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Treatment of residual water using filter filled with sand and brazilian biomass

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ABSTRACT

This work has evaluated the efficiency of modified biosand filters filled with two different biomass or materials: coffee hulls or pine bark *in natura*, for the removal of chemical and physical contaminants from non potable water. Cylindrical filters were constructed with PVC pipes 2 in in diameter and 25 cm length, with inner layers composed of sand and biomass. The filters were fed with synthetic contaminated tap waterwhich was prepared daily. Filtrate samples were analyzed once a week for four weeks for each material used. The results showed that the pine bark can be used as a complement filtration to reduce turbidity and apparent color in primary treatment, since it was able to reduce an average of 57% of initial turbidity, while for coffee hulls this reduction was less than 35%. Moreover, both materials showed a tendency to maintain the filtrated pH in the neutral.

KEYWORDS

Raw water;
Slow filtration;
Biomass;
Sand.

INTRODUCTION

The quantity and quality of available water for human consumption are not enough in many places in the world. Worldwide, one in six people suffers from a shortage of drinking water[1]. This is due to poor distribution of water resources combined with accelerated degradation of natural areas, deforestation, pollution and water[2,3]. It is the quality of the water that is leading to water/ wastewater born diseases leading to death, not the inadequacy of consumption[4]. In Brazil, it is estimated that 45% of the population has no access to water treatment services, while 40% of treated water distributed in Brazil is wasted[5].

It is known that water is a vital source for all the organisms, from the very simplest like the bacteria, viruses and protozoa to the most developed. Thus its importance in health, since it may be the transmitter medium of many diseases such as cholera, typhoid, leptospirosis, ascariasis, schistosomiasis, among other[1,5,6]. Water contamination comes mainly by the release of sewage into streams and rivers[7].

The need to control pathogens that causes diseases and chemical contaminants in drinking water has resulted in the development of water treatment systems. Water treatment methods include aeration, coagulation, flocculation, clarification, filtration and disinfection. The development of membrane technology in the form of microfiltration has been a replacement for coagulation, flocculation, clarification and filtration[8,9]. According to several authors, reverse osmosis has been introduced to take the place of activated carbon adsorption[10,11]. Although there is a vast number of water treatment systems, most of them are costly and hence are unaffordable to people of developing countries[11].

Toreduce turbidity at the domestic level, can be employed sedimentation and filtration processes with fiber filters and slow sand filters[12]. A modification of the latter is the so-called BSF, biosand filter, which differ in the prior greater ability to remove contaminants, including microorganisms[11,13]. BSF is one of the affordable decentralized or household water treatment options which has been practiced for a long time and is economical to construct, operate and maintain[8,14]. Moreover, modifications of the BSF are studied to improve the performance and dirt holding capacity[13,15].

Materials with particle retention capability with porous surface may be an alternative to the modification and improvement of these treatments[16,17,18]. The biomass, for example, is generated as waste in many cultures in Brazil and in some cases have potential environmental contamination. Thus, this study aimed to combine the treatment of water for sustainable disposal of this type of organic waste, since the country has not research this.

Therefore, the goal of this study was the development of a modified biosand filter filled with coffee straw and pine bark in order to evaluate the efficiency in reducing pathogens and physicochemical pollutants thereby promoting an improvement in water quality. It could be done using a system of easy implementation and operation to reach the household properties levels.

MATERIALANDMETHODS

Modified filter

Regarding the good results obtained by Baig and co-workers[13] using this design of biosandfilter at a not so large scale we have built a scaled-down adaptation of their technology at thehousehold level of intermittent operation. The filters were constructed with PVC pipe of 25 cm in length and 5.0 cm, approximately, in diameter. They were attached to the bottom of the container that had the contaminated water to be treated. It is allowed analyzing the performance of the two filters at the same time. Each filter was connected to graduated cylinders for collecting the filtrate

The filter medium consisted of layers of sand and biomass. The last one could be, pine bark of species *Caribeahondurensis* produced in the Mining Triangle region or the coffee hulls of the arabica species, produced in the Alto Paranaíba region of Minas Gerais. Wherein the amount of biomass represented a 50% reduction in the amount of sand filtration medium.

