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Multi-Stage Filtration (MSF) Technology with Natural Coagulants for Raw Water Treatment from the Sinu River in Colombia

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Abstract

Objective: To determine turbidity removal efficiency of raw water samples, by using Multi-Stage Filtration technology and complemented with natural coagulants. **Methods/Analysis:** Water samples were taken from the Sinu River. A pilot plant was set up in laboratory, and treatability tests were carried out on samples with different scenarios. **Findings**: The best treatment for raw water was obtained when 240 $m^3m^{-2}d^{-1}$ rates were applied for 200 NTU initial turbidity. There were no alterations in pH and water alkalinity after treatability tests. **Application**: This raw water treatment technology is very useful and appropriate to be applied in rural areas with difficult access and scarce economic resources, since its simplicity does not require costly inputs or maintenance.

Keywords: Activated Carbon, *Moringa oleifera*, Multi-Stage Filtration, Natural Coagulants, Water Treatment

1. Introduction

Quality Risk Index of Water -IRCA[1] is used in Colombia as an indicator to determine water quality, based on degree of risk of diseases occurrence related to non-compliance with physical, chemical and microbiological characteristics of water for human consumption. Generally, in the country, large and medium urban centers receive a supply of decent quality water, without risk or minimal risk to human health and; as urban size decreases and rurality increases; water quality worsens, increasing risk level[2]. In this way, in smaller municipalities and rural areas, IRCA is predominantly high and in some cases sanitarily unviable. In 2016, out of the total of departments that administratively make up the country, 37.5% presented water with no risk in the urban area and 15.6% in rural area. In contrast, 31.25% of the departments had a high-risk level in the rural area[3].

This situation is mainly due because in rural population centers infrastructure for provision of potable water and basic sanitation, is built without a technical and financial analysis to allow choosing the most appropriate alternative to fit demand features. Therefore, in many cases, the selected alternative requires substantial investments and continuous technical assistance, representing high operation and maintenance costs that communities are not able to pay. Therefore, infrastructure is neither operated nor used[4].

Multi-Stage Filtration (MSF) can provide a robust treatment alternative for surface water sources of variable quality in rural communities, with low operation and maintenance costs. MSF is a combination of slow sand filters (Slow Sand Filters (SSFs)) and pre-treatment systems. It was developed in the 1990s by researchers in Colombia, where is now being applied on a larger scale. In addition, some efforts are being made to support wider

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dissemination and further development, particularly in Latin America[5]. Worldwide experience with MSF shows the significant potential of this treatment concept to produce potable water from contaminated turbid water[6].

Water Quality obtained using MSF technology is comparable, and even better than the one obtained with a potabilization plant with conventional technology, since MSF elimination processes are mainly physical and biological[5].

The use of natural coagulants is an important option in water treatment for small communities. They can be prepared manually, allow a considerable reduction in turbidity and apparent color of raw water[7] and they do not produce significant changes in pH and alkalinity of treated water[8,9].

Among the most effective and proven natural coagulants is *Moringa oleifera* seed extract. Its coagulant features have been widely recognized and it is undoubtedly the natural coagulant most studied by the scientific community[10].

This study aimed at determining the efficiency of MSF technology in raw water treatment clarified with *Moringa oleifera* seed coagulant and at verifying its technical viability as a purification solution in rural areas.

2. Material and Methods

2.1 Samples of Raw Water

Water samples for this study were taken from the Sinu River, specifically from the irrigation channel located in the Mocari neighborhood, city of Monteria. Two simple samplings were carried out, the first in the dry season and the second in the rainy season of the region in 2013.

2.2 Filters Materials and Preparation of Natural Coagulant

Sand and gravel for the filter train were taken from the Sinu River. It was necessary to carry out washing and sieving processes to achieve the desired quality. For sieving the sand, a 0.7 mm sieve was used, while for the average gravel a 0.5 "- 2" sieve was used. The 2 "- 4 sieve was used for the gravel[11].

The coagulant used for this work was obtained from *Moringa oleifera* seeds following the procedure described by [12]. Turbidity, pH and alkalinity of water were estimated, according to the standard methods proposed by The American Public Health Association[13].

2.3 Multi-Stage Filtration Pilot Plant (MSF) Assembly

Three (3) filters were mounted on 6" PVC pipe, with a length of 75 cm for each tube. The first tube corresponded to the Coarse Gravel Filter, which stones had a diameter between 2 to 4in and filled the tube 60 cm. The second tube was the medium gravel coarse filter, with stones diameter between 0.5 to 2 in and filling up to 60 cm. The third Tube was the slow sand filtration unit, made up of a 10 cm thick gravel base of the tube filling, followed by an average 10 cm gravel filling and, finally a 20 cm sand layer. The filters were connected in line, by means of Ø½ "PVC hoses.

2.4 Filtration Rates

Hydraulic pre-tests were carried out in the MSF pilot plant to define the best application rates. The flow was calculated by volumetric gauging and filtration rate was determined with the pipe surface area.

