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Alternatives to the use of synthetic organic coagulant aids in drinking water treatment: improvements in the application of the crude extract of Moringa oleifera seed

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ABSTRACT

Drinking water treatment is a process based on multiple stages that has a main objective to provide water safe enough to be consumed by humans. Coagulation–flocculation is used to remove colloidal and suspended solids. This process improves the performance of subsequent stages (as sedimentation or filtration) as well as the water quality with a desired end-use. For many years, inorganic and organic synthetic polyelectrolytes have been used in coagulation–flocculation processes. However, its use has been deeply studied recently to determine the potential impact of residual concentration of these substances on human health and the environment. Strict regulations limit the concentration of free residual monomer after the addition of polyacrylamide (PAM) in drinking water treatment and study the effect of interaction of the residues with disinfection products. Therefore, in the last years there has been a resurgence of interest to use natural materials with the same performance that synthetic, but with lower hazard for the environment and humans. This work studies the use of the flocculant extracted from *Moringa oleifera* seed, in combination with polyaluminum chloride (PAC). The performance is compared with the combination PAC–PAM in terms of coagulant activity and physical–chemical quality of the water treated. Jar test was carried out using two types of natural water (with presence of bentonites) and different combinations of coagulant and flocculants. Results show that coagulant activity of PAC–*Moringa* combination is comparable with the results obtained with PAC–PAM, reducing initial turbidity up to 90% in all the tests. With regard to physical–chemical quality of the treated water, PAC–*Moringa* produces values under the drinking water quality standards for all the parameters analyzed. It is remarkable that the decrease of 50% in the trihalomethanes formation potential rate shown for PAC–*Moringa* combination, observed when treating natural water with presence of bentonites. Therefore, the results obtain in this work encourage the use of *Moringa oleifera* extract as a natural, low cost, effective, and low-toxicity alternative to the use of synthetic organic polyelectrolytes as polyacrylamide for drinking water treatment.

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1. Introduction

Water purification is a comprehensive process based on multiple stages that has the purpose of obtaining an effluent with suitable quality for human consumption. The number and sequence of stages depend on the quality and quantity of the effluent to be treated, on the effluent to obtain, as well as its end-use. Fig. 1 shows a scheme of a general sequence of water purification.

The raw surface water may contain large amount of natural matter in suspension such as clays, silica, micro-organisms, or algae that can settle or not, depending on their size. The matter in solution or in colloidal form (less than 10^{-4} mm size) usually forms dispersions/suspensions that do not settle and cannot be effectively treated by filtration. Such effluents require, therefore, a preliminary treatment for destabilizing the colloidal particles and for inducing them to aggregate in the form of flocs or larger particulates, prior to their separation. This treatment is known as flocculation.

The performance of this stage has a direct influence on the performance of subsequent stages such as sedimentation or filtration, which have an effect on the quality of the final effluent.

1.1. Coagulation and flocculation

Coagulation is the physical–chemical process of neutralization of the surface charge of suspension particles present in the raw water, with the aim to reduce the forces of separation between them, destabilizing them, and facilitating their agglomeration. The main coagulants, used alone or in combination, are the following:

- inorganic coagulants such as simple aluminum salts (alumina sulfate or sodium aluminate) or polymerized salts (aluminum polychloride), iron salts (ferric sulfate or ferric chloride), or lime [1,2];
- natural organic coagulants, which can be cationic such as chitosan or starch, anionic as sulfated polysaccharides, or non-ionic such as some starch derivatives, cellulose derivatives, or gelatin [3];
- synthetic organic coagulants, being polyacrylamide one of the most commonly used.

Flocculation refers to the agglomeration of coagulated particles in flocs. Once colloids are destabilized, a smooth blend of particles is done to increase the rate of encounter or collisions between them. This stage should not break or disrupt pre-formed aggregates, but increase their size and facilitate their sedimentation or subsequent removal. Flocculants can be organic or inorganic, such as clay (bentonite), salts of calcium carbonate or activated carbon, alginates, starches, gums, pectins, or xanthates, among others.

1.2. Use of coagulants and flocculants: advantages and drawbacks

Inorganic coagulants have been traditionally used for their effectiveness. Currently, aluminum polybases, also known as polyaluminum chloride (PAC), are often used since they provide a lower concentration of residual aluminum in treated water. This point is very important in the treatment of drinking water, as there is some evidence about the relationship between high levels of residual aluminum in treated water with certain diseases such as Alzheimer's disease [4–12].

