Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.837010

53 (2015) 15–26
January

Taylor & Francis
Taylor & Francis Group

Water filtration through wood with helical cross-flow

Mauricio Luiz Sens*, Marcelo Luiz Emmendoerfer, Laura Cecilia Müller

Department of Sanitary and Environmental Engineering, Technology Center of Federal University of Santa Catarina, Florianopolis 88040-970, Brazil
Tel. +55 48 3721-9470; email: mls@ens.ufsc.br

Received 11 June 2013; Accepted 14 August 2013

ABSTRACT

The use of wood as a filter element for water treatment can be an efficient, low-cost alternative because wood is a renewable material. Therefore, pioneering a study to examine the possibility of filtering water through wood was advantageous. In 2002, the first experiments with wood filtration in the perpendicular direction of fibers were conducted (Correa and Sens [1]). With the continuation of this study, a new research developed as presented in this article. This study was conducted in two steps by the construction of pilot systems. The first step studied dead-end filtration and the second step studied helical cross-flow. The three species of wood studied were: caixeta (*Tabebuia cassinoides* Lam P. DC.), garapuvu (*Schizolobium parahyba* Vell. Blake), and pine (*Pinus elliottii*). The images obtained in the scanning electron microscope had the same approximations for all the three samples in the pores' direction as well as in the direction of fibers. The porosity of the wood fits within the size of the microfiltration. The observation of the wood's permeability revealed that the more porous the wood, the greater the permeability and the smaller the apparent mass. Filtration in the perpendicular direction of the fibers did not prove valuable because of its very low filtration rate and the need for high working pressure. Pine proved to be the superior option when considering the quality and production of water in the dead-end filtration. In this study, the value for wood density which is calculated to be 0.50 g/cm^3 and the porosity in the range of 40% proved to be significant factors for this treatment system. This implied a correlation between wood density and its porosity when choosing wood for water filtration. With respect to the observed wood, the pore diameter with higher performance was approximately 0.02 mm. The results in the helical cross-flow filtration generated an average removal of 70% to apparent color removal and 93% for average turbidity. The working pressure did not exceed 40 psi for a filtration rate of 15 m^3/m^2.d. The helical cross-flow filtration tests involving coagulation showed enhanced results and higher efficiency. Fouling on the surface of the wood reached a depth of 5 mm, not found in 10 mm. In summary, this treatment system exhibited improved and cost-effective results with minimal power consumption due to low working pressures.

Keywords: Water treatment; Filter element; Helical cross-flow; Water filtration through wood

1. Introduction

The need for potable water for human consumption and other applications in communities and residences has increased over the years with elevated expense due to the poor conditions of water sources.

The use of wood as a filter element can be efficient and cost effective since wood is a renewable material found in different environments throughout the earth.

*Corresponding author.

Therefore, it was worthwhile to initiate a study examining the possibility of filtering water through wood. This coursework was completed by Correa [1], under the guidance of Sens [1], who carried out the first filtration experiments of wood in the perpendicular direction of fibers.

This research evaluated the performance of the water filtration system in wood with the frontal and helical cross-flow determining the efficiency of the three species of wood. In addition, the best direction of water flow in the filtration process was observed (parallel or perpendicular direction of fibers).

Correa [1] studied the following species of wood: pine, virola, and cedar. The tests intended to reproduce a similar tubular filter with the wood.

Thus, the filter elements produced three diameters for cross-flow filtration. The differences are relative to the filtering wall thickness in the range of 1.0–3.0 cm (Fig. 1).

These experiments tested the removal of color and turbidity with the flow in the perpendicular direction of fibers. Results are shown in Fig. 2.

As observed, there is little difference in respect to the efficiency of membranes with a thickness between 1.0 and 2.0 cm. Both membranes are in the range of 30–35% efficiency for color and turbidity. The membrane with a thickness of 3.0 cm had enhanced performance with a 50% average efficiency for color and turbidity.

The anisotropy of wood can be problematic when deformation occurs with loss or gain of humidity causing cracks during the drying process, with respect to the observed direction. Additionally, bacteria, fungi, insects, etc. can attack a biodegradable organic material. Thus, precautions against rain and sunlight are necessary by paying special attention to the drying process. Drying can cause deformations, which are more severe when the longitudinal tangential direction of the rings is cut. It averages out when the cut is made in the cross-section and insignificant in the radial longitudinal direction (see Fig. 3) [2].