2.5 Experimental Design

An experimental design 2^3 was made, that is, of 3 factors in two levels. The first factor taken was filtration rates (100 and 160 $m^3\ m^{-2}\ d^{-1}$), the second factor was turbidity of raw water of the Sinu River (105 and 208 NTU) and the third factor was coagulant application (clarified water and not clarified water). The variables measured responses were turbidity, pH and alkalinity of the effluent water of the MSF pilot plant. The Statgraphics Centurion XVI Software (Version 16.0.07) was used to analyze the results and an ANOVA was applied with a 95% confidence level

3. Results and Discussion

Initial characteristics of samples of raw water from the Sinu River, used in the different trials, are shown in Table 1.

Table 1. Characteristics of turbidity, pH and alkalinity of raw water

Sample	Turbidity (NTU)	pH	Alkalinity (mg L^{-1} $CaCO_3$)
#1	105	6.90	22.0
#2	208	7.15	24.0

The raw water samples show a tendency to neutral pH in the water body, with an alkalinity indicating a balance between carbonates and bicarbonates present in raw water[14]. However, low alkalinity of water can affect removal efficiency of some synthetic coagulants during the coagulation process[15]. In contrast, water alkalinity does not interfere with efficiency of natural coagulants such as extracts of *Moringa oleifera* seed[16].

Results of turbidity removal in water samples are shown in Table 2, which shows behavior of the MSF on treating raw water and clarified water with natural coagulant of *Moringa oleifera*.

When an ANOVA analysis was applied to the removal efficiency from the filtration rates, turbidity of raw water and use of natural coagulant, a P-value of 0.2392 was obtained, which was higher than 0.05, indicating that there is no statistically significant difference between the mean turbidity removal when using or not using coagulant, with a 95.0% confidence level. However, when the ANOVA is calculated with the final turbidity values, a P-value of 0.0219 is obtained, which is less than 0.05, that is, there is a statistically significant difference between the means of the final concentrations of turbidity in water when natural coagulant is applied. This result is very useful, since it shows that when coagulant is not applied to raw water treated with MSF technology, it is not possible to comply with the turbidity required in the Colombian potable water standard (equal to or less than 2.0 NTU[1]) since higher turbidities were obtained to 5.0 NTU. Whereas when coagulant was applied in the treatment with MSF technology, lower turbidities were achieved than the required by the standard.

Figures 1, 2 show the behavior of pH and water alkalinity, respectively, after the use of coagulant and MSF technology.

In Tables 3, 4, results of the ANOVAS for pH and Alkalinity are shown, from the values shown in Figures 1 and 2, respectively.

Table 2. Efficiency of turbidity removal according to the application rate, initial turbidity of the samples and use of natural coagulant

Filtration Rate	Raw Water Turbidity (NTU)	Coagulant (*M. oleifera*)	Final Turbidity (NTU)	Removal (%)
$100\ m^3\ m^{-2}\ d^{-1}$	105	With	1.16	99.99
	208	With	1.20	99.40
	105	Without	6.37	99.94
	208	Without	5.80	97.10
$160\ m^3\ m^{-2}\ d^{-1}$	105	With	1.19	99.99
	208	With	0.94	99.53
	105	Without	8.00	99.92
	208	Without	17.30	91.35

Table 3. ANOVA for the pH of treated water

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-Value
Between Groups	0.12005	1	0.12005	1.2	0.3149
Intra Groups	0.59910	6	0.09985		
Total (Correlation)	0.71915	7			

Table 4. ANOVA for alkalinity of treated water

Source	Sum of Squares	DF	Mean Square	F-ratio	P-Value
Between Groups	0	1	0	0	1
Intra Groups	8	6	1.33333		
Total (Correlation)	8	7			

