TECHNICAL PAPER

WATER TREATMENT BY MULTISTAGE FILTRATION SYSTEM WITH NATURAL COAGULANT FROM *Moringa oleifera* SEEDS

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ABSTRACT: This study presents an evaluation of a pilot multistage filtration system (MSF) with different dosages, 131 mg L^{-1} and 106 mg L^{-1}, of the natural coagulant extracted from *Moringa oleifera* seeds in pre-filtration and slow filtration stages, respectively. The system was comprised by a dynamic pre-filter unit, two upflow filters in parallel and four slow filters in parallel, and in one of the four filters had the filter media altered. The performance of the system was evaluated by monitoring some water quality parameters such as: turbidity, apparent color and slow filter load loss. The stages that have received the coagulant solution had better treatment efficiency compared with the steps without it. However, the direct application of the coagulant solution in the slow filter caused rapid clogging of the non-woven blanket and shorter career length.

KEYWORDS: multistage filtration system, slow filtration, water coagulation.

TRATAMENTO DE ÁGUA PARA ABASTECIMENTO PELO SISTEMA FILME COM EXTRATO DE SEMENTES DE *Moringa oleifera*

RESUMO: O trabalho apresenta uma avaliação do sistema-piloto de filtração em múltiplas etapas, com aplicação de diferentes dosagens (131 mg L^{-1} e 106 mg L^{-1}) do coagulante natural extraído de sementes de *Moringa oleifera*, nas etapas de pré-filtração e filtração lenta, respectivamente. O sistema foi constituído por uma unidade de pré-filtro dinâmico, duas unidades de pré-filtros de fluxo ascendente em paralelo e quatro unidades de filtros lentos em paralelo, sendo que, em um dos filtros lentos, houve variação do meio filtrante. O desempenho do sistema foi avaliado por meio de parâmetros como turbidez, cor aparente e perda de carga dos filtros lentos. As etapas que receberam a solução coagulante tiveram maior eficiência de tratamento se comparadas com as etapas sem o recebimento da mesma. Entretanto, a aplicação direta da suspensão coagulante no filtro lento causou rápida colmatação da manta e menor tempo de duração da carreira.

PALAVRAS-CHAVE: filtração em múltiplas etapas, filtração lenta, coagulação da água.

INTRODUCTION

Water is a vital resource to life, essential for the population, agriculture, industry, recreation, livestock watering, aquatic life support, etc. Its importance depends on the abundance, wants and needs in its use and management. However, many applications are restricted to a range of water quality, which is indicated by means of physical, chemical and biological assessments of the presence of elements, substances and organisms. So, it is defined if the water is polluted and it is established the need or not to subject it to any process or treatment technique.

Water contamination can occur through the release of untreated sewage into water bodies; garbage that is often deposited on the bottom of rivers; agrochemical, manure and fertilizers, pesticides used in farming, which are sources of diffuse pollution, other materials such as non-degradable pollutants and industrial waste. The discharge of domestic untreated or deficiently treated sewage in surface waters provides an increase in the concentration of pathogens that can cause disease directly or indirectly in men and animals (BAUER, 2011).

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Concerns about the availability of drinking water has required all new awareness regarding this feature, i.e., the optimization of the use and search for quality treatment at low cost, which may be available to the various segments of society. In locations where there are no policies defined regarding water treatment, as small communities, there should be a search for technologies suitable to the quality of water to be treated, with the use of material available in society, insertion of the population in the steps of searching, implantation, development and maintenance of treatment and prioritize the low cost and subsequent ease to the company in question (GLEICK, 2008; VERAS & DI BERNARDO, 2008; OCHIENG, 2004; JAVARES JR et al., 2007).

Among the water treatment options for small communities are: slow filtration, use of solar disinfection, chlorination, use of natural coagulants, and use of ceramic pots and boiling water. The slow filtration is a very feasible option to be implemented in small communities, as it presents ease maintenance due to the possibility of using synthetic non-woven blankets on the top layer of the filter media. However, the increase of improper disposal of household and industrial waste in water bodies causes increased turbidity and solid levels that hinder employability of these filters. In seeking to reduce the impact of poor water quality in slow filters, pre-treatments have been used as gravel filters that reduce the concentration of particles present in water gradually to the step of filtration, this technology that unites pre-treatment to slow filtration is named multistage filtration system - MSF system (OCHIENG et al., 2004; VERAS & DI BERNARDO, 2008; ANDERSON et al., 2009).