Organic polyelectrolytes have been widely used in the process of coagulation–flocculation in the last 40 years [13]. In comparison with the use of metal salts they show some advantages: lower doses of coagulant,

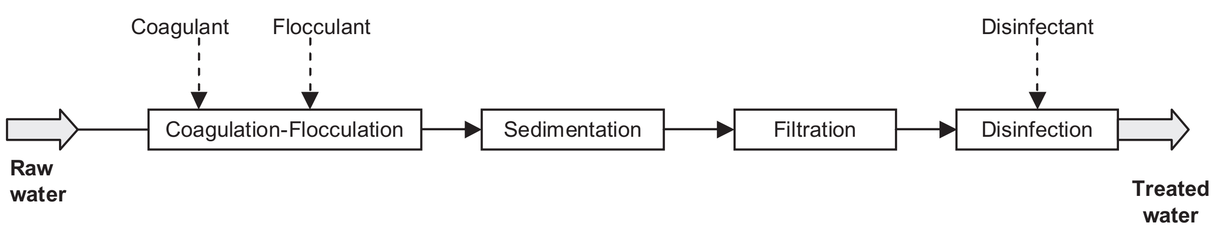

Fig. 1. General scheme of drinking water treatment.

easier settling and consistency of the flocs [14], lower volume of sludge, smaller increase of the ionic charge of the treated water, lower level of aluminum in treated water, and costs reduction by 25–30%.

However, their use is increasingly most questioned due to:

- environmental problems [15,16], primarily for the generation of toxic sludge that cannot be used in agriculture;
- connection with cancer [17–19]. Acrylamide, in particular, is classified as CMR substance (Carcinogenic, Mutagenic, or Toxic for reproduction) by health authorities.

In fact, some reports linked the presence of waste monomers from the use of organic polymers (especially the cationic ones), with possible toxic effects to humans and the environment [20,21].

Within organic polyelectrolytes, anionic and non-ionic polymers have lower toxicity, in comparison with the cationic ones, especially for aquatic organisms, either flora or fauna [22]. In fact, some countries such as Japan or Switzerland forbade the use of organic polyelectrolytes in the treatment of drinking water [23], and others such as Germany and France have established strict limits for using organic polyelectrolytes due to their potential toxicity and their high impact on aquatic organisms such as fish or algae [20].

On the other hand, since monomers are more toxic than polymers [24], strict regulations have been adopted in terms of free monomer present in treated water, especially with products derived from acrylamide.

According to current legislation in Spain, to ensure that the monomer concentration is less than 0.1 mg/L in treated water [25,26], PAM dosages must be in the range of 0.2–0.5 mg/L. The central value of this range (0.3 ppm) is usually taken as the reference dose of PAM so guarantees an adequate operation of coagulation–flocculation stage avoiding monomer concentrations higher than those required.

For drinking water production, the NSF (*National Sanitation Foundation*) of USA has recommended a maximum dose for the most commonly used commercial polymers, not exceeding 50 mg/L for the p-DADMAC and 1 mg/L for any type of polyacrylamide [27,28]. It has also been studied the interaction of the polymer remaining in the water and its reaction with components of water, which causes the formation of trihalomethanes (THMs) [29,30] or the disinfection by-products [29,31,32].

1.3. Potential of natural coagulants

Natural coagulants have been traditionally used to remove turbidity of the water in the domestic environment [33–35]. Natural coagulants are water soluble substances, coming from vegetable or animal materials [36–39] that act similarly to synthetic coagulants, aggregating particles of small size, present in the suspension of the raw water, facilitating its sedimentation, and reducing water initial turbidity.

Some of the most commonly used natural coagulants are chitosan, modified starch, or sodium alginate. Within natural coagulants, the primary vegetable coagulant most studied nowadays due to its great potential is *Moringa oleifera* seed. It has a high efficiency as primary natural coagulant, achieving a high reduction of turbidity (between 92 and 99%) [40,41], and producing lower sewage sludge than that produced by aluminum sulfate [42].

