REGET/UFSM
Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental

UFSM
REGET, Santa Maria v.24, e41, 2020
DOI: https://doi.org/10.5902/2236117045214
ISSN 2236-1170

Environmental Management Submissão: 08/01/20 Aprovação: 05/05/19 Publicação: 27/05/20

Low turbidity water treated with seeds of Moringa oleífera Lam.

Água de baixa turbidez tratada com sementes de Moringa oleífera Lam.

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Abstract

Effective and affordable solutions are being researched to reduce the problems generated by water scarcity in rural communities. Moringa is a natural polymer composed of cationic proteins, which are highlighted as a coagulant in the treatment of water for human consumption. Thus, the objective was to find the best concentration values for the removal of color and turbidity and sedimentation time, thus evaluating the power of Moringa seeds in the removal of Escherichia coli (E. coli) and heterotrophic bacteria in waters of low turbidity, since it does not perform well. The dosages used were 500, 600, 800 and 1000 mg L-1 and the sedimentation times tested were between 18 and 90 minutes. The best values of color removal and turbidity were found with lower dosages, because it is low turbidity water, resulting in the ideal contraction of 500 mg L-1. The minimum sedimentation time for maximum clarification efficiency was 90 minutes. Finally, after the definition of the dosage and better sedimentation time, removals of up to 29% for E. coli and 66% for heterotrophic bacteria were obtained, being within the parameters of potability for water for human consumption.

Keywords: Natural coagulants; Potability; Jar test; Quality

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Resumo

Soluções eficazes e acessíveis vem sendo pesquisadas para diminuir os problemas gerados pela escassez dos recursos hídricos em comunidades rurais. A Moringa é um polímero natural constituído por proteínas catiônicas, que obtêm destaque como coagulante no tratamento de água para consumo humano. Assim, o objetivo foi encontrar os melhores valores de concentração para remoção de cor e turbidez e tempo de sedimentação, com isso, avaliar o poder das sementes de Moringa na remoção de Escherichia coli (E. coli) e bactérias heterotróficas em águas de baixa turbidez, já que a mesma não apresenta bom desempenho. As dosagens utilizadas foram de 500, 600, 800 e 1000 mg L-1 e os tempos de sedimentação testados foram entre 18 e 90 minutos. Os melhores valores de remoção de cor e turbidez foram encontrados com menores dosagens, por se tratar de água de baixa turbidez, resultando na contração ideal de 500 mg L-1. O tempo de sedimentação mínimo para a máxima eficiência de clarificação foi aos 90 minutos. E, por fim, após a definição da dosagem e melhor tempo de sedimentação obtiveram-se remoções de até 29% para E. coli e 66% para bactérias heterotróficas, estando dentro dos parâmetros de potabilidade para água de consumo humano.

Palavras-chave: Coagulantes naturais; Potabilidade; Jar test; Qualidade

1 Introduction

Northeastern Brazil suffers from one of the main problems faced in this century, water scarcity (EZE; ANANSO, 2014), with more than 14 million people without access to drinking water (NHIS, 2017). Thus, one of the main challenges faced today is to adapt treatments that purify water (PATERNIANI et al., 2010) reducing the spread of diseases and their effects, especially in rural areas. In Brazil, the Consolidation Ordinance No. 05 / 2017 (Annex XX) establishes the control and surveillance of water quality for human consumption and its standard of potability.

Potable water must comply with physical, chemical, organoleptic and microbiological standards. And for them to be achieved, it is necessary that the water then undergoes various processes, which include coagulation, flocculation, sedimentation, filtration and disinfection. The first three processes make up the clarification, the most important being coagulation, because through it occurs the destabilization of colloidal particles or in suspension present in the water captured for supply. Its main function is to remove part of the color and turbidity of the water (LIBANION, 2010).

The coagulants used may be of synthetic or natural origin. The most used in Water Treatment Plants (WTP) are the trivalent salts of iron and aluminum, but as described by Yin et.al (2010), there are disadvantages associated with the use of chemical coagulants, such as high acquisition costs, production of large volumes of sludge and the fact that it significantly affects the pH of treated water.

Therefore, the study of natural coagulants applied in water clarification has grown, which can compensate for the effects on human health, as well as be easy to use in rural areas. Moringa oleifera (MO) seeds can be used in both drinking water clarification and wastewater (KALIBBALA et al., 2009).

The seed extract solution contains cationic proteins that prove the strong coagulating effect of dissolved and suspended particles, especially in high turbidity waters (>100 uT) (CAMACHO et al., 2017). Its benefits are several, for example, biodegrability, does not present toxicity, low production of residual sludge and does not alter the pH and alkalinity of water (DÍAZ et al., 2014; YARAHMADI et al., 2009).