The use of natural coagulants is also an important option in the treatment of water for small communities, which can be prepared by hand and it provides a reduction in turbidity and apparent color of the contaminated water. The seeds of *Moringa oleifera* tree species have been shown effective for this operation, since they have coagulant activity responsible for the aggregation of particles and microorganisms, which can be more easily removed during the water treatment (FERREIRA et al., 2011). Other authors also emphasize the use of *Moringa oleifera* as a low cost alternative when compared with the use of chemical coagulants (MATOS et al., 2007). This species also has benefits for human consumption due to the properties present in combating anemia, rapid growth and ability to produce soap and cosmetics.

In the search for expanding the employability of the multistage filtration process, the use of natural coagulants may assist in the aggregation of colloidal particles and microorganisms, if coupled to the stages of pre-treatment and slow filtration system (KATAYON et al., 2006).

Therefore, the objective of this study is to evaluate the use of different doses of the extract of natural coagulant extracted from *Moringa oleifera* seeds on the stages of upflow pre-filtration and Multistage Filtration System slow filtration during the water treatment.

MATERIAL AND METHODS

The pilot installation of the Multistage Filtration System for the experimental investigation was mounted at the Laboratory of Hydraulics, Faculty of Agricultural Engineering at UNICAMP, in the city of Campinas, state of São Paulo, Brazil.

The raw water used as affluent in the experiment was prepared artificially by the addition of Bentonite to the water network, in order to achieve initial turbidity of 100 NTU and kept under constant stir at 140 rpm in an external reservoir with a capacity of 1 m^3.

Then, the water flow to the dynamic gravel pre-filter unit (PFD), and subsequently distributed to two treatment lines. The first line (Line 1) was comprised of a unit of upflow gravel pre-filter (PF1), which fed two slow downflow filters (FL3 and FL4) running in parallel, and FL4 received the application of the *Moringa oleifera* seed extract. The second treatment line (Line 2) was also composed by upflow gravel pre-filter (PF2), in which occurred the application of the seed extract of *Moringa oleifera*. This pre-filter fed other two slow filters (FL1 and FL2). The final effluent of all slow filters was directed to an internal reservoir (R2), which, when reached its maximum level, directed the water back to the external reservoir, thus maintaining a continuous flow of the system operation. A general scheme of the pilot installation and points of application of the suspension coagulant are shown in Figure 1.

