used to analyze results and an ANOVA was applied with a 95% confidence level. For cases where there was a significant difference between treatments, multiple range tests were performed to determine which means are significantly different from others [29].

III. RESULTS

Concentration of salinity and conductivity of solvents used in the preparation of coagulant extracts, are shown in Table 1.

Table 1. Saline concentration and solvent conductivity for *M. oleifera* seeds.

Solvent	Salinity (% chlorides)	Conductivity (mS/cm)
Distilled water	0.00	0.00
Saline solution (NaCl)	0.98	16.77
Seawater	2.85	44.20

It is normal that distilled water does not have saline concentration and conductivity, because in its distillation process there is no entrainment of electrolytes and mineral salts present in natural water and, it simply remains as purified water. Concentration of chlorides in the saline solution is as expected, because a concentration of 10 g/L of salt in water is

equivalent to a concentration of 1% saline solution. Seawater salinity is much higher than the concentration of the saline solution, 2.85. Correspondingly, its conductivity is proportional to concentration of chlorides. The above is mainly due to high concentrations of Ca^{++} , Mg^{++} and K^{+} typical of seawater [30].

Tables 2, 3 and 4 show the results found for the proposed experimental design to verify removal efficiency and coagulant activity of the *Moringa oleifera* seeds dissolved in distilled water, saline solution and seawater.

Table 2. Treatability Results using *M. Oleifera* Seeds in distilled water.

Initial Turbidity Raw Water (NTU)	Dosage (mg/L)	Final Turbidity (NTU)
50,36	10	50,73 ± 1,76
	20	44,27 ± 2,13
	30	43,43 ± 1,61
148,66	10	21,83 ± 2,70
	20	22,67 ± 0,80
	30	27,00 ± 0,10
300	10	125,67 ± 3,78
	20	85,07 ± 1,19
	30	66,70 ± 0,70

Mean concentration ± Standard deviation

From results shown in Table 2, it can be verified that natural seed coagulant of *M. oleifera* dissolved in distilled water shows very low removals when the initial turbidity is equally low. Nonetheless, turbidity removal increases as the initial turbidity of raw water also increases. None of the final turbidity values shown comply with the turbidity value required by Colombian sanitary regulations, since all are much higher than 2.0 NTU ([31] MINANMBIENTE, 2007). Except for the final turbidity achieved in the raw water of 300 NTU, it could be seen that the coagulant doses applied do not significantly affect the final turbidity after treatment, which allows to infer that coagulant activity of the seeds of *M. Oleifera* is low when distilled water is used as a solvent.

Table 3. Treatability Results using *M. Oleifera* Seeds in Saline Solution.

Initial Turbidity Raw Water (NTU)	Dosage (mg/L)	Final Turbidity (NTU)
50,2	10	22,33 ± 0,96
	20	24,63 ± 0,50
	30	26,73 ± 0,28
150	10	25,80 ± 1,31
	20	31,10 ± 1,32
	30	39,43 ± 1,55
307,66	10	27,13 ± 1,76
	20	19,13 ± 0,25
	30	22,10 ± 0,17

Mean concentration ± Standard deviation

Table 4. Treatability Results using *M. Oleifera* Seeds in Seawater.

Initial Turbidity Raw Water (NTU)	Dosage (mg/L)	Final Turbidity (NTU)
53,63	10	37,03 ± 1,53
	20	41,60 ± 0,43
	30	42,10 ± 0,10
147	10	23,63 ± 0,23
	20	35,03 ± 0,41
	30	47,50 ± 1,48
307,33	10	19,43 ± 0,73
	20	20,57 ± 0,40
	30	27,63 ± 0,87

Mean concentration ± Standard deviation

Based on the results shown in Tables 3 and 4, average values found for the final turbidity, when saline solution and seawater were used as solvent, are very similar when turbidity of the raw water was 150 NTU and 300 NTU, but different in turbidity tests of 50 NTU. Coagulant doses directly influenced final turbidity of all samples in an inversely proportional manner, i.e., that the lower dose (10 mg/L) achieved the best turbidity removals, both for samples treated with saline *M. oleifera* as in seawater. Nonetheless, all the final turbidity values found remained higher than the value required by the Colombian sanitary regulations.