In addition, other studies such as those of Akınyeye et al. (2014), Bukar et al. (2010) and Rahman et al. (2010) state that BM can also contribute to the disinfection process. Because, with the removal of turbidity, microorganisms are also removed, part of them can be found aggregated to particles disseminated in water.

Most studies using MO for clarification do so in high turbidity waters. Because it is in these situations that it achieves its best performance (FRANCO et al., 2017; MADRONA et al., 2010). Thus, the objective of this research was to evaluate the performance of MO in the removal of color, turbidity and E. coli in the water of the São Francisco River, considered water with low level of turbidity (0 to 20 NTU), in order to understand the behavior of MO in these situations.

2 Materials and methods

2.1 Preparation of the coagulant solution

The seeds were collected from Moringa Oleífera trees at the Universidade Federal do Vale do São Francisco - UNIVASF - Juazeiro, Bahia. This was followed by the sequence described above: the seeds were peeled, ground, dried in an oven at 100℃ and sieved on an ABERT.EM 355 mm um-1 sieve. Then, the sieved powder was added in distilled water and the solution was stirred for 10 minutes on a magnetic stirrer (IKA C-MAG HS 7), preparing a mother solution of 20 g L-1 (2%) (EZE; ANANSO, 2014).

The solution was used in an interval of up to 24 hours, following the deadline proposed by Cardoso et al. (2008) whose storage interval of the recommended Moringa Oleifera solution was a maximum of 3 days, so as not to lose its characteristics and its coagulant power.

2.2 Collection and characterization of raw water

The raw water used in the tests was collected at the pumping station of the Autonomous Water and Sewage Service (SAAE), located on the banks of the São Francisco River, in the municipality of Juazeiro, Bahia, being collected in three different days (3 lots), during the months of January and February, times when the river water presents alterations in turbidity values, due to the higher precipitation rate. The water collected was characterized as to the apparent color, turbidity and pH parameters for the first stages of the experiment (determination of the best dosage and ideal sedimentation time) (Table 1). Then, the hardness, alkalinity and microbiological analyses were included: E. Coli and heterotrophic bacteria count.

Table 1 - Physical-chemical characterization of raw water.

Turbidity (uT)	Color (uH)	pH
21,9 ± 2,9	163,5 ± 17,5	7,89 ± 0,83

The pH values between 6 and 9.5 do not compromise the action of the coagulant (HEREDIA; MARTIN, 2009). So it was not necessary to correct the pH of the raw water. The turbidity values remained in the range of 20 uT, considered low turbidity water.

2.3 Water treatment: Jar Test operating conditions, dosage and filtration

To perform the clarification test, the Jar test device (Milan Test JT303M) was used, following the procedure described: at first 2 L of the water collected in each Jar test container was added, soon after, the solutions of the seeds of Moringa Oleífera were added in order to obtain the previously defined dosages (500 mg L-1, 600 mg L-1, 800 mg L-1 and 1000 mg L-1).

The operational parameters adopted were rapid mixing gradient of 280 rpm for 2 minutes, slow mixing gradient of 40 rpm for 30 minutes and sedimentation times of 60 and 90 minutes. Thus, after these times, samples were collected from the jars and the sample of clarified and unfiltered water (SF) was then analyzed for turbidity, color and pH parameters.

Subsequently, the samples of sedimented (or clarified) water were submitted to filtration (F) on slow filter paper (porosity 2 μm). Finally, turbidity, color and pH analyses were performed to verify the slow filtration action after the clarification process.

The color and turbidity removal values were adjusted by 2nd degree polynomials in order to evaluate the action of the Moringa Oleífera seed. In order to obtain the optimum dosage point of the coagulant, the Tukey test was performed at 95% probability, selected as the best based on efficiency and economy. The SISVAR program was used as a statistical tool in order to obtain the concentration of the most effective solution of Moringa Oleifera seeds in water treatment. The tests were performed in triplicate.

2.4 Sedimentation kinetics

To determine the sedimentation kinetics, the same procedure as in the previous item was performed for the preparation of Moringa Oleifera, rapid and slow mixing conditions, varying only the sedimentation times: 18, 36, 54, 72 and 90 minutes. At this stage there was no filtration, since the objective was to study the sedimentation speed. All samples were taken in triplicate and the data were treated in the SISVAR tool, identifying the best results.