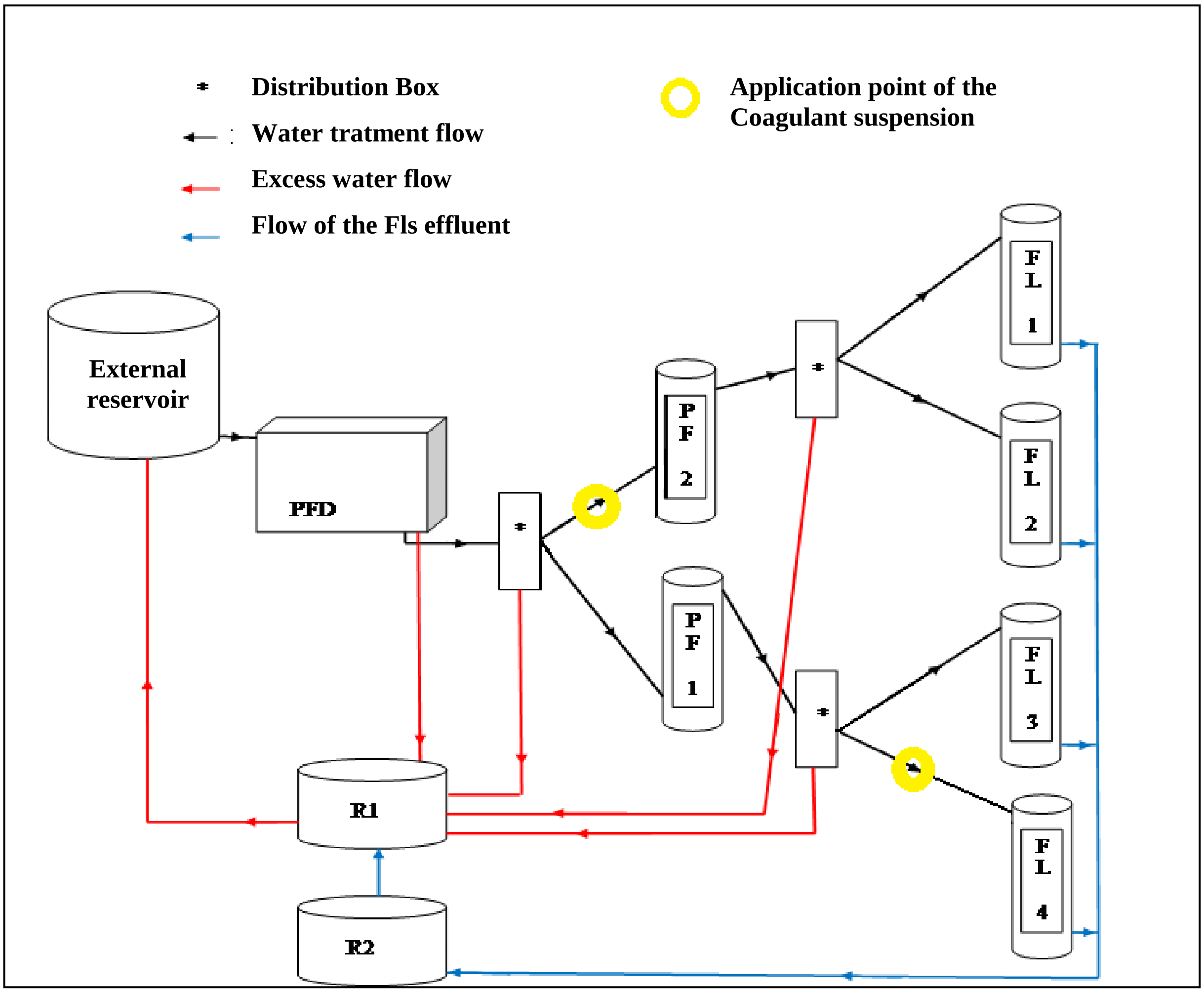

FIGURE 1. Pilot installation of multistage filtration system.

The desired intake PFD flow was obtained through a rotameter control. After the PFD output, water was intended for distribution box that had two spillways that fed the PF1 and 2. The PFs effluent was intended for two distribution boxes that worked in parallel and each box contained two spillways that fed their slow filters. Each distribution box intended their excess water to another internal reservoir (R1), which, when reached its maximum level, also intended the water to the external reservoir.

All seven units were built in acrylic, the PFD in a prismatic shape, volume of 0.06 m^3 (0.10 m x 0.75 m x 0.80 m), with an application rate of 48 $m^3(m^2\ day)^{-1}$, downflow and gravel filter media; PF1 and 2 in cylindrical shape with a diameter of 0.16 m, 1.60 m in height and volume of 0.032 m^3, upward flow and application rate of 24 $m^3(m^2\ day\ )^{-1}$; the FL1; 2; 3 and 4 had the same dimensions as the PFs, downflow, with application rate of 6 $m^3(m^2\ day)^{-1}$. The characteristics of the filter media in each unit are shown in Table 1.

The characteristics of the non-woven blankets used in the top layer of the filter media of slow filters are shown in Table 2. Initially, all slow filters had three M2 layers, however, due to the rapid clogging verification of the blankets by applying the coagulant suspension in the slow filter 4, only in this filter it was changed the number of layers of non-woven blankets, from three M2 layers to only one M1 layer.

TABLE 1. Media filter features of the dynamic gravel pre-filter PDF, upflow filter PF and slow downflow filter FL.