The main drawback of *Moringa oleifera* and other natural coagulants is a consequence of being added in water as powdered seeds. As a result of this, they cause a significant increase of the organic load of water (up to 90%) due to the organic substances coming from seeds that do not act as flocculating agents (Jahn, 1988) [42,43]. This fact prevents storing treated water for more than 24–48 h (Jahn, 1988). In fact, some research about *Moringa* is focused on the purification of the active compound by simple methods [44,45], in order to avoid such inconvenience.

However, they are very interesting compounds because of low cost, natural origin, and less impact on the environment and the human being. These advantages have resulted in increasing research on them. This paper studies the application of the coagulant extracted from *Moringa oleifera* in natural water, comparing its effectiveness and the physical–chemical quality of the treated water with that obtained using PAC as coagulant and PAC/PAM as coagulant–flocculant. Two types of raw water, with and without presence of bentonite, have been used.

2. Materials and methods

2.1. Coagulant preparation

2.1.1. PAC coagulant preparation

Aluminum polychloride (PAC) used in this work is the commercial product called PAX XL-63 (KEMIRA). It is diluted at 1% (w/v) in tap water for use in the jar test. The solution must be prepared again after 24 h.

2.1.2. *Moringa oleifera crude extract preparation*

Moringa oleifera seeds (MO) were collected from the surroundings of Ressano Garcia (Mozambique). Pods and shells were removed manually, and the kernels were ground in a domestic blender (Elma) and sieved through a 600 μm stainless steel sieve. Approximately 50 g of *Moringa oleifera* crushed seeds were fed to a lab-scale Soxhlet extractor fitted in a 500 mL round-bottom flask with 350 mL of solvent (ethanol, Panreac SA). Extraction time was 6 h and 20 cycles were performed. A protein extract was prepared with defatted seeds and local tap water in a 5% (w/v) suspension, which was mixed with a magnetic stirrer for 60 min and left to settle for 20 min. The *Moringa oleifera* crude extract was then filtered through a 0.45 μm cellulose acetate filter (Spartan 30 B, VWR International).

2.1.3. *PAM preparation*

In the case of polyacrylamide, the commercial product is the CROSEFLOC A-200 supplied by KEMIRA. Solutions of 1 mg/mL with tap water were used. The useful life of the solution is 24 h, after which a new dilution is prepared.

2.2. *Coagulant activity test*

Jar tests were carried out in 1 L beakers to determine the effective dosage of coagulant or coagulant–flocculant that is able to reduce the turbidity of the sample. Conditions for Jar test are specified in Table 1.

After settling time, supernatant was collected from each beaker and the turbidity was measured using a D 112 turbidimeter (DINKO Instruments).

The residual turbidity was used as a basis for comparing the coagulant activity (in percentage), calculated with equation 1:

$$\text{Coagulant activity (\%)} = \frac{(\text{Initial turbidity} - \text{Residual turbidity})}{\text{Initial turbidity}} \times 100 \quad (1)$$

Each test series includes a control or blank corresponding to a sample of water without addition of coagulant or flocculant, but perform with the same conditions of agitation and settling to samples containing coagulant.

Jar tests were performed using two types of water:

- Type 1: natural water of low turbidity collected from Turia River, which supplies water to the water treatment plant "La Presa" located in Manises (Valencia).
- Type 2: natural water of medium turbidity, collected from the vicinity of the River Turia which contains natural bentonite in a concentration range between 200 and 300 mg/L.

2.3. *Physical–chemical analysis of water samples*

Once each test is performed, a sample of supernatant is taken for analyzing the main physicochemical characteristics of the blank and of each of the tested samples. The results obtained are compared with the limit established in Spanish RD 140/2003 legislation that sets the guidelines for drinking water.

3. Results and discussion

3.1. *Results of Jar test for type 1 water*

Firstly, the results of Jar test made with raw water from the River Turia (type 1 water) are shown. These results show the curves of settling expressed as coagulant activity versus the concentration of coagulant or coagulant–flocculant used.

3.1.1. *Results with PAC*

Fig. 2 shows the results obtained with the coagulant PAC. It can be observed the low turbidity of raw water in all samples, with values lower than 6 NTU.