Apart from the depth of biomass that was set in 9 cm the amount of sandandgravel used wereproportional to the sizeof the pipes used. Comparing to the Baig's work all of them were divided by three. Figure 2 illustrates all the depth used. It was workedupwith two distinctsandparticle sizes, coarse sand(1.68 to 0.71 mm),fine sand(0.25 to 0.08 mm), and gravel(6.00 to 4.00 mm)and gravelthin (3.00 to 2.00 mm). The size of thebiomassparticles was kept between2.36 to 4.75mm which can be considered a little big when compared withBaig's biomass size that was between 3-6 mm.

Preparation of biomass

The biomass has not suffered any physical or chemical treatment for activation. It was only previously rinsed with running water for color removal[13] and after was conducted oven drying at 65°C[19], grinding and classification by strainer to obtain the range 4.75 to 2.36 mm. The particle sizewas also adjustedappropriately for the pipe diameter. A cross sectional area of the filter is shown in Figure 1 highlighting the internal structureof the filtersfilled withdifferent packing.

Forcharacterization of thebiomassan analysis ofmicrostructurecharacteristicswas performed usingscanning electronic microscopy, SEM. The sampleswere coatedwith goldblades tobecomeconductivein order todissipatethe electri-

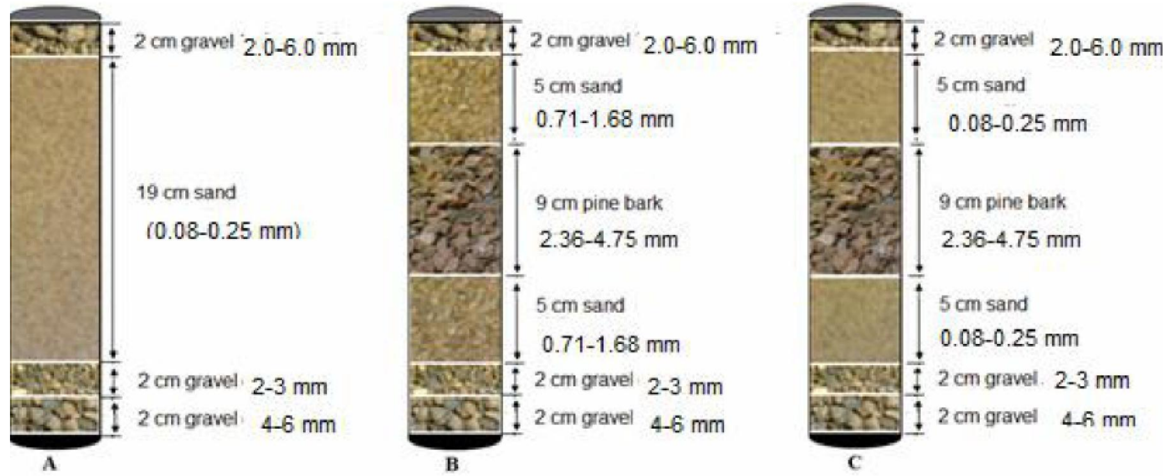

Figure 1 : Internal structureof the filters: a) sand filter, B) thick biosandfilter withpine barkandC) finebiosand filterwithpine bark

cal loadandheatwas introducedby exposureof the electron beam. The analysis was performedinthe multiuserLaboratoryMicroscopy, Faculty of Chemical Engineering, Federal University of Uberlândia.

Experimental setup

The system was operated for four weeks. Twenty liters of synthetic contaminated water was added to the common reservoir daily. Water samples were collected and analyzed before and after the filtration, in the beginning and in the end of each operating week.

In order to analyze the behavior and the durability of the system, with interruptions in the feed, there was no operation on weekends. Then, a real situation of water treatment household level was simulated. Furthermore, due to the restriction of tube diameter, it was not performed the periodic cleaning of superficial sand layer[20,21].

Preparation of synthetic water.

To impart color and turbidity it was used 2 grams of soil diluted with 500 mL of tap water. This sewage water was kept under magnetic stirring with heating for 30 minutes to improve solubility. Then,the one was added to the water remaining to complete 20 liters that will be fed to thesand or biosand filter.