Units	Layer	Layer thickness (mm)	Granulometry (mm)
PFD (gravel)	higher	200	3.36 to 6.35
	intermediate	200	9.52 to 12.7
	lower	200	19.1 to 25.4
PF (gravel)	higher	200	1.68 to 2.4
	higher intermediate	200	3.36 to 6.35
	lower intermediate	200	9.52 to 12.7
	lower	200	12.7 to 19.1
FL (sand)	-	400	0.15 to 1.2

TABLE 2. Features of non-woven blanket used in the intermediate layer top of slow filter media.

Name	Brand	Weight
M1	Ober	150 g m^{-2}
M2	Ober	400 g m^{-2}

Initially, tests were performed only with Raw Water and they were conducted until the time when all slow filters reached the load drop of 1.0m, which occurred after 18 days. During the water treatment, with the introduction of the coagulating suspension in the steps of pre-filtration and slow filtration, the system has operated normally, except that when FL4 reached the maximum load loss with 3M2 on the top sand layer had its operation stopped, clean and reestablished after replacing the blankets by 1M1. Only when the FL4 reached its maximum load loss with 1M1 is that the rest of the system had also shut down its operation.

The cleaning of the dynamic pre-filter was performed by revolving the top of the granular media, with the aid of a rake and then a bottom discharge for the removal of solids retained in the filter media occurred. This operation was performed once a week. A pre-cleaning of filters was carried out through bottom discharges, also held once a week. The slow filters had their careers filtration initiated by the introduction of water upwardly to remove air bubbles. Then, the water addition downwardly occurred. The careers of filtration of slow filters were considered closed when the load drop reached 1.0m. At this time occurred the filters washing, by opening the outlet valve to drain all contained water and then manual removal of layers of non-woven blankets from the top of the sand layer, to washing in running water and subsequent replacement.

The coagulant suspension responsible for the aggregation of particles in the water treatment system was prepared from the seeds of *Moringa oleifera*. In this study, dry pods were harvested from the experimental field of the Faculty of Agricultural Engineering at Unicamp, Campinas; seeds were removed from the pods and placed in a desiccator for 24 hours, in order not to acquire moisture and stored under refrigeration, according to recommendations of KATAYON et al. (2006), for up to 4 months.

In the days of the coagulant suspension preparation, seeds were peeled and processed in a grinding machine, then the resulting powder was passed through a domestic sieve of openings of 0.8mm; the milled powder was mixed with distilled water to the concentration of 11.884 g L^{-1} of *Moringa oleifera* seeds, stirred for 2 minutes on a magnetic stirrer and sifted the solution using a sieve of openings of 125 µm, being suitable for application in water of pH around 7. Daily, it was prepared 9 L of solution to maintain the system constant supply for 24 hours. According to PRASAD (2009), after three days of storage at room temperature, the color removal efficiency of the extract of seeds of *Moringa oleifera* decreases. In an attempt to minimize the effects of loss of efficiency of the coagulant solution, it was prepared for the system supply for only 24 hours.

From this initial suspension two metering pumps direct appropriate dosages for the pre-filter and slow filter stages.

After performing a first test of treatment of raw water without the addition of coagulant in the multistage filtration system, it was performed a turbidity results average obtained from each treatment stage. From these data and the values obtained by ARANTES (2010), who establishes the relationship between different values of turbidity of raw water for different values of concentration of seed extract of *Moringa oleifera*, it was determined to investigate the dosages of 131 mg L^{-1} of coagulant suspension per liter of water to be treated in the pre-filtration stage and 106 mg L^{-1} for the slow filtration stage.

The coagulant solution used in both application points came from the same reservoir, thus the dosage control for each application point was made by controlling the flow of metering pumps and valves arranged in small outputs of their respective hoses.

For the evaluation of the treatment system efficiency, it was conducted a monitoring of physical and chemical characteristics in the affluent and effluent of the units, with sampling frequency shown in Table 3, according to recommendations of VERAS & DI BERNARDO (2008) and Standard Methods (APHA/AWWA/WEF, 2005). Besides these parameters, it was monitored the filtration rates through spillways, in all stages of the system, and the load loss in slow filters. It was defined eight points of sample collection for the analyzes: raw water (AB), the effluent stages: dynamic pre-filter (PFD), pre-filters (PF1 and 2) and slow filters (FL1; 2; 3 and 4).