In all the tests, the settling rate is above 85% for doses of PAC of 15 ppm and 93% for the doses of PAC of 20 ppm. The turbidity value obtained for this

Table 1
Jar test conditions

	High stirring speed/time	Speed reduction (rpm)	Flocculant addition	High speed/time	Low stirring speed/time	Settling time (min)
Coagulant test	250 rpm/1 min	40	No	250 rpm/1 min	40 rpm/15 min	15
Coagulant + flocculant test	250 rpm/1 min	40	Yes	250 rpm/1 min	40 rpm/15 min	15

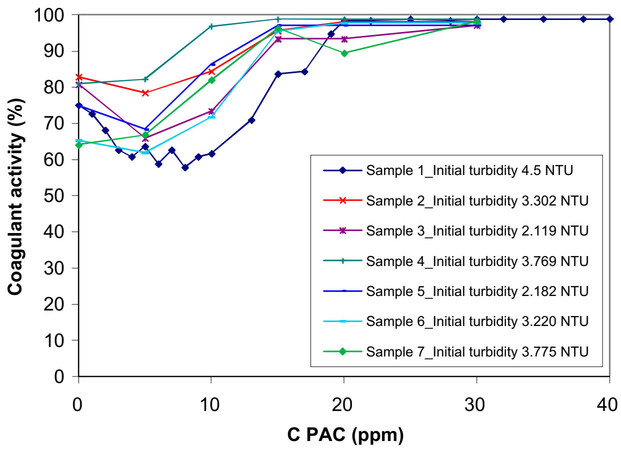

Fig. 2. Results of Jar test using PAC as coagulant with type 1 water.

concentration is nearly the same than the one of distilled water and less than 1 NTU (the limit set by RD 140/2003 for drinking water).

3.1.2. Results with PAC–MO

Fig. 3 shows the results obtained with the coagulant PAC and *Moringa* as coadjuvant. The best results according to the results of Fig. 2 have been selected, i.e. those obtained with 15–20 ppm of PAC.

It is observed that the coagulant activity is above 85% in all cases. This activity is not significantly increased with the addition of *Moringa*. Furthermore, significant differences in the coagulant activity are not appreciated with concentrations of PAC–MO of 15 ppm and 20 ppm.

On the other hand, it might be said that in waters with very low initial turbidity (as those tested), the effect of the addition of *Moringa* does not show an improvement in turbidity removal. However, it is observed as an improvement in the size of the flocs, which are larger as the concentration of *Moringa* increases.

3.1.3. Results with PAC–PAM

Fig. 4 shows the results obtained with the coagulant PAC and the coadjuvant PAM. The figure shows that the percentage of coagulant activity increases by increasing the concentration of PAC, resulting in values higher than 70% in all cases. The highest value (99.8%) is obtained for PAC concentration of 20 ppm.

As it happened in the case of the MO, the addition of PAM does not show an improvement of the coagulant activity with the addition of PAC alone, since the initial turbidity of the water is very low. But there is an increase in the size of the observed flocs.

3.2. Physical–chemical quality of treated water from type 1 water tests

Table 2 shows the results of the physicochemical analysis of samples selected from the Jar test with type 1 water:

- In the case of PAC, concentrations of 15 and 20 ppm have been selected since they are those that have provided the highest values of coagulant activity.
- In the case of the combination of PAC–PAM, 20 ppm of PAC and 0.3 ppm of PAM have been selected, as they showed higher percentages of coagulant activity and larger size of the flocs.

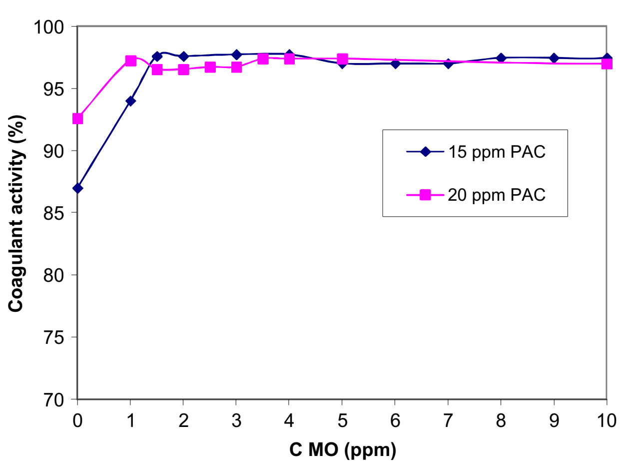

Fig. 3. Results of Jar test using PAC and *Moringa* in type 1 water.