For microbiological contamination, it was diluted 5 mL of sewage water in thecontainer of the Advanced Research Unit, which is located the Thermo-Environmental Laboratory, diluted in 20 liters of tap water[13,22].

Analysis

The water quality was analyzed before and after each filtration for each of the treatments over four weeks of operation. Physical, chemical and microbiological, parameters such as turbidity, pH, color, chlorides and total coliforms were monitored at the beginning and at the end of each week. To evaluate the chemical parameters, tests were conducted using a kit purchased from ALFAKIT (Florianopolis-Brazil) for analysis of potable water. All tests were performed following the instructions of the kit itself, whose parameters were established from Ordinance No. 518 of the Ministry of Health March 2004.

Chloridelevelswere analyzedby titration withsilver nitrate,byArgentometricmethod, whereasthe hardness of thewater before andafter filtrationwas determinedby complexationwith EDTA. The apparent colorwas alsomonitored withthe aid ofcolor comparisonchartbased on theplatinum-cobalt method. Microbiological contaminationwas monitoredusingColipaperkit, whichconsists ofcardsimpregnatedwith culture mediumin gel formdehydratedfor analysisof total coliforms*(Enterobacter cloacae*).

For analysis of the physical parameters was used pHmeter GEHAKA 1400 model, with accuracy of ± 0.01 pH units and for the turbidity was used model AP2000 of the brand Poly Control to within ± 0.01 NTU or ± 0.1 NTU depending on the range selected for reading.

The flow filtration of system was monitored by measuring the volume of filtrate in each treatment, with graduated cylinders of 500 mL with an accuracy of ± 5 mL being the measurements performed during the first hours of operation.

RESULTS AND DISCUSSION

The experiments were conducted in the months of February, April and May 2014, in the Thermo-Environmental Laboratory of Advanced Research Unit, School of Chemical Engineering. All the ones were performed with analyzes carried out at room temperature.

The surface of the each biomass was analyzed by scanning electronic microscopy. Images generated with an increasing of 400 times. It has showed that the surface of pine bark features has lots of pores of different sizes, while the two materials generated by the coffee processing, bark and grain parchment, on the same scale magnification presents only shallow cracks. Thus, the physical characteristic of the material can determine its particle retention performance.

Hydraulic flow rate over operating time

The filtersconstructedwith two differentgrain sizesof sand, showed a decreasingflowfiltrationover time[13].

The filterbuiltwith coffee hullsandcoarse sand(C1)showed the greatest variationinthe flowvalueranged from29.9±1.4mL min^{-1}in the first weekto 2.2±0.2mL min^{-1}in the last week. In addition, thefilterP1, of pinebarkand sand, this variationwas 14.6±0.6mL min^{-1}to 2.6±0.2mL min^{-1}. Whilemore uniformflowbehaviorwas observed for theC2filterwhosefilter mediaconsisted ofcoffee andfine sand,for whichtheflowvaried between9.0±0.5mL min^{-1} and 0.2mL min^{-1}, butshowedan abruptdeclinein the second weekofoperation andremainedat lowflow ratesin themajority ofstudies, probably due to compaction of thebiomass layerofthe filter medium[13]. Figure 2 showstheflowfiltrationbehavior as a function of time.

From Figure 2, it is observed that regarding hydraulic aspect, P1 was the filterwith the best performance. In this filter, the hydraulic flow rate did not sufferabruptreductionswhile maintaining reasonable valuesof the filtrateduring the study.

The flow rate of many designed BSF for daily 20 L water charged was approximately 0.4-0.9 L/min[13-14] and the flow rate of various BSFmodels ranged 0.6–1.0 L/min and too small and too high flow inthe BSF was unacceptable for use[21]. Then, regarding that the highest flow rate of our system was 0.04 L/min it can explain some disappointed