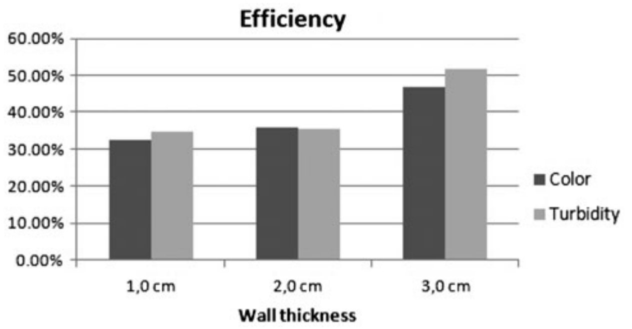

Fig. 2. Relationship between wall thickness and efficiency (Source: Correa, 2002 [1]).

The use of membrane filters intended for the separation of materials proved to be effective. Several processes are in the initial phase of development, in which the main determining factor is the relationship between filtration and the pore size of the filtered material.

Due to the geometric conformation of membranes, the filtration performed in a conventional manner passes in the cross-flow direction (see Fig. 4). The reason for this is that the flow observed certain turbulence on its surface obtaining results in the dragging of particles that cause incrustations. With cross-flow filtration, it is advisable to apply some pressure to "push" fluid through the pores of the membrane for collection on the other side. The applied pressures must comply with the manufacturer's recommendations to avoid damaging your own surfaces [3].

The wood is mainly composed of lignin (ranging from 18–35%), hemicelluloses, and cellulose (ranging from 65–75%) polymeric materials which are considered complex, such as polymeric substances

Fig. 1. Filter elements with varying degrees of thickness (source: Correa, 2002 [1]).

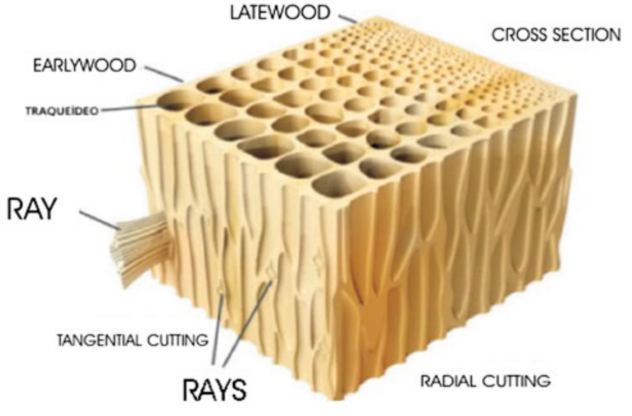

Fig. 3. Schematic drawing of the anatomy of a conifer - not a species of pine (source: Gonzaga, 2006 [2]).

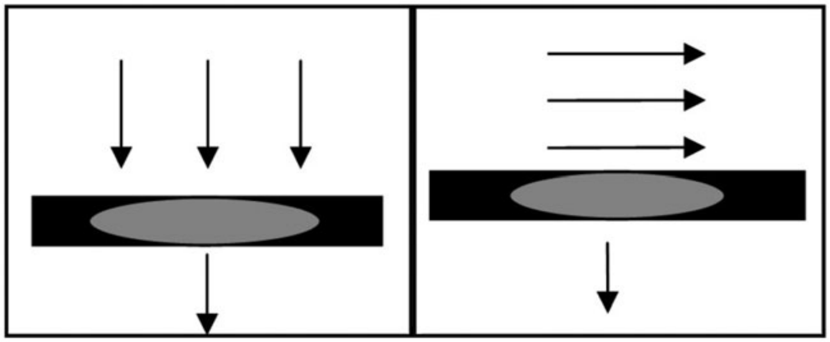

Fig. 4. Conventional filtration (with dead-end filtration) × cross-flow filtration.

and secondary substances of low-molecular weight that can be responsible for taste, odor, and color [4].

To understand how the water will pass through the wood, we have to be familiar with some of the its chemical compositions. These compositions vary according to several factors, such as geographic location, climate, and soil type. Therefore, the chemical composition is not accurately defined for a wood species or even for a specific wood.

There are other components that are present mainly in the form of extractable organic and inorganic substances, such as oils, resins, sugars, starches, tannins, nitrogenous substances, organic acids, and organic salts (ranging from 4–10%). These extracts give the organoleptic properties of wood, such as smell, color, taste, and its resistance to fungi and insects. The elements that make up the wood, in general, are carbon (50%), oxygen (44%), hydrogen (5.5%), and traces of many metal ions.