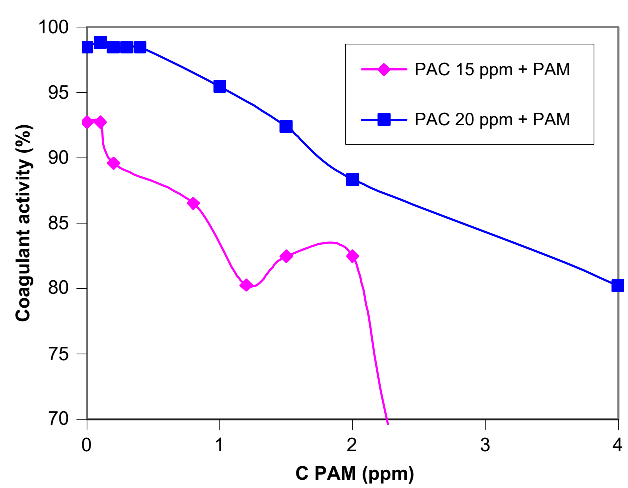

Fig. 4. Results of Jar test using PAC and PAM in type 1 water.

Table 2
Physical—chemical quality of treated water (type 1)

Concentration added (ppm)									
PAC	0	15	20	20	15	15	20	20	
Coad.	0	0	0	0.3 PAM	5 MO	10 MO	3 MO	8 MO	
Water quality obtained									Limit RD 140/2003
Turbidity (NTU)	5.53	0.9	0.35	0.45	0.54	0.44	0.43	0.5	1
Color (mg/L Pt–Co)	2.6	2.4	1.7	1.8	3.2	3.2	3	4.3	15
pH	8.5	8.2	8.2	8.2	8.3	8.2	8.2	8.2	6.5–9.5
Conductivity (μS/cm)	999	985	988	980	1,007	1,001	992	995	2,500
$KMnO_4$Oxidability(mg O_2/L)	<0.2	<0.2	<0.2	<0.2	1.3	1	0.3	1	5
Nitrites (mg/L)	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.1
Ammonium (mg NH_4/L)	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5
Aluminum (μg/L)	<25	142	152	138	124	120	138	162	200
Absorbance at 254 nm	0.024	0.029	0.022	0.023	0.037	0.040	0.026	0.052	—
THMs (μg/L)	138	117	107	118	210	294	157	290	100

- In the case of the combination of PAC–MO, 15 and 20 ppm of PAC have been selected. Concentrations of MO were: 5–10 ppm for 15 ppm of PAC, and 3 and 8 ppm for 20 ppm of PAC. These MO concentrations were selected in order to observe the effect of the addition of various concentrations of this extract on the quality of the treated water.

As it can be seen in Table 2, the results obtained for all parameters measured in this physical–chemical analysis are below the legal limit established according to the RD 140/2003, except for the case of the THMs formation potential, which is not met for any of the samples (including blank).

In greater detail, it is observed that:

- For all samples treated with coadjuvant turbidity, pH, conductivity, nitrites, and ammonia have similar values to the blank and are below the limit established by the RD 140/2003.
- Oxidability to permanganate and absorbance at 254 nm of the water treated with *Moringa* are below the limit established by RD 140/2003, but they are higher than the values of the same parameters for blank and above the values obtained in the water treated with PAC–PAM. This would be indicative of the organic content of the water, which logically increases as a consequence of the addition of *Moringa* extract. This trend is observed in four of the samples treated with *Moringa*, but it is much less relevant in the case of 20 ppm of PAC with 0.3 ppm of MO.
- In all samples treated with MO, THMs formation potential is increased in comparison with blank. The samples treated with PAM or with PAC alone show values below those of blank, but in all cases above the limit established by RD 140/2003.
- For residual aluminum, it can be seen that samples treated with *Moringa* show values of this parameter below the ones of the samples treated with coagulant.