In Figures 1 to 3, the removal efficiencies of each coagulant extract prepared with *M. oleifera* seeds are shown.

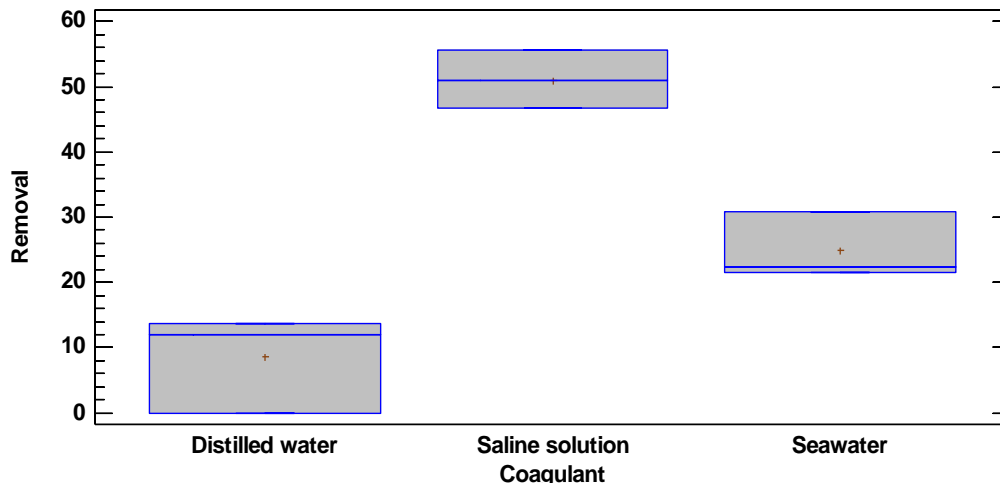


Fig. 1. Removal efficiency of *M. oleifera* in raw water with turbidity of 50 NTU.

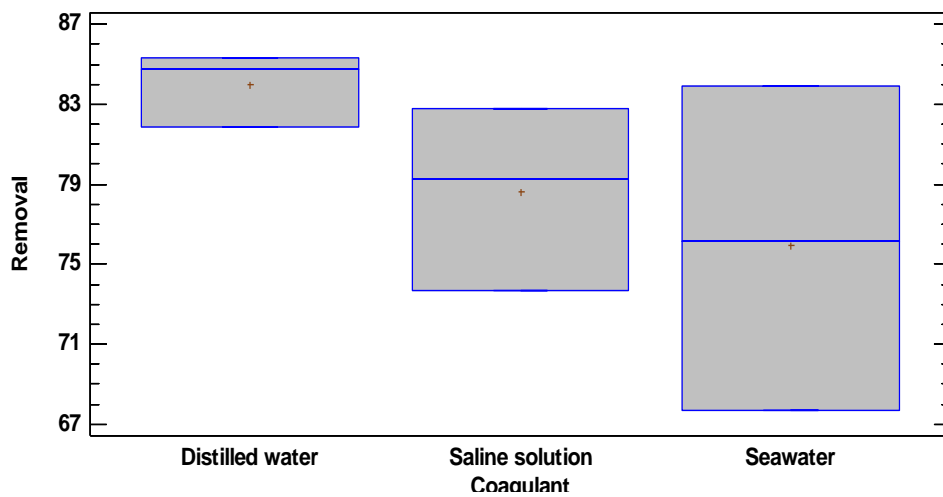


Fig. 2. Removal Efficiency of *M. oleifera* in raw water with turbidity of 150 NTU.