2. Materials and methods

This study was conducted in two steps by the construction of pilot systems. The first step studied the dead-end filtration and the second step studied the helical cross-flow filtration.

The raw water used in this treatment as input for the pilot system was prepared using water provided by the public supply system with the addition of clay to achieve the desired parameters for the tests. As the focus of the research was to study the cross-flow filtration in the wood, only a few parameters [5] were considered to characterize the raw water as shown in Table 1.

2.1. Step 1—Dead-end filtration test

The three species of wood (see Fig. 5) studied were: caixeta (*Tabebuia cassinoides),* garapuvu (*Schizolobium parahyba*), and pine (*Pinus elliottii*).

Table 1
Raw water parameters

Parameters	Raw water-step 1		Raw water-step 2	
Apparent color (pt–Co unit)	12	45	56	64
Turbidity (NTU)	2.7	12	10.9	11.5
pH	6.81	6.77	6.84	6.95
Total dissolved solids (ppm)	36	35	32	31
Conductivity (μS/cm)	72	70	64	62
Temperature (°C)	20	21	25	27

Fig. 5. The three species of wood studied (caixeta, garapuvu, and pine, from left to right).

During the preparation of filter elements, special consideration was taken for the species of wood, the flow direction regarding the fibers (// = parallel or # = perpendicular), and autoclaving as pretreatment (see Table 2 and Fig. 6).

For step 1, the pressures applied in the dead-end filtration were measured from the manometer connected to the output valve in a pressurized synthetic air cylinder. The flow adjustment was made in the same valve.

Table 2
Species of wood, pretreatment, flow direction, and specific mass (dead-end filtration)

Flow Species	No autoclaving		With autoclaving		ρ (g/cm^3)
	//	#	//	#	
Garapuvu	1G	2G	3G	4G	0.31
Pine	1P	2P	3P	4P	0.47
Caixeta	1C	2C	3C	4C	0.61

Fig. 6. Filter elements for the dead-end filtration.

It is noteworthy that for the dead-end filtration with coagulation, the samples without previous flow test were discarded (Table 3), as well as autoclaved (Table 4). It was observed that, in general, working pressures increased with the addition of a coagulant.

For both steps, the conditions for the jar test were the same:

- Fill the jar (s) with raw water up to the 2 liter mark.
- Adjust control agitation for 90 s^{-1}.
- Add the required amount of coagulant solution of aluminum sulfateAl_2SO_4 at 1% and white-wash.
- solution $Ca(OH)_2$ at 0.5%.
- Change the agitation from 90 to 1,200 s^{-1}, with a mixing time of 30 s.
- Decrease the velocity gradient to 112 s^{-1}, with a mixing time of 60 s.
- Filter the coagulated water in the pilot system.

For Steps 1 and 2, the dosage of aluminum sulfate (Al_2SO_4) was 8 mL, representing a concentration of 40 mg/L and an addition of 8 mL of whitewash ($Ca(OH)_2$) to adjust the pH value between 5.6 and 6.0. The coagulation pH for the first step was 5.66 and 5.74 for the second step.

The dead-end filtration study was carried out using a pilot filter system made of stainless steel as shown in Fig. 7.

Table 3
Filtration pressure for step 1 without coagulation (dead-end filtration)

Sample	Filtration pressure (psi)	Sample	Filtration pressure (psi)	Sample	Filtration pressure (psi)
1G	3	1P	11	1C	21
2G	No flow	2P	57	2C	No flow
3G	3	3P	3	3C	6
4G	No flow	4P	57	4C	No flow

Table 4
Filtration pressure for step 1 with coagulation (dead-end filtration)

Sample	Filtration pressure (psi)	Sample	Filtration pressure (psi)	Sample	Filtration pressure (psi)
1G	6	1P	9	1C	36
2G	Discarded	2P	64	2C	Discarded
3G	Discarded	3P	Discarded	3C	Discarded
4G	Discarded	4P	Discarded	4C	Discarded

Fig. 7. Filter pilot for the dead-end filtration.

2.2. Step 2—Helical cross-flow filtration

In the second study, to observe the helical cross-flow filtration, another pilot filter system was constructed as shown in Figs. 8 and 9.