According to the results obtained for the raw natural water type 1, it can be concluded that:

- The optimum concentration of PAC to treat low turbidity (less than 6 NTU) water is 20 ppm. This concentration results in values of turbidity similar to those of distilled water.
- The effect of coadjuvant in the decrease of water turbidity is practically insignificant. This difficulty is increased by the low turbidity of the water and the natural sedimentation that occurs over time in the original samples. As a consequence of this, the optimal dosage of coadjuvant to low turbidity water cannot be found.
- Concerning the physical–chemical quality of the treated water, it can be stated that the addition of coadjuvants (PAM and MO) does not alter the pH, conductivity, nitrites, and ammonia of the water. PAM decreases the THMs formation potential by 15%, as well as the absorbance at 254 nm and the oxidability to permanganate. Whereas, *Moringa* increases all these parameters,

but they are in any case below the limit established by RD 140/2003, with the exception of THMs formation potential. THMs formation potential is over the limit established by RD 140/2003 for all the tested samples, including the blank.

- The increase of absorbance at 254 nm and oxidability to permanganate observed for samples treated with *Moringa* is due to the contribution of organic matter of the extract.
- For residual aluminum, it can be seen that the samples treated with *Moringa* show values of this parameter lower than the samples treated with coagulant (PAC) and similar to those treated with PAC and PAM.

3.3. Results of Jar test for type 2 water

Results of the Jar test carried out with raw water type 2 are shown following. Results show the curves of settling expressed as coagulant activity versus the concentration of coagulant or coagulant and coadjuvant used.

3.3.1. Results with PAC

Fig. 5 shows the Jar test results for type 1 and type 2 raw water, using PAC as coagulant. First of all, it can be seen that type 2 water has a higher initial turbidity value, which is close to 14 NTU (in comparison of 2 NTU of type 1 raw water). This allows to more easily observing the effect of coadjuvant in flocs as well as in the turbidity of treated water.

Furthermore, it can be observed that the optimal concentrations of PAC coagulant to achieve residual values below 1 NTU (limit set by RD 140/2003) must be higher than 15 ppm in both cases (water type 1 and type 2).

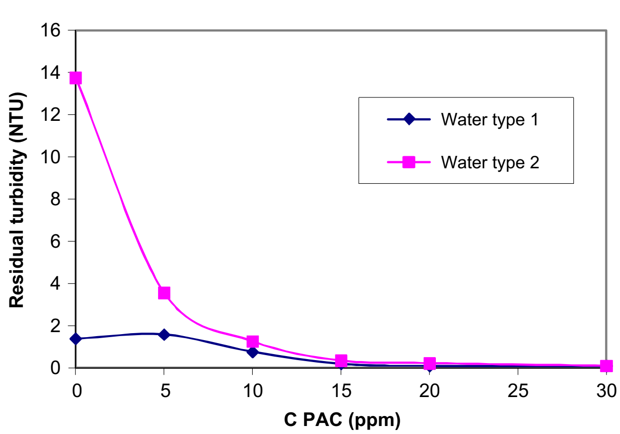

Fig. 5. Results for Jar test with water type 1 and water type 2.

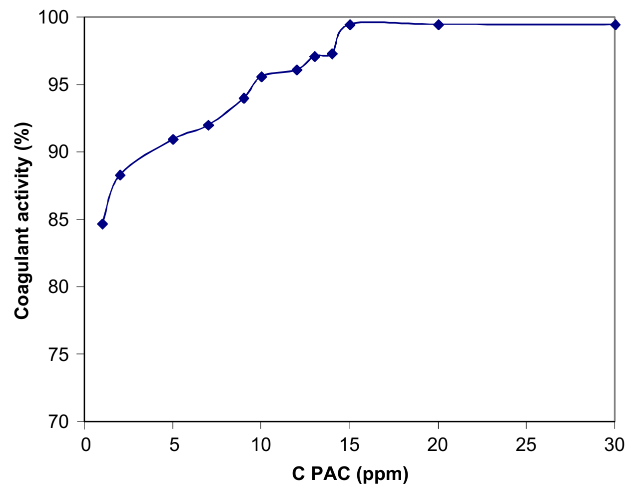

Fig. 6. Jar test results for type 2 water, using PAC as coagulant and 0.3 ppm of PAM.

3.3.2. Results with PAC–PAM

Fig. 6 shows the results obtained for the Jar test using PAC as coagulant and PAM as coadjuvant. Different concentrations of PAM were tested (results not shown). The best results were obtained for concentrations of this coadjuvant of 0.3 ppm and higher. However, since 0.3 ppm is the representative value of the range of doses used to ensure that the monomer concentration does not exceed the limit established by legislation, the best results obtained for this concentration of 0.3 ppm are shown.