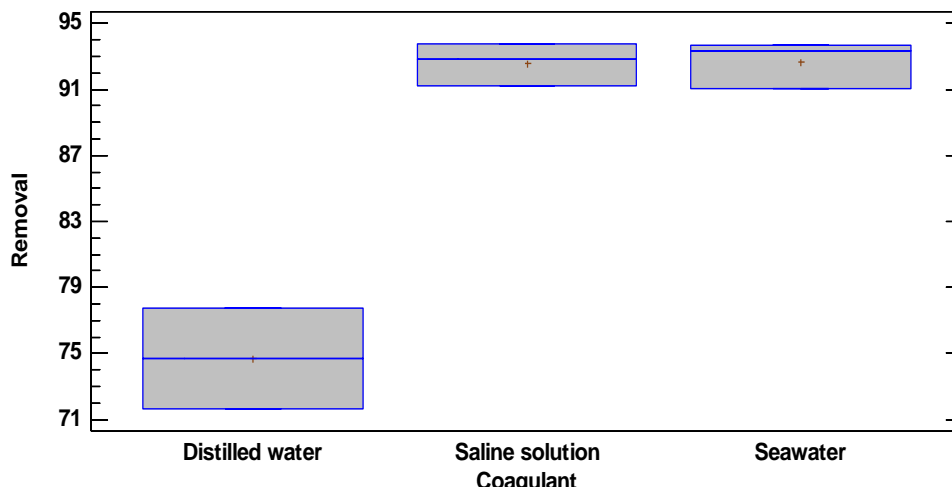


Fig. 3. Removal efficiency of *M. oleifera* in raw water with turbidity of 300 NTU.

ANOVAS were carried out to verify whether there are statistically significant differences in turbidity removals when the three different coagulant extracts were used at each initial turbidity of the raw water samples tested. Results are shown in Table 5.

Table 5. P-value of the ANOVAS carried out for turbidity removal tests.

Initial Turbidity (NTU)	50	150	300
P-value	0.0001	0.1535	0.004

Since P-value from turbidity removals for raw water tests of 50 NTU and 300 NTU are less than 0.05, there are statistically significant differences between the means of the results found for these two treatments, i.e., type of solvent used for preparing *M. oleifera* seed extracts influences the turbidity removals achieved in jar tests. The multiple range test allowed to establish that when saline or seawater is used, there are no statistically significant differences between the removals obtained, but if there are significant differences when using distilled water, this extract is the one with the lowest efficiency of removal turbidity. These results are similar to those found by [32], who demonstrated that the coagulant extracted using saline and seawater as solvent has a removal capacity like that from aluminum sulfate, and the lowest removal is when water is used distilled as solvent. Nonetheless, for turbidity of raw waters with 150 UNT there are no statistically significant differences, since P-value was greater than 0.05.

Generally, greater turbidity removal efficiencies were achieved in raw water samples with high initial turbidity and with extracts prepared with saline solution, either NaCl or seawater. This behavior can be explained by the increased solubility of proteins responsible for the coagulant effect by the addition of salts, also known as the salting effect [33]. This mechanism suggests the breakdown of protein-protein or protein-polysaccharide or other existing associations in the *Moringa Oleifera* seed powder, thereby increasing soluble proteins in saline solutions resulting in an increase in their coagulant activity, the solutions of sodium chloride and seawater act, therefore, better than distilled water [32]. In that sense, [34] carried out similar tests using extracts of *M. oleifera* with KCl saline solution, of 1 Molar concentration, demonstrating better turbidity and color removal efficiencies in the tests than when distilled water was used as solvent.

IV. CONCLUSIONS

Moringa oleifera seeds achieved excellent turbidity and coagulant activity removals in high turbidity raw water samples, i.e., the more turbid the raw water is, the better performance will be obtained from this coagulant extract, even independently of the dose applied in treatments. Nevertheless, in none of the trials was it possible to obtain the turbidity required by Colombian sanitary regulations, which demands complementing coagulation-flocculation treatment with sedimentation and filtration. Finally, it is necessary to prepare seeds in saline extract, since this aqueous medium potentiates the effect of proteins responsible for coagulant activity of the seeds of *M. oleifera*. In this study, no statistically significant differences were found in the increase in coagulant activity when aqueous NaCl solution or seawater was used in the preparation of extracts, i.e., seawater can be used as a replacement for saline solutions and obtain similar effects in the removal of turbidity in raw water, particularly when its concentration is greater than 150 NTU.