The interpretation of results was made with simple statistical analysis, using averages, standard deviation and variance.

TABLE 3. Analyzed physico-chemical parameters and sampling frequency.

Parameter	Frequency
Turbidity	Daily
Apparent color	Daily
pH	Daily
Temperature	Daily
Electrical conductivity	Daily
Dissolved oxygen	Daily

RESULTS AND DISCUSSION

The raw water reached peaks of 117NTU and the dynamic pre-filter, in this case, reached maximum efficiency of 54% in this turbidity removal during the days of treatment. On average, the turbidity removal efficiency of the first stage of pre-treatment was 30%. The effluent from the pre-filter 1, without the addition of coagulant suspension, averaged 23 NTU during the days of treatment, while the pre-filter 2, with the addition of coagulant suspension, had an average of 10 NTU (with a minimum of 4.49 NTU), a difference of 20% in efficiency between the stages that ran in parallel, which demonstrates the effect of the coagulant suspension in reducing turbidity. The average removal efficiency in turbidity was 62% for PF1 and 84% for PF2.

The slow filters 3 and 4 of the treatment Line 1, from the pre-filter without receiving natural coagulant (PF1) showed distinct values of final turbidity, since FL4 will receive the coagulant suspension. The FL3 presented the turbidity final value of 2.3 NTU, which accounted for the treatment line an average efficiency reduction of 97%, while the FL4 achieved 99% of removal efficiency, with a final value of 1.3 NTU. The FL3 had reached 0.10 m of load drop after a day of testing, while the FL4 had already completed his career, reaching 1.0 m. The replacement of three layers of synthetic blankets (3M2) above the sand layer of this slow filter by only one layer of M1 blanket increased the duration of filtration career for just one more day, and the removal efficiency of the filter remained sluggish around 99%, with an average final value of turbidity of 1.1 NTU. In this study, it was obtained the highest reduction in water turbidity than that obtained by PINTO & HERMES (2005), in a study conducted also with *Moringa oleifera* seed extract. The authors point out a reduction of turbidity of 23.6 NTU to 3.2 NTU after coagulation and slow filtration and 6.4 NTU only with slow filtration without addition of coagulant solution.

The load loss in slow filters may be visualized in Figure 2. The 1st test day presents all filters with three layers of M2 blanket, the 2nd and 3rd days refer to the test after changing three layers of M2 blanket, by a M1 blanket layer, on the top filtering layer of FL4, demonstrating that the loss of maximal load for this slow filter occurred in just one day. Then, there was the emptying of this slow filter, removing three layers of M2, replacement for only one layer of M1 and restart of the filtration process of only this filter, whereas the other slow filters were still operating normally.

It is apparent that the addition of coagulant suspension from the seeds of *Moringa oleifera* directly influenced the duration of the career filtration, which was only one day before the filling of the blanket, as in experiment without applying the coagulant solution career lasted 18 days. This demonstrates the ability of flake formation and sedimentation on top of the layer of filter media from FL4. The change in non-woven blanket in FL4, these assays with coagulant suspension did not affect the duration of its career, because after switching the blanket the career yielded just one more day of filtration.

The FL3 without receiving coagulant solution had the longest duration. While the FL4 had already reached the maximum water column twice, the slow filter 3 was still with a height of 0.30 m, and the FL1 and 2 had reached about 0.4 and 0.7 m of load loss at the same time.