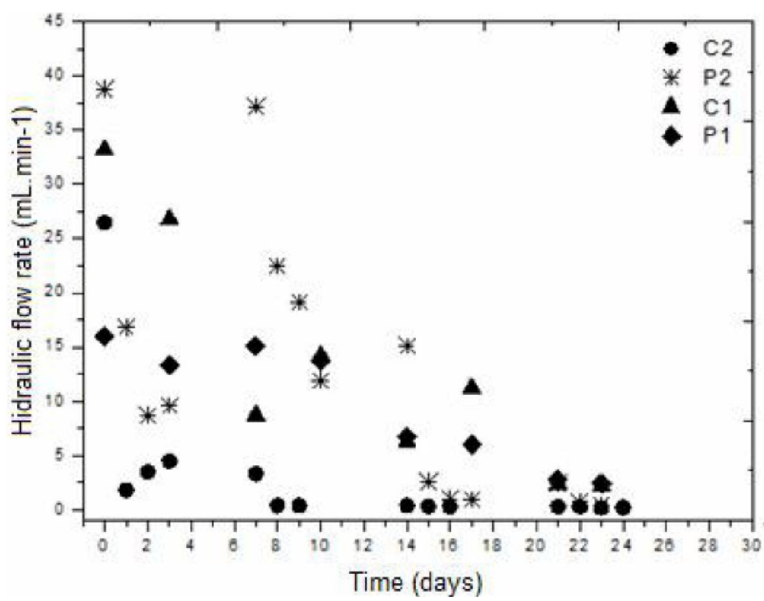

Figure 2 : Hydraulic flow rates during the time for the treatments with both biomasses and with two sizes of sand. (▲C1, ●C2, ♦P1 and ∗ P2)

TABLE 1 : Turbidityremovalpercentage offiltersbuilt withcoarse sand

Time (days)	Filter	T_0 (NTU)	T_f (NTU)	%R
0 – 7	C1	15.40±0.4	12.13±0.3	21
	P1	15.40±0.4	10.40±0.2	32
7 – 14	C1	20.40±0.5	14.47±0.4	29
	P1	20.40±0.5	12.80±0.2	37
14 – 21	C1	18.45±0.4	12.00±0.2	35
	P1	18.45±0.4	9.81±0.1	47
21 – 28	C1	29.90±0.4	13.90±0.2	53
	P1	29.90±0.5	12.50±0.3	58

results obtained.

Turbidity and color removal

TABLE 1 shows the findings before and after filtration, using the filters modified with both biomass built with sand of the largest size. The percent removal or reduction (%*R*) was calculated by Equation 1.

$$\%R = \left|\frac{T_0 - T_f}{T_0}\right| \times 100 \qquad (1)$$

Where: *%R* is the reduction (%), T_0represents the initialturbiditybeforefiltration and $T_f$represents the finalturbidityafterfiltration.

From the Figures 3 and 4, it is observed that the filters were not efficient in remove turbidity when constructed with coarse sand, resulting in removal percentages below 60%.

The modified filter with pine bark had an average percentage of turbidity reduction of 43% when constructed with coarse sand (filter P1), on the other hand, when used fine sand, P2 filter removal reached higher values, up to 68% in the third week of study. On average turbidity removal capacity of the P2 filter was 55%, with values about 6 NTU throughout the study. Interestingly, the best turbidity removal performance of the P2 filter was 68% and occurred when was observed the higher turbidity (16 NTU), while the smaller percentage 42%, was observed for the lowest turbidity value of the synthetic contaminated water (11.00 NTU).

Thus, the particle size of the sand used as a filter medium influenced performance, since the turbidity reductions were greater when worked with fine sand. However, the modified filter with pine bark was more efficient than a filter constructed with sand in the same proportions, only at the beginning of the study, since in the third week of filtration the