It is observed that in all cases, coagulant activity values are above 85%. The maximum values of coagulant activity are achieved for concentrations of PAC from 15 to 20 ppm. These results agree with those obtained with the raw water type 1 shown in paragraph 3.1. These optimal values will be selected for the physical–chemical analysis of samples.

3.3.3. Results with PAC and MO

Fig. 7 shows the results for the Jar tests using PAC as coagulant and MO as coadjuvant. It is observed that values of coagulant activity above 97% are reached for 15 and 20 ppm of PAC. Regarding the addition of *Moringa*, values of coagulant activity are hardly improved by the addition of *Moringa* extract at concentrations below 10 ppm, being even reduced from that concentration. However, the floc size observed is increased with the addition of coagulant–flocculant in comparison with the addition of coagulant alone.

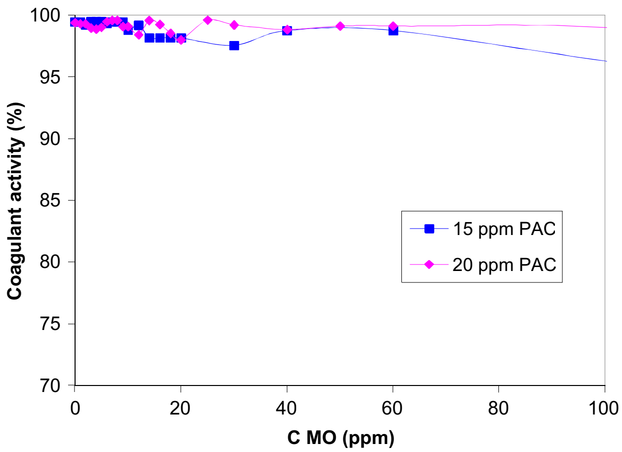

Fig. 7. Jar test results for water type 2, using PAC as coagulant and a MO as coadjuvant.

3.4. Physical–chemical quality of treated water from type 2 water tests

Results of Table 3 show the physical–chemical analysis performed with samples selected as best in previous trials of Jar test.

Firstly, it is observed that the presence of bentonite in type 2 water increases the final turbidity in the supernatant and also parameters like color, oxidability to permanganate, aluminum concentration, absorbance at 254 nm, and the potential for formation of THMs. All of these parameters are below the limits set by the RD 140/2003, except the turbidity and the potential of THMs, which are above the limit, as it happened with the type 1 raw water.

On the other hand, the addition of PAC allows to decrease the color, the absorbance at 254 nm, maintains pH, conductivity, nitrates and ammonia, increases the oxidability to permanganate, the concentration of aluminum, and slightly the potential of THMs formation. All values remain below the limit set by the RD 140/2003, except turbidity and THMs formation potential.

Finally, Table 4 shows the results obtained with the combination of coagulant and coadjuvant. First of all, it is observed that the residual turbidity values for all samples where coagulant and coadjuvant are added are below the limit set by RD 140/2003.

In relation to the addition of PAM with PAC, it is observed that all values remain similar to those of raw water type 2 and below the limit set by RD 140/2003, except for the concentration of aluminum that increases with the increase of PAC concentration, even reaching a value above the limit with 20 ppm of PAC. The addition of PAC and PAM decreases the potential of THMs formation between 9 and 20%, in comparison with the value of the raw water. This fact is not observed with the addition of coagulant alone.

In relation to the addition of MO with PAC, it can be seen that as concentration of PAC increases and concentration of MO decreases there is a decrease of color and turbidity. Although turbidity and color values decrease in comparison with blank, these values are higher than those obtained with the PAM–PAC combination. Anyway, they are in all cases below the limit set by the RD 140/2003.