2.5 Efficiency test for the removal of E. coli and heterotrophic bacteria in clarified and filtered water

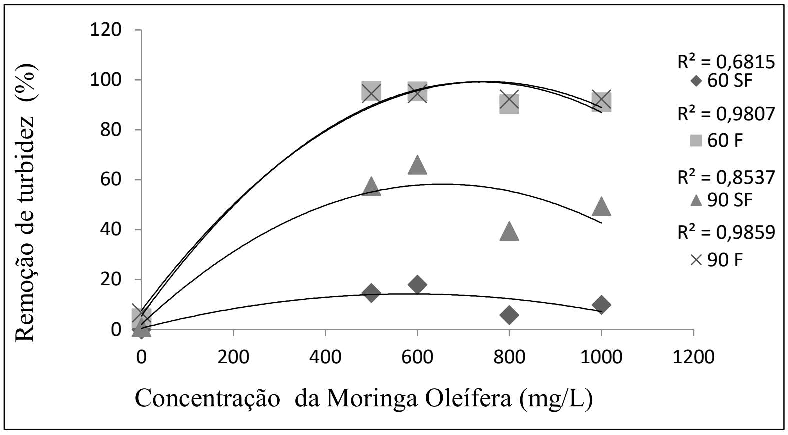
Taking into consideration the information from the previous stages, the same procedure was performed for the preparation of the seed and for the operations in the Jar Test. However, besides the color, turbidity and pH analyses, physical-chemical, hardness and alkalinity analyses were performed, as well as microbiological analyses of E. Coli and heterotrophic bacteria, for the collected water (raw water), water after clarification, and water after filtration. All analyses performed throughout this study were based on the Standard Methods for Examination of Water (APHA, 2012).

3 Results and Discussion

3.1 Selection of the best dosage

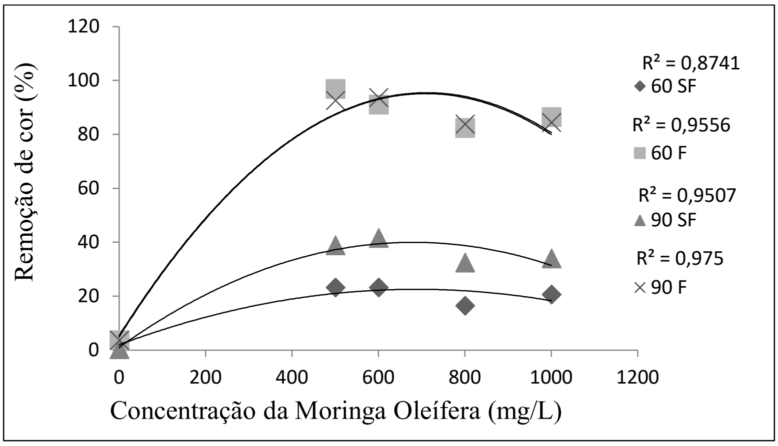
The graphs presented in Figures 1 and 2 present the average results of the removal efficiencies for turbidity and color respectively with filtration (F) and without filtration (SF). The good adjustments of the collected points, most of the variation coefficients (R2) close to 1, to the second degree polynomials can be noticed.

Figure 1- Removal of the turbidity of the raw water by the seeds of Moringa oleifera



Source: Research results by the authors.

Figure 2 - Removal of the color of the raw water by the seeds of Moringa oleifera



Source: Research results by the authors.

When observing the behavior of the curves of Figures 1 and 2, one can notice the reduction in the removal of color and turbidity, while a larger quantity of coagulant is added to the test, especially after the point of inflection of the curve, starting from 600 mg L-1. This behavior can be explained, because the water that was treated, being of low turbidity, does not present a large amount of dispersed minerals or clays and, therefore, to remove them it is necessary a smaller amount of the coagulant agent. Therefore, when the seeds are added in excess of what is necessary for complete coagulation, the particles of the seed powder are added to the suspended solids, contributing to the increase in color and turbidity values. Even for the same reason there is a significant difference between the removals of clarified water and after filtration, because all material suspended in the water is retained in the filter paper.

Tables 2 and 3 show that, according to the Tukey Test, the 500 and 600 mg L-1 dosages showed the best performance in the removal of turbidity and color, however, among the mentioned dosages there was no significant difference, thus, the most indicated dosage to be used in the clarification tests in low turbidity water is 500 mg L-1, because besides the best coagulation ratio, the material economy parameter was also considered. The letters "a" and "b" represent the significant difference between the data within each line.

Table 2 - Turbidity removal (%) for different sedimentation times and different dosages.