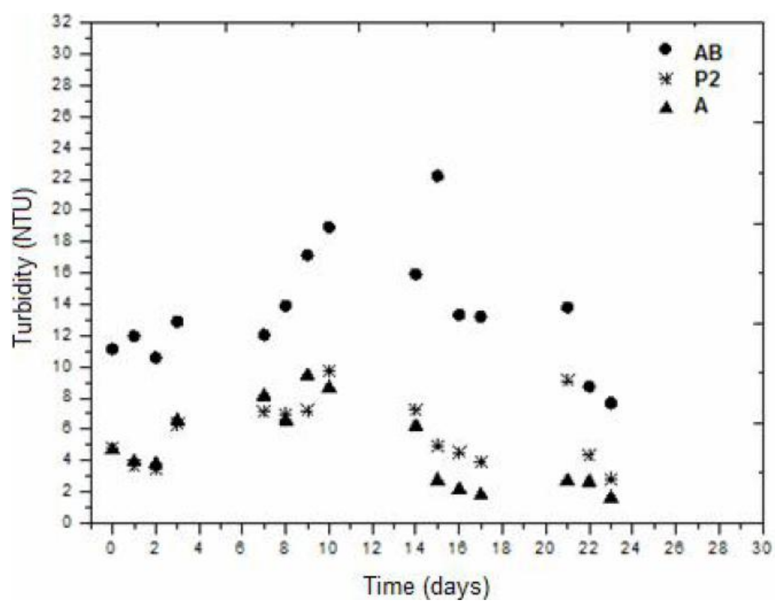

Figure 3 : Variation of turbidity effluent sand filter and of the modified filters using pine bark. (●AB, *P2, ▲ A)

turbidity of the modified filter was biggest than that the sand filter. As shown in Figure 3, where AB (●) represents the value of the synthetic contaminated water turbidity, P2 (∗) due to treatment with the modified filter with pine bark and fine sand and A (▲) the turbidity values of the treatment with the sand filter thin.

Moreover, the performance of this filter was worse than of the BSF modified with natural zeolites used by Mwabi et al., (2011) that showed percentage of turbidity higher than 90% under the conditions adopted by them. Baig et al., (2011) also managed removals of turbidity above 80% in the first 30 days with the BSF modified with higher quantity of pine bark, probably due to structural changes proposed for the system.

The most efficient biomass for the apparent color removal of water,considering two sand particle size, was pine bark. The same result was presented for the turbidity. However, when compared with the sand filtration, the treatment with the pine bark was not more effective in removing this parameter. Both showed high color reduction percentage, approximately 65% over time, reducing its removal capacity during the last week of the study.

When the comparisons involve only biomass, the pine bark showed percentage of satisfactory removal throughout the study, with reductions of almost 70% of the apparent color of the water, which enables the use of this material as an efficient modification to reduce this parameter.

Moreover, the filter effluent modified with coffee hulls and fine sand, had the turbidity and color values greater than the synthetic water after the first week of treatment, this may be due to the release of substances caused by biomass decomposition inside the filter, since the material has about 4.5% lipids and other components[19,20].

Therefore, higher porosity of pine bark may be the justification of its largest particle retention potential. This means that the physical characteristic of the materials can explain their behavior in relation to reduction of color, turbidity and flow rate during the studied period, where only the pine bark was appropriate to be used.

pH results

Figure 4 shows the pH values before and after filtration with each modified filter, where A represents the initial pH of the water, values of pH for filter constructed with coffee hulls and sand is C1, C2 the values for the filter of coffee hulls and fine sand, P1 for the filter of pine bark and sand and P2 for the filter built with pine bark and fine sand.

In general, the filtration treatment with the biomass caused a reduction in the pH value of raw water, remaining close to neutral which is permitted by law, above 6 pH units[23]. On average, the pH value of the filtrate by treatment with coffee hulls and coarse sand was 5.8 and when used fine sand had an aver-