The materials used in the second pilot system were: (1) raw water input, (2) raw water tank, (3) suction pipe (10 mm), (4) ¼ hp pump rotor with carbon and Teflon coating, (5) discharge pipe (10 mm), (6) manometer input, (7) filter (Fig. 10), (8) treated water tank, (9) raw water return pipe, (10) manometer output, and (11) needle valve (to control flow and pressure).

The system operated with recirculation. Thus, the water returns to the raw water tank mixing the part that had not passed through the wood, concentrating the soluble and/or dissolved substances.

In the pipe, where the water returns to the raw water tank, another manometer was installed to

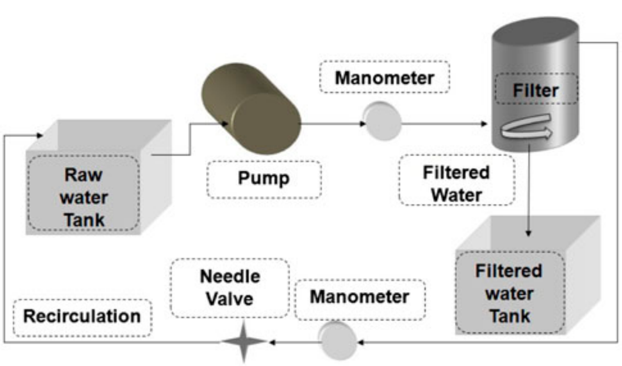

Fig. 8. Diagram of the pilot system for the helical cross-flow filtration.

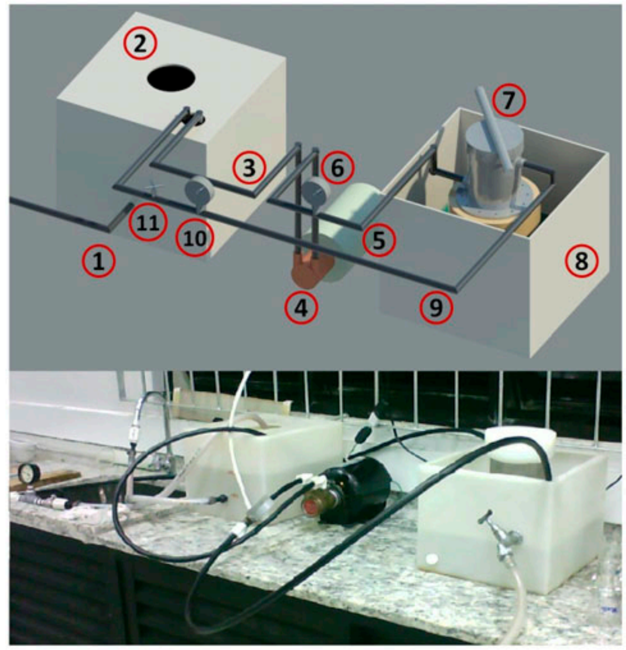

Fig. 9. Pilot system for the helical cross-flow filtration.

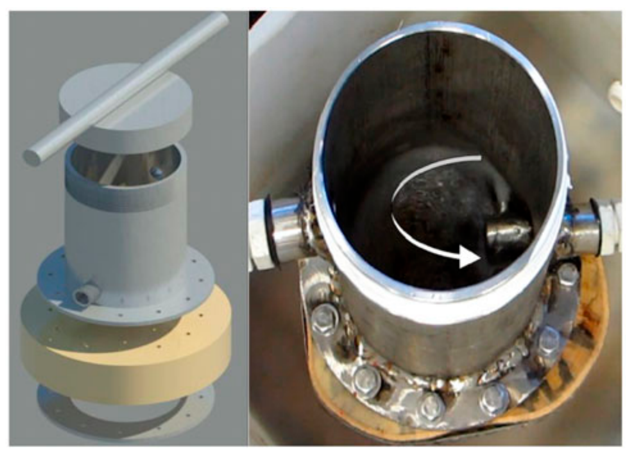

Fig. 10. Details of the filter pilot and the helical cross-flow filtration system.

measure the pressure output allowing the determination of head loss in the system. To allow the passage of water through the wood, a needle valve was installed after the second manometer. Adjusting the valve is possible to restrict the passage flow forcing water to pass through the wood.