Sedimentation time	**Blank**	**500 mg L-1**	**600 mg L-1**	**800 mg L-1**	**1000 mg L-1**
60 min (SF)	-1	15 (ab)	18 (a)	6 (ab)	10 (ab)
60 min (F)	4	96 (a)	95 (a)	90 (a)	91 (a)
90 min (SF)	1	57 (a)	66 (a)	39 (b)	33 (b)
90 min (F)	6	95 (a)	95 (a)	92 (a)	92 (a)

SF - Clarified water without filtration. F - Clarified and filtered water.

Table 3 - Color removal (%) for different sedimentation times and different dosages.

Sedimentation time	**Blank**	**500 mg L-1**	**600 mg L-1**	**800 mg L-1**	**1000 mg L-1**
60 min (SF)	1	23 (a)	25 (a)	17 (a)	21 (a)
60 min (F)	4	97 (a)	91 (ab)	83 (b)	87(ab)
90 min (SF)	1	39 (a)	42 (a)	33 (ab)	22 (b)
90 min (F)	4	93 (a)	94 (a)	84 (a)	85 (a)

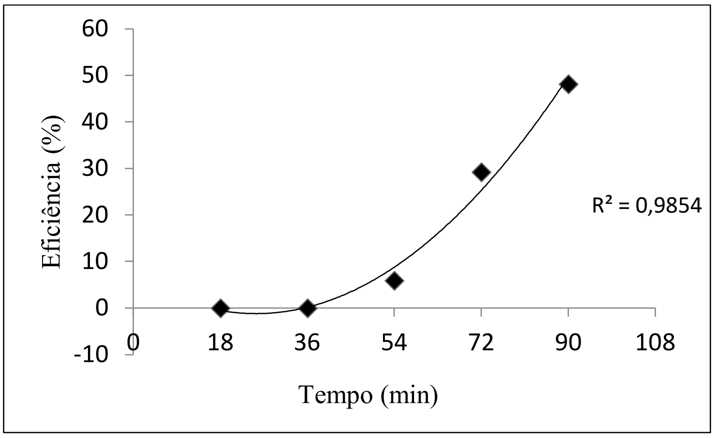
SF - Clarified water without filtration. F - Clarified and filtered water.

In terms of absolute values for color and turbidity, it was observed that the turbidity obtained after filtration was 1.0 to 1.3 uT above what is recommended by PRC 05, with a limit of 1.0 uT for 95% of the samples, after slow filtration. For the apparent color, the limit is 15 uH and the values found were between 5.5 and 12.2 uH, thus complying with the values established by the ordinance.

3.2 Sedimentation kinetics

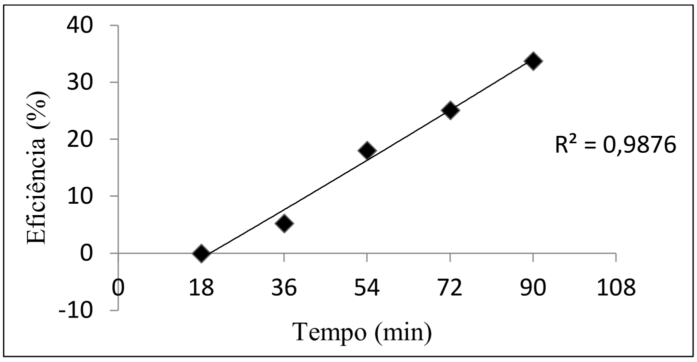
After performing the experiments with a dosage of 500 mg L-1 and collecting the samples within the previously established sedimentation times (18, 36, 54, 72 and 90 minutes), the turbidity and color removal data were shown in Figures 3 and 4.

Figure 3 - Sedimentation kinetics of turbidity in raw water



Source: Research data by the authors

Figure 4 - Color sedimentation kinetics in raw water



Source: Research data by the authors

When observing the color and turbidity curves presented in Figures 3 and 4, it can be noticed that their behavior is similar, increasing the removal values while there is an increase in the sedimentation time. This shows that the optimal times are around 90 minutes. Sufficient time for the sedimentation of soluble and suspended materials that are contained in the water to occur, components responsible for color and turbidity. Similar behaviors were presented in the works of Cardoso et al., (2008) and Lo Monaco et al. (2012), where the ideal sedimentation times were also around 90 minutes, with no significant difference for higher times in color and turbidity removal.

3.3 Efficiency test for the removal of E. coli and heterotrophic bacteria in clarified water

The raw water used in the tests for the removal of E. coli and heterotrophic bacteria was clarified with the solution of Moringa Oleifera seeds according to the optimal conditions established in the previous steps (500 mg L-1 and 90 minutes). In these conditions, the values obtained for turbidity, color and pH are described in Table 4. The results for E. coli and heterotrophic bacteria, after clarification and filtration, are described in Table 5, with the respective removal values.