Conductivity, pH, ammonia, and nitrite values remain constant with regard to blank, and are below the limit set by the RD 140/2003. Values of permanganate

Table 3
Physical–chemical quality of water type 1, water type 2, and water type 2 treated with PAC

Concentration added (ppm)					
PAC	0[a]	0[b]	15	20	
Coad.	0	0	0	0	
Water quality obtained					Limit RD 140/2003
Turbidity (NTU)	5.53	6.6	6.8	5.3	1
Color (mg/L Pt–Co)	2.6	8	4	4	15
pH	8.5	8.4	8.2	8.2	6.5–9.5
Conductivity (μS/cm)	999	986	981	978	2,500
$KMnO_4$ Oxidability (mg O_2/L)	<0.2	1.28	1.51	1.91	5
Nitrites (mg/L)	0.01	0.03	0.02	0.02	0.1
Ammonium (mg NH_4/L)	0.1	<0.2	<0.2	<0.2	0.5
Aluminum (μg/L)	<25	59	174	199	200
Absorbance at 254 nm	0.024	0.061	0.016	0.016	—
THM's (μg/L)	138	141.9	152.5	157.5	100

[a]Water type 1.
[b]Water type 2.

Table 4
Physical–chemical quality of raw water type 2 and water treated with PAC–PAM and PAC–MO

Concentration added (ppm)							
PAC	0	15	20	15	15	20	
Coad.	0	0.3 PAM	0.3 PAM	12 MO	7 MO	3 MO	
Water quality obtained							Limit RD 140/2003
Turbidity (NTU)	1,3	0,35	0,32	0,98	0,6	0,58	1
Color (mg/L Pt–Co)	7	2	3	9	7	5	15
pH	8.4	8.2	8.1	8.0	8.1	8.1	6.5–9.5
Conductivity (μS/cm)	987	987	989	981	989	985	2,500
$KMnO_4$ Oxidability (mg O_2/L)	1	1.3	1.2	4.9	3.7	3.1	5
Nitrites (mg/L)	0.02	0.02	0.02	<0.02	<0.02	0.03	0.1
Ammonium (mg NH_4/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5
Aluminum (μg/L)	62	175	219	142	144	197	200
Absorbance at 254 nm	0.038	0.024	0.025	0.057	0.046	0.045	—
THM's (μg/L)	162	129	147	62.5	66.5	96.4	100

oxidability and absorbance at 254 nm increase with respect to the blank, and with the increase in the concentration of *Moringa* extract added, as a consequence of the addition of organic matter coming from Moringa extract. In any case, values do not exceed the limits set by the RD 140/2003.

The value of the aluminum concentration increases with the increase of PAC concentration in the same way that happened in the case of PAC alone, or in the case of the PAM–PAC, and it is attributed to the aluminum present in PAC.

Finally, it should be noted that the combination of PAC–MO reduces the initial value of THMs formation potential of raw water, in percentages between 40.5 and 61.4%, being in all cases below the limit set by the RD 140/2003. The best results are achieved for concentrations of PAC of 15 ppm, and concentrations of *Moringa* extract of 12 and 7 ppm.

This result had neither been observed in the tests made with type 1 water nor with type 2 water. So it seems that the presence of natural betonite combined with *Moringa* extract decreases potential formation of THMs in water. This result is very useful because it allows:

- delete the main problem associated with the use of this natural coagulant, which is the contribution of organic load to water, and which is responsible for the numerous present researches aimed to purify coagulating extract of *Moringa*.
- consider this coagulant natural as a low cost, effective, low-toxicity alternative to the use of organic synthetic polyelectrolytes as PAM, whose use is more and more limited for the treatment of drinking water.

4. Conclusions

The main conclusions of this work are the following ones:

- Jar tests have allowed validating *Moringa oleifera* as an effective coagulant for the treatment of drinking water from natural waters.
- The increase in turbidity of raw water allows observing more clearly the effect that coagulant or coagulant/flocculant has on treated water.
- *Moringa* is less effective than PAM in the reduction of the initial turbidity of raw water and require higher concentration of PAC coagulant to produce comparable results of coagulant activity.
- In relation to the physical–chemical quality of the treated water, it is observed that tests with PAC and PAC–PAM enable to obtain (at optimum concentrations) water considered safe, with the exception of potential of trihalomethanes formation.
- Addition of PAC, bentonite, or PAC–PAM combination increases or remains the potential of trihalomethanes formation in the raw water, with values above the limit set by the RD 140/2003.
- The presence of natural bentonite in water type 2 in combination with *Moringa* extract reduces the potential formation of trihalomethanes in water, up to values that allow meeting the RD 140/2003 and allows qualifying it as drinking water.

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