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REFERENCIAS

- [1] G.L. McConnachie, G.K. Folkard, M.A. Mtawali, and J.P. Sutherland, Field trials of appropriate hydraulic flocculation processes, *Water Research*, 33(6), 1999, 1425-1434. DOI: 10.1016/S0043-1354(98)00339-X.
- [2] M. Asrafuzzaman, A.N.M. Fakhruddin, and A. Hossain, Reduction of turbidity of water using locally available natural coagulants, *ISRN Microbiology*, 2011(1), 2011, 1-6, DOI: 10.5402/2011/632189.
- [3] S. Bondy, The neurotoxicity of environmental aluminum is still an issue, *Neuro Toxicology*, 31(5), 2010, 575-581. DOI: 10.1016/j.neuro.2010.05.009
- [4] J.J. Feria, L. Polo, and E.J. Hernández, Evaluation of coagulation sludge from raw water treated with *Moringa oleifera* for agricultural use, *Ingeniería e Investigación*, 36(2), 2016, 14-20. DOI: 10.15446/ing.investig.v36n2.56986.
- [5] M.V. Jadhav, and Y.S. Mahajan, A comparative study of natural coagulants in flocculation of local clay suspensions of varied turbidities, *Journal of civil engineering and technology*, 1(1), 2013, 26-39.
- [6] S.A. Muyibi, and C.A. Okuofu, Coagulation of low turbidity Surface waters with *Moringa Oleifera* seeds,

- International Journal of environmental Studies, 48, 1995, 263-273. DOI: 10.1080/00207239508710996.
- [7] S. Bhatia, Z. Othman, and A.L. Ahmad, Palm oil mill effluent pretreatment using *Moringa Oleifera* seeds as an environmental friendly coagulant: laboratory and pilot plant studies, Journal Chemical Technology and Biotechnology, 81, 2006, 1852-1858. DOI:10.1002/jctb.1619.
- [8] M. Chaudhuri, and P.S. Khairuldin, Coagulation–Clarification of coloured water by natural coagulant (*Moringa Oleifera*) seed extract, Nature Environmental and Pollution Technology, 8(1), 2009, 137-139.
- [9] J.J. Feria, S. Bermúdez, and A.M. Estrada, Eficiencia de la semilla de *Moringa Oleifera* como coagulante natural para la remoción de la turbidez del río Sinú, Producción + Limpia, 9(1), 2014, 9-22.
- [10] R. Sanghi, B. Bhattacharya, A. Dixit, and V. Sanghi, Ipomoea dasysperma seed gum: an effective natural coagulant for the decolorization of textile dye solutions, Journal of Environmental Management, 81(1), 2006, 36-41. DOI: 10.1016 / j.jenvman.2005.09.015.
- [11] Y. Caldera, I. Mendoza, L. Briceño, J. García, and L. Fuentes, Eficiencia de las semillas de *Moringa oleifera* como coagulante alternativo en la potabilización del agua, Boletín del centro de investigaciones biológicas, 41(2), 2007, 244-254.
- [12] J.J. Feria, J.P. Rodiño, and G. Gutiérrez, Behavior of turbidity, pH, alkalinity and color in Sinú river raw water treated by natural coagulants, Revista Facultad de Ingeniería, Universidad de Antioquia, 78, 2016, 119-128. DOI: 10.17533/udea.redin.n78a16.
- [13] M. Meza, K. Riaños, I. Mercado, R. Olivero, and M. Jurado, Evaluation of the coagulant power of aluminum sulfate and *Moringa oleifera* seeds in the clarification process of water in the swamp of Malambo, Atlántico, Revista UIS Ingenierías, 17(2), 2018, 95-104. DOI: 10.18273/revuin.v17n2-2018009.
- [14] M. Hassan, A review of the applications of *Moringa oleifera* seeds extract in water treatment, Civil and Environmental Research, 3(8), 2013, 1-10.
- [15] G.K. Folkard, J.P. Sutherland, and W.P. Grant, Optimization on the use of natural coagulants for water purification, Technical report No. R4254 (Leicester, USA: University of Leicester, 1989).
- [16] A. Ndabigengesere, K.B. Narasia, and B.G. Tolbot, Active agents and mechanisms of coagulation on turbid waters using *Moringa oleifera*, Water Research, 29(2), 1995, 703-710. DOI: 10.1016/0043-1354(94)00161-Y.