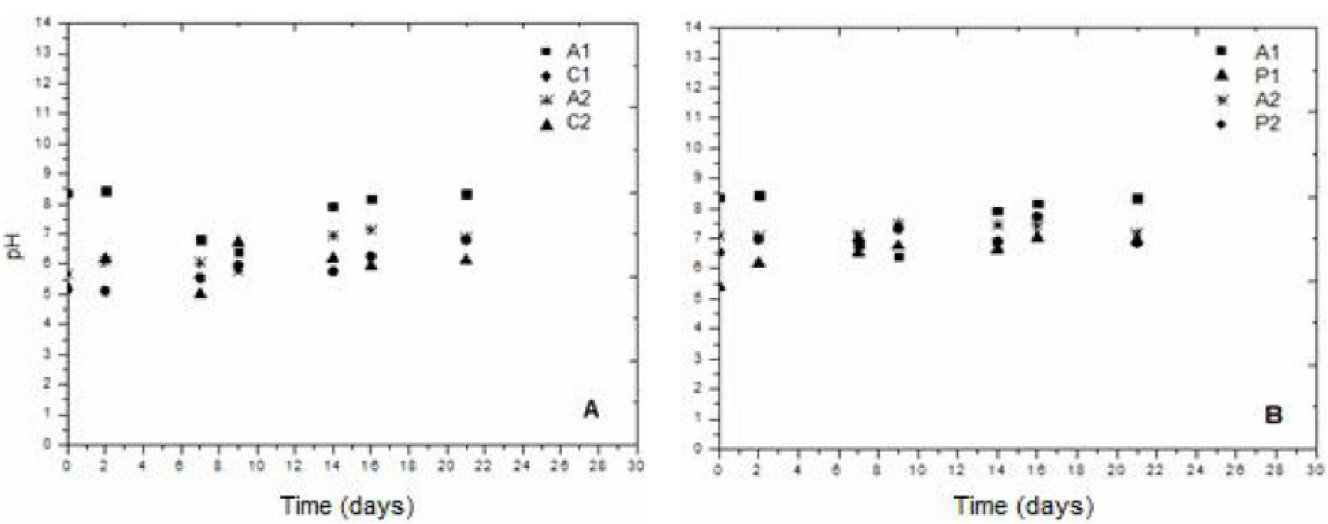

Figure 4 : A) pH of the water before and after filtration using coffee biomass and B) pH of the water before and after filtration using pine biomass

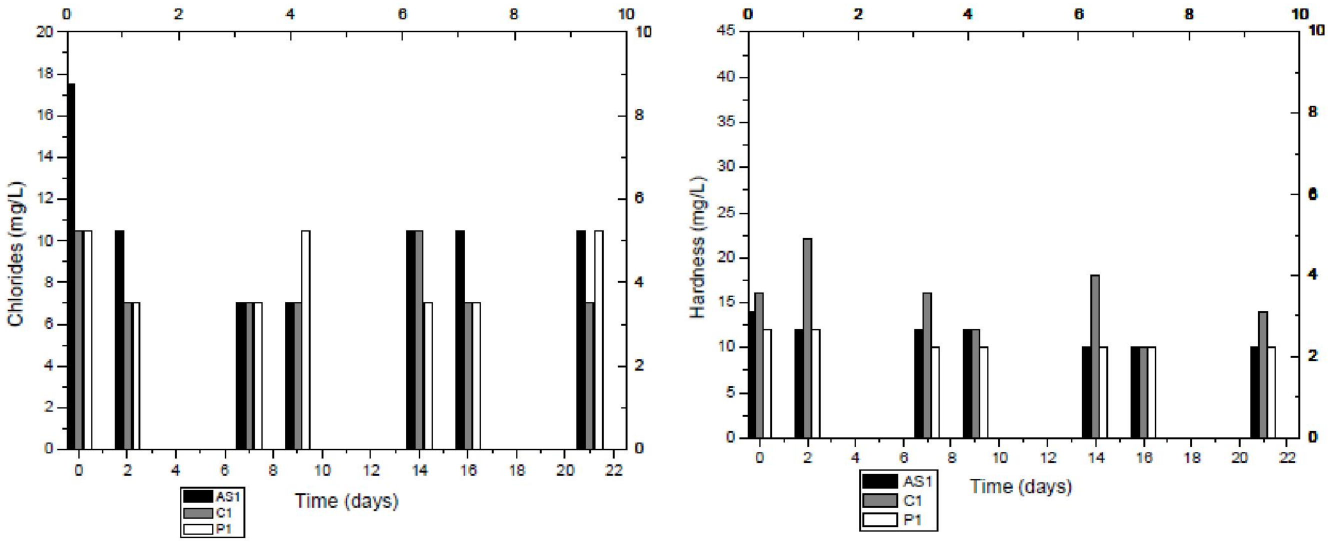

Figure 5 : A) Chloride level of the contaminated synthetic and filtered water using coffee hulls, C1, and pine bark, P1, B) synthetic and filteredwater hardness using biomass of coffee, C1 and of pine, P1 as a function of time

age value of 6.0. The pine biomass also decreased the value pH, but with less intensity than the coffee biomass. In the filter constructed with pine bark and sand, the value of pH of the water after filtration was an average 6.5 and when used fine sand the value average pH of the filtrate was 7.0.