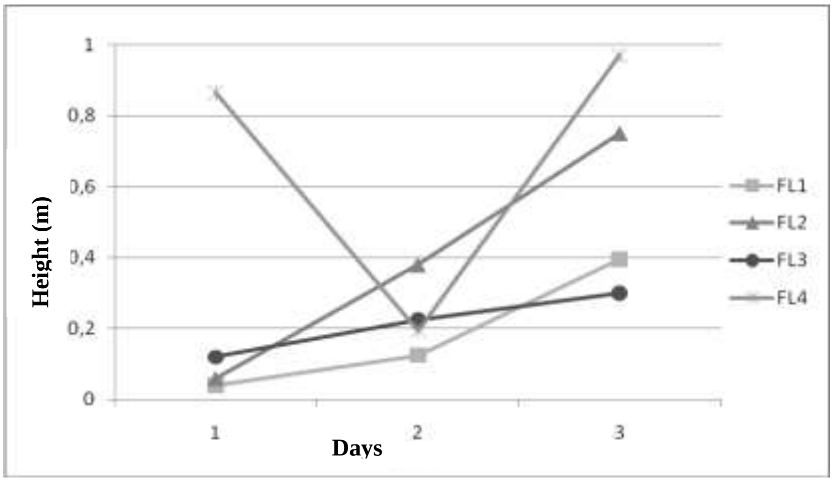

FIGURE 2. Load loss on slow downflow filters from the Multistage Filtration System – presence of coagulant suspension, PF2: 131 mg L^{-1}, FL4: 106 mg L^{-1} - 1st day FL 1; 2; 3 and 4 with 3 M2 - 2nd and 3rd day FL 1; 2 and 3 with 3 M2, FL4 with 1 M1.

For the apparent color parameter, the removal efficiency of the dynamic pre-filter was on average 23%, whereas the peak day reached 48%. The PF1 and 2 reached 62 and 82% efficiency reduction, respectively, values which show the benefit of adding the coagulant suspension at this stage, the effluent ready for the subsequent step. In the treatment line 1, the FL3 contributed to the removal of 89% and the final effluent showed 16.0mg.L-1 PtCo, with overall removal efficiency of 97%. The FL4, when with three layers of M2, averaged final apparent color of 11.0 mg L^{-1} PtCo, with 98% of removal of the final system. With only one M1 layer, this filter showed the same slow removal capacity, i.e., 98%. In the treatment line 2, the slow filters 1 and 2 reached average 87% of removal efficiency of apparent color of the effluent over the pre-filter and the final line of treatment achieved 98% removal efficiency in these filters with final value of 9.0 mg L^{-1} PtCo. The final values obtained by treatment lines, which at some stage come into contact with the suspension coagulant, can be framed within acceptable limits for human consumption, 15 mg L^{-1} PtCo, according to the ORDINANCE 2.914 of the MINISTRY OF HEALTH (2011). The average values of apparent color and turbidity throughout the stages of the MSF system can be seen in Figure 3.

During application of the coagulant solution it was observed the formation of a layer of gelatinous aspect on top layer of the pre-filter and the non-woven blankets layers of PF4, resulting from the flake formation from the coagulant suspension.

The remaining analyzed parameters, electrical conductivity, dissolved oxygen; pH and temperature were kept constant throughout the stages of treatment, as can be seen in Figure 4.