Table 4 - Characterization of clarified and filtered water using the best dosage results and sedimentation time

Form of Care	Turbidity		Color		pH
	uT	%	uH	%	
Raw Water	14,0		144		7,15
Unfiltered	7,3	48%	99,7	31%	7,05
Filter	1,5	89%	32,3	77%	7,00

Table 5 - Removal of E. coli and heterotrophic bacteria (%)

Bacterias	Raw Water	Água clarificada

		No filtration	% Removal	Filtered	% Removal
E. coli (VMP/100 mL)	1600	1133	29%	1133	29%
Bacterias Heterotrophic (UFC/100 mL)	84	77	8%	28	66%

The E. coli count for the raw water of the São Francisco River showed high values, well above those found in the waters of the Rivers studied by Megersa et al. (2016) when they obtained an average value of 159 VMP/100 mL. The limit values presented in Portaria PRC nº 5 (BRAZIL, 2017) are absent in 100 mL, both at the exit point of the treatment system and at the point of use. It can be seen from the results presented in Table 5, that both the clarification and the filtration process did not promote the removal of E. coli that fit the water in the standard established by the PRC nº 5 (Annex XX) presenting maximum removals of 29%.

Regarding the removals of heterotrophic bacteria, the treatment added to the filtration promoted removal of 66%. As an auxiliary analysis on the microbiological quality of water, PRC nº 5 recommends that this should be performed as one of the parameters to assess the integrity of the distribution system, with the maximum allowed value of 500 UFC mL-1 (BRAZIL, 2017). The clarification followed by filtration reduced the values to 280 mL-1 CFU, below the maximum allowed, removal values close to those found by Megarsa et al. (2016).

Studies such as those of Bina et al. (2010) achieved removals around 90% in the analysis of E. coli and about 80% for heterotrophic bacteria. Results were higher than those found in this study. However, this can be justified, because the cited studies used the seeds of BM in the clarification of waters with initial values of color and turbidity higher than those found in the São Francisco River, source of this study.

Thus, the removal of microorganisms is associated with the removal of turbidity. Therefore, the ordinance (PRC nº 05) establishes turbidity as an important parameter to be respected, because it is an auxiliary indicator to microbiological parameters to assess water quality (BRAZIL, 2017). In addition, it is important to mention that the seeds of Moringa oleifera are not a disinfectant agent, but only an aid in this process.

In his work Megersa et al. (2016) also mentions that water characteristics, type and size of particles, alkalinity and other properties of the river can directly affect the performance of coagulants, unlike samples of synthetic water. The results obtained in the Kero River belonging to Ethiopia, in waters with low tubidity, obtained good results in the removal of E. coli and heterotrophic bacteria.

Results in conditions similar to this study were found by Nkurunziza et al. (2009), analyzing low turbidity waters in the range of 30-40 NTU. They concluded that MO seed extract was not effective in reducing E. coli, being one of the alternatives found to combine clarification with treatment of exposure to solar radiation.

3.4 Hardness

The water analysed had a calcium carbonate concentration of less than 60 mg L-1. It was noticed that the hardness remained with the values very close to the initial value, even after the treatment. In their study Nkurunziza et al. (2009), under the same conditions, they concluded that even after treatment the hardness also remained in the same concentration range. Validating the results acquired in this study.

The hardness values were well below the maximum allowed, obeying the limit of 500 mg L-1 established by CRP nº 05 (BRAZIL, 2017).

3.5 Alkalinity

For water directed to supply, according to the ordinance, the established limit is 400 mg L-1, described in Annex XXI of PRC No. 5 (BRAZIL, 2017). It can be seen that the values remained within the permitted limits, remaining practically unchanged, even after treatment. Similar results were obtained by Eze and Ananzo (2014), when they performed the treatment with MO seeds in low turbidity waters, obtaining results with small variations even after the treatment.

4 Conclusion

Among the various dosages of the tested MO seed solution, the one with the best performance was 500 mg L-1, achieving turbidity and color removals of up to 66% and 42%, respectively. For lower turbidity values, lower concentrations of MO are required.

Among the sedimentation times tested, the time of 90 minutes showed a maximum efficiency for turbidity and color removal.

As for bacteriological characterization, E. coli had a maximum removal rate of 29%, and it was necessary to submit the water to a disinfection process. The value of heterotrophic bacteria after treatment was 280 mL-1 CFU, being within the limit allowed by CRP. Thus, the link between removal of microorganisms and removal of turbidity was validated.

Thanks

The authors thank MEC/FNDE for the financial support and scholarships granted through the PET Knowledge Connections Environmental Sanitation Tutorial Education Program.

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