Soon, the reduction of pH value may be due to chemical composition of the biomass itself, since the coffee hulls have acid nature with pH of 5.9[21]. However, Baig et al. (2011) observed a slight increase of about 1% in the initial pH of the water, with an average pH values after filtration 7.9.

Interestingly, as the flow decreased seems that there was a trend of increasing pH value. This occurred for the coffee pods filter and coarse sand and the two filters modified pine bark. Moreover, higher pH values were obtained when the percentage turbidity removal was larger; this occurred to C1 and P1. However, this apparent trend was not observed for the filters C2 and P2.

Variations of hardness and chloride

In the present study, both filters modified with biomasses caused a slight reduction in the chloride levels[13] in the initial contaminated synthetic water. It could be just because of the influence of coffee hulls was greater than the pine bark. Figure 5-A) shows the level of chlorides (A) in the water before and after treatment with the modified filter for each biomass used.

Moreover, the behavior of different biomass for the water hardness was really different. The pine biomass caused slight reduction, while coffee hulls increased levels of water hardness, and when using fine sand it was more pronounced. Figure 5-Billustrates the water hardness before (A) and after each treatment using biomass and coarse sand as filter medium.

It seems that the filtrate hardness was smaller when the pH values were higher for the treatments with coarse sand. Remember that the level of hardness is measured by the concentration of carbonates and bicarbonates of calcium, which are present basic character.

Total coliforms reductions

From the results obtainedit was observedthatthe sandfiltersconstructed withsmaller particle size wasnot efficientfor removingmicrobiological contaminantsafter two weeksof treatment. The modifiedfilterwith coffee hulls, C1, and the one with pine bark, P1, reduced the concentration ofcoliformsonlyin the first and second week, while the filterwithsand, A1, causeda low reductionof this parameterin the final of twoweeks of the study only.

TABLE 2 showed the removal of total coliforms for all four modified BSFs or treatments and two sand filters, where a high removal of the total coliforms was not observed in the most treatments times. However, around 100% removal of the total

TABLE 2 : Reduction of total coliforms (% age) in the six treatments or BSFs during the operating time period

Time	Filter					
Days						
	P1	C1	A1	C2	A2	P2
0-7	56	43	-	-	10	10
8-14	25	25	-	-	29	-
15-21	-	-	10	-	-	-
22-29	-	-	33	-	92	-

coliforms was found in the filter A2.

At treatment time (22-29 days), the efficiency of the filter A2 was found higher than the other three sets of BSFs or treatments. The total coliforms removal efficiency of the filters P1 and C1 showed a decline in total coliforms removal efficiency, while other treatments showed an inappropriate result in total coliforms removal efficiency. It could be explained due to the low controlled intake of mean total coliforms or the high amount of biomass used for the media. The symbol (-) was used in TABLE 2 when the concentration of coliforms was higher than 100 cfu/100 mL or more.

This result could be caused due to the proposed changing to batch operation, as there was no water supply on the weekend was not possible to maintain the biological layer, main responsible for removing microbiological contaminants[20]. Then, the proposed increasing in the biomass amount totheslowfiltration processcannot be consideredable to ensure the microbiological safetyofdrinking water.

CONCLUSION

The best removing performance was observed for the modified filter filled with pine bark. For both sand particle sizes used, the filtrate showed turbidity, apparent color, concentration of chlorides and hardness lower than the raw water. Furthermore,the filtrate pHs wereslightly smaller thanthe original, but remainedbetween 6.5 and 7.0.

However, biomass manufacture from the coffee was less efficient in removing turbidity and apparent color of the water, and increased the initial water hardness.

Both treatmentswere not able toreduce microbiologicalcontaminationfrom the secondweek of the studyprobablydue tostructural modification sproposed for the system or operation.

Thus, the sand size employed in the system may have hampered the removal efficiency of some contaminants. Furthermore, the batch process can also be the cause of low efficiency in the retention of biological contaminants, once damaged or even prevented maintaining biological layer. Therefore, the structural changes proposed under the conditions used for the treatment, were not efficient for water purification to domestic level.

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