The water enters the filter pilot through the input pipe that connects the pump to the filter, which is responsible for the helical cross-flow on the surface of the wood causing the water to pass in the perpendicular direction to the wood's surface. Inside the filter pilot, a small stainless steel pipe reduces the diameter

Fig. 11. Samples of wood during the cutting process and prepared with the gold covering.

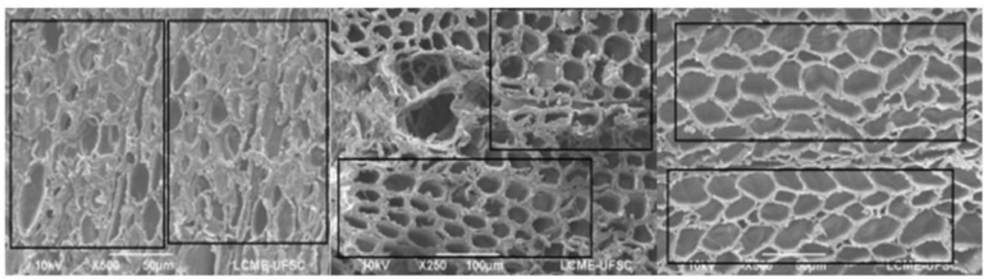

Fig. 12. Images from pore counting of caixeta, garapuvu, and pine wood.

providing helical cross-flow into the pilot wall. That contributes to cleaning the filter element with a circular jet causing the detachment of material adhered to the wood's surface, which can increase the filtration time.

As described above, there are two kinds of water: concentrate and permeate. The concentrate comes out from the top of the pilot at the return pipe (see Fig. 10) collecting the particles that did not adhere to the wood's surface. Permeate is the water that passes through the wood and is collected in the tank of filtered water (treated water).

In sequence, controlling the pressure between the inlet and outlet, exercised by the closing or opening of the needle valve is accomplished through the flow of water passing through the filter element (wood). The passage of water through the wood depends on several factors: the system pressure, filter element thickness, density, and characteristics of the wood's pores (pore diameter, pore density, etc.). These factors promote higher or lower flow.

When designing and building the filter element, its thickness combined with its resistance must be considered. As a result, the filter element must have a minimum thickness to promote the necessary strength for the filtration. By minimizing the thickness of the wood, the filter element becomes less resistant. On the other hand, the greater the thickness, the greater the difficulty of passing water through the filter element.

Even though wood is an anisotropic material, its characteristics can change depending on the direction evaluated (depending on the direction of the cut). Therefore, a good sealing becomes significant. A rubber ring inserted between the filter pilot and the end of the wood for compression prevents leakage.

For step 2, the tests were conducted only in wood of better quality and the pressures of the helical cross-flow filtration, both with and without the coagulation test were:

- Input pressure: 40 psi.
- Output pressure: 26 psi.
- Head loss in the pilot system: 14 psi.

It was noted that throughout the period of filtration, pressure remained constant. It was also observed that the test without coagulation there was a considerable decrease in the flow of filtered water. On the other hand, this decrease was smaller for the coagulation test.

2.3. Scanning electron microscope

Samples of wood were analyzed in a scanning electron microscope (SEM) JEOL JSM-6390LV, at the Central Laboratory for Electron Microscopy (LCME) at UFSC following specific procedures recommended by the LCME.

Preparation of samples: The samples were extracted in cubes with approximate dimensions of 0.5 cm × 0.5 cm × 0.5 cm (see Fig. 11). The extraction of the cubes began with the wood's surface cut without deformity using a blade in order to avoid damaging the pores. After the cut, they were identified by observing the correct side in the microscope and the species of wood. As for drying the samples, they were stored at 70˚C in a kiln for a period of 22 h before being taken to the gold overlay (gold pulverization).

The samples were stored in plastic containers with silica to prevent humidity and pulverized with gold for electric conduction.

Analysis: with an adjusted, manual zoom, images were determined by the SEM, with the same approximations for the three samples in the direction of the pores, parallel fibers, and a specific approach to the direction perpendicular to the fibers in the smaller pores of the pine. With four images per sample, they were selected in order to have an overview of the wood's structure (with a zoom of 22 × s), an approach counting the number of pores in a given area (with a zoom of 50 × s), and to have the dimensions of the small and large pores (with zooms of 250 × s, 500 × s and 1000 × s).

3. Results and discussion

3.1. Preliminary studies

The natural state of the wood species was observed through SEM (before filtration). Next, the images were obtained by the respective scales and approximations.