- [17] S.A.A. Jahn, Using *Moringa oleifera* seeds as coagulant in developing countries, Journal American Water Works Association, 6, 1988, 43-50.
- [18] A. Ndabigengesere, and K.S. Narasia, Quality of water treated by coagulation using *Moringa* seeds, Water Research, 32(3), 1998, 781-791. DOI: 10.1016/S0043-1354(97)00295-9.
- [19] M. Broin, C. Santaella, S. Cuine, K. Kokou, G. Peltier, and T. Joët, Flocculant activity of a recombinant protein from *Moringa oleifera* Lam. Seeds, Applied Microbiology and Biotechnology, 60, 2002, 114-119. DOI: 10.1007/s00253-002-1106-5
- [20] K.A. Ghebremichael, K.R. Gunaratna, H. Henriksson, H. Brumer, and G. Dalhammar, A simple purification and activity assay of the coagulant protein from *Moringa oleifera* seed, Water Research, 39(11), 2005, 2338-2344. DOI: 10.1016/j.watres.2005.04.012.
- [21] P.H. Chuang, C.W. Lee, J.Y. Chou, M. Murugan, B.J. Shieh, and H.M. Chen, Antifungal activity of crude extracts and essential oil of *Moringa oleifera* Lam, Bioresource Technology, 98(1), 2007, 232-236. DOI: 10.1016/j.biortech.2005.11.003.
- [22] U. Eilert, B. Wolters, and P. Nahrstedt, The antibiotic principle of *Moringa oleifera* and *Moringa stenopeta/a*, Plant Medica, 2, 1981, 55-61. DOI: 10.1055/s-2007-971546.
- [23] T. Okuda, A.U. Baes, W. Nishijima, and M. Okada, Coagulation mechanism of salt solution extracted active component in *Moringa oleifera* seeds, Water Research, 35(3), 2001, 830–834. DOI: 10.1016/S0043-1354(00)00296-7.
- [24] American Society for Testing and Materials, Standard Practice for Coagulation-Flocculation Jar Test of Water D2035-08 (Pensilvania, USA: ASTM, 2008).
- [25] Procedimiento para el ensayo de coagulación- floculación en un recipiente con agua o método de jarras, Norma Técnica Colombiana 3903 (Bogotá, Colombia: NTC, 2010).
- [26] American Public Health Association – APHA, Standard methods for examination of water and wastewater, 21 ed. (Washington D.C., USA: APHA, 2005).
- [27] S.H. Lee, S.O. Lee, K.L. Jang, and T.H. Lee, Microbial flocculant from *Arcuadendron* SP-49, Biotechnology Letters, 1995, 17(1), 95-100. DOI: 10.1007/BF00134203.
- [28] M. Antov, M. Sciban, and J. Prodanovic, Evaluation of the efficiency of natural coagulant obtained by ultrafiltration of common bean seed extract in water turbidity removal, Ecological Engineering, 2012, 49, DOI: 10.1016/j.ecoleng.2012.08.015.
- [29] R. Solís, J. Laines, and J. Hernández, Mezclas con potencial coagulante para clarificar aguas superficiales,

Revista Internacional de Contaminación Ambiental,
2012, 28(3), 229-236.

- [30] W. Soler, H. Durango, and J.P. Soler, Control microbiano de agua de mar mediante microfiltración, Revista Facultad Nacional de Salud Pública, 2010, 28(2), 141-148.
- [31] Características, instrumentos básicos y frecuencias del sistema de control y vigilancia para la calidad del agua para consumo humano, Resolución número 2115, 22 de junio de 2007.
- [32] M.M. Sandoval, and J.R. Laines, *Moringa oleifera* una alternativa para sustituir coagulantes metálicos en el tratamiento de aguas superficiales, Ingeniería, Revista Académica de la FI-UADY, 2013, 17(2), 2013.
- [33] D. Voet, And J.G. Voet, Bioquímica Tercera Edición (Pennsylvania, USA: Universidad de Pennsylvania, Swarthmore College, 1990).
- [34] G.B. Serpelloni, A. Vieira, L. Nishi, K. Cordeiro, and R. Bergamasco, Study of the effect of Saline Solution on the extraction of the *Moringa oleifera* seed's active component for water treatment, Water Air and Soil Pollution, 2010, 211(1), 409-415. DOI: 10.1007 / s11270-009-0309-0.