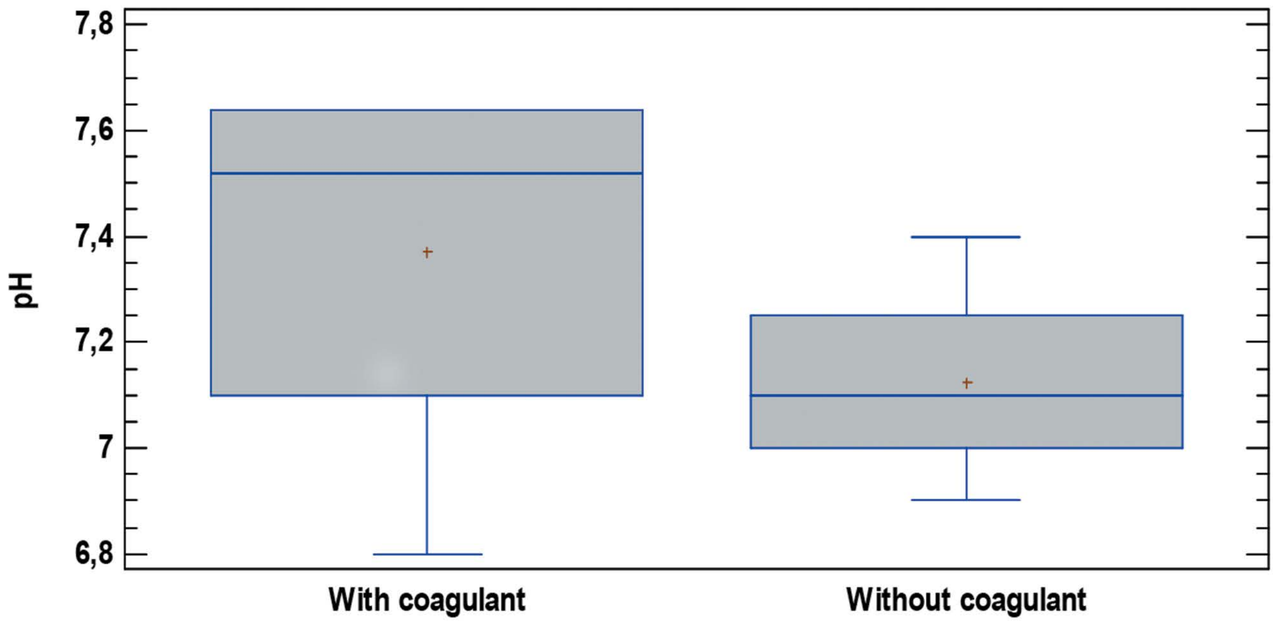

Figure 1. pH behavior of water treated with MSF.

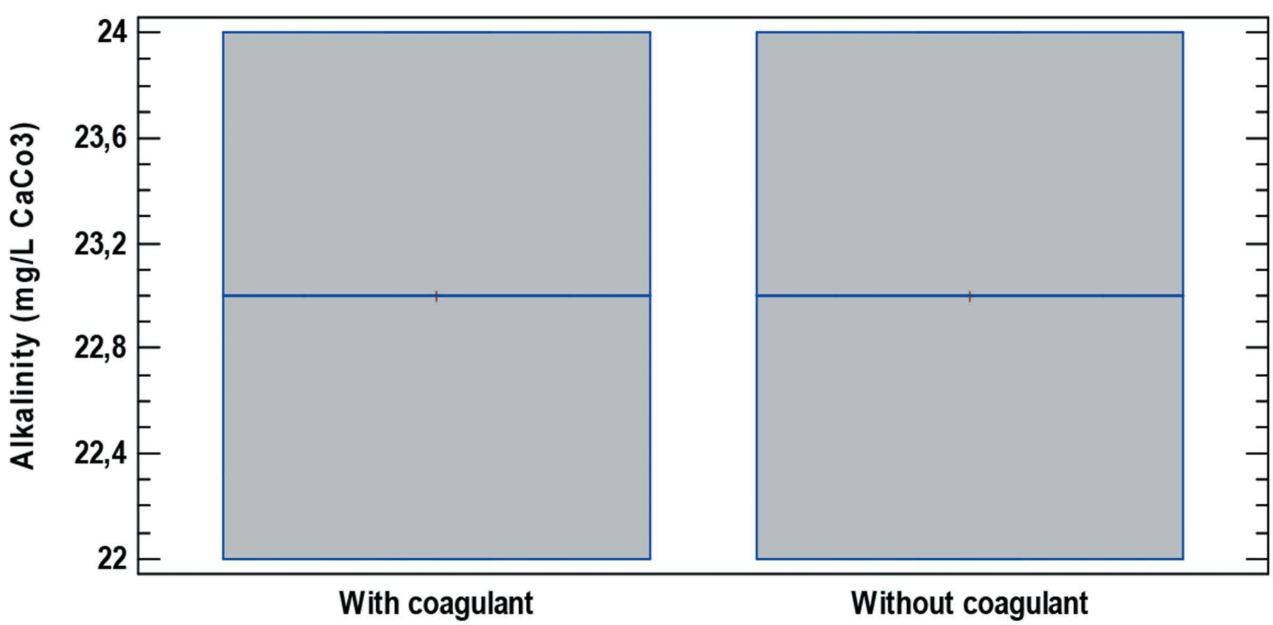

Figure 2. Alkalinity behavior of water treated with MSF.

Since the P-value is greater than or equal to 0.05, both for pH and for alkalinity of treated water, there is no statistically significant difference between pH mean and alkalinity mean, when the coagulant is applied or not, with a 95.0% confidence level. In other words, there is no statistical evidence that the use of natural coagulant and MSF technology significantly alter the pH and alkalinity of the water from Sinu River when it is used for the purification of raw water. The same results were reported by[9] and by[16] when natural coagulant extracts were used in the treatment of raw water from the Sinu River.

4. Conclusions

MSF Technology complemented with coagulation with extracts of *Moringa oleifera* seed allows that, with relatively fast filtration rates, high efficiencies to be achieved in the raw water treatment from the Sinu River. Without the use of natural coagulant, samples treated would not achieve quality standards for turbidity required in the Colombian sanitary standard. The application of MSF technology, with and without natural coagulant, did not significantly affect the initial pH and alkalinity characteristics of the treated samples.

Filtering in multiple stages is much more efficient than performing only slow filtration in sand. Thick gravel filters are key to reducing water turbidity to acceptable levels for slow filter and MSF fast filter, to achieve near 100% of removals. The use of MSF is recommended in rural areas of the country where access is difficult and communities have limited economic resources.

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