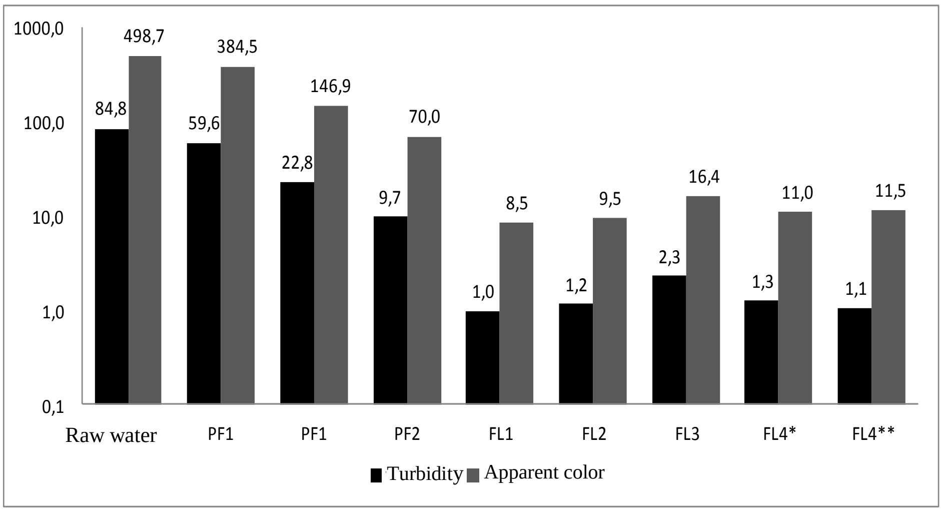

FIGURE 3. Turbidity (UNT) and apparent color (mg L^{-1} PtCo) on stages of Raw water, dynamic gravel pre-filter, upflow filter (PF1 and 2) and slow downflow filters (FL 1; 2; 3 and 4). Presence of coagulant suspension - PF2: 131 mg L^{-1}, FL4: 106 mg L^{-1} - FL 1; 2 and 3 with 3 M2 - FL 4* 3M2 **1M1.

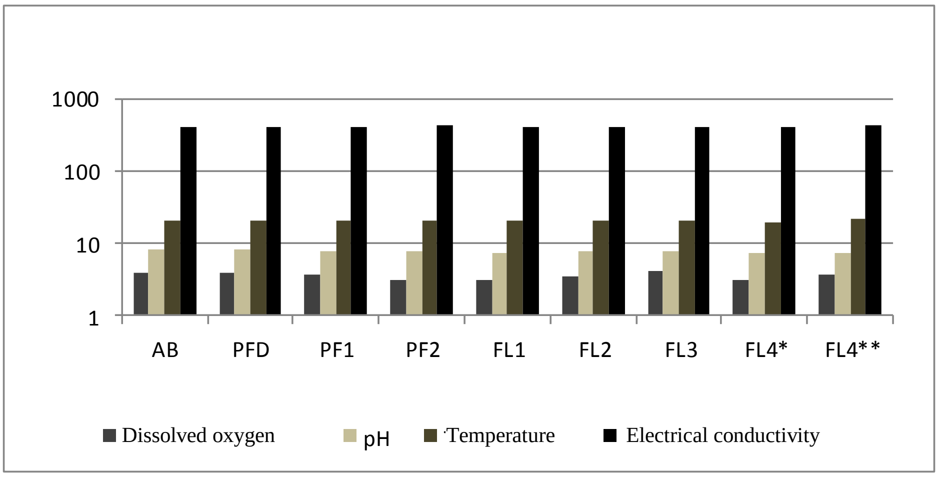

FIGURE 4. Dissolved oxygen (mg L^{-1}), pH, temperature (°C), electrical conductivity (µS cm^{-1}) on stages of Raw water, dynamic gravel pre-filter, upflow filters (PF1 and 2) and slow downflow filters (FL 1; 2; 3 and 4). Presence of coagulant suspension - PF2: 131 mg L^{-1}, FL4: 106 mg L^{-1} - FL 1; 2 and 3 with 3 M2 - FL 4* 3M2 **1M1.

CONCLUSIONS

The dosages of 131 mg L^{-1}, 106 mg L^{-1} of coagulant solution extracted from seeds of *Moringa oleifera*, the steps employed in pre-filter and slow filter, respectively, proved to be efficient in removing turbidity and apparent color of the water, through the MSF system, as a filter aid.

The pre-filtration without applying the coagulant suspension had 62% efficiency in removing turbidity and apparent color of the water. The application dosage of 131 mg L^{-1} of coagulant suspension of seeds of *Moringa oleifera* in the affluent pre-filter efficiency of 89% resulted in the removal of turbidity and 86% in apparent color.

The slow filtration stage without application of coagulant suspension showed 90% of efficiency in removing turbidity and 89% of the apparent color. The application dosage of 106 mg L^{-1} of coagulant suspension extracted from the seeds of the *Moringa oleifera* in the affluent of slow filter provided overall efficiency of 99% in removal of turbidity and 98% in the apparent color, regardless of the use of three layers of M2 blankets M2 or a M1 layer.

The process of obtaining the used coagulant allowed the presence of particles in suspension, which contributed to the reduction in the duration of the career of slow filtration.

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