As observed in the analysis, there are pores in the parallel direction of fibers in all species (on the surface of cross-section). However, the pine's pores had a perpendicular direction of fibers, but in a lower amount.

3.2. SEM—before filtration

The images of Fig. 12 propitiated the measurement of the pore diameter and its amount in a delimited area, determining the average diameter. Counting the pores was accomplished by the demarcated area to obtain the number of pores per unit area. Thus, it was possible to calculate porosity ε, which shows the pores' areas Σ per total area (see Table 5).

The pores enlarge from caixeta to garapuvu, as shown in Table 5, ranging from 0.013 to 0.26 mm, respectively.

The observation of the wood's permeability revealed that the more porous the wood, the greater the permeability and the smaller the apparent mass. The pore size studied can be considered similar to a microfiltration membrane.

Furthermore, imperfections were discovered in the fiber wall, specifically in the anatomy of the wood (see Fig. 13). These imperfections within the pores are normal and commonly found in pine, also contributing to the filtration process.

As previously stated, there are pores in pine (*gynminosperma*) with fibers in the perpendicular direction (see Fig. 14), but disregarded because they do not have a significant contribution in the filtration process. The angiosperms wood (caixeta and garapuvu) do not have this characteristic feature.

With reference to the study of autoclaving in wood, water treatment was not efficient under the conditions studied, worsening the water quality in most tests. This is because autoclaving produces small cracks in the wood, causing leaks (preferential channels). Therefore, these samples were discarded in the next stage of the research.

3.3. Dead-end filtration

In previous tests, it was not possible to pass water with the applied pressure of up to 60 psi using cut

Table 5
Results of SEM - pore diameter (mm), porosity (%) and pore density (pores/mm^2) for pine, garapuvu and caixeta

		Small pore	Great pore
PINE	Average diameter (mm)	0.026	–
	Porosity (%)	41.81	–
	Pore density (pores/mm^2)	784	–
GARAPUVU	Average diameter (mm)	0.018	0.0259
	Porosity (%)	65.15	
	Pore density (pores/mm^2)	1,935	2
CAIXETA	Average diameter (mm)	0.013	0.062
	Porosity (%)	30.8	
	Pore density (pores/mm^2)	6,803	228

NOTE: count repetition: 3 × s.

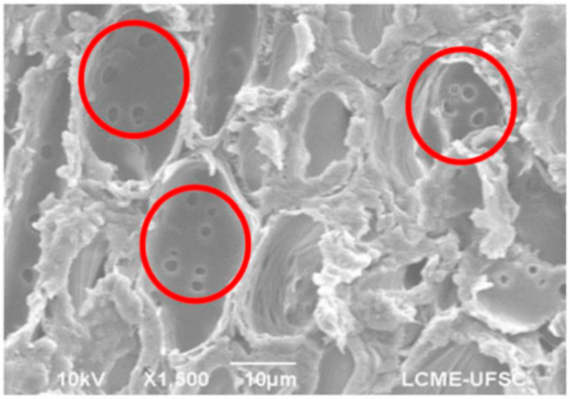

Fig. 13. Imperfections of pine.

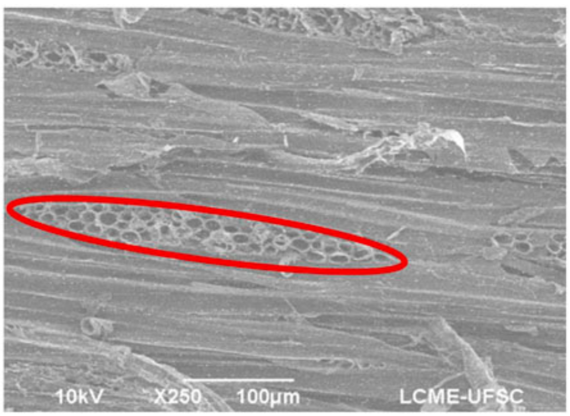

Fig. 14. Pores in pine with fibers in the perpendicular direction.

samples with fibers in the perpendicular direction, except for pine. Therefore, the samples, caixeta and garapuvu, were discarded for the dead-end filtration.

With regard to the quality of the treated water, in the dead-end filtration without coagulation, the parameter turbidity was generally better. On the other hand, the apparent color worsened (see Fig. 15). In this experiment, it was unclear which species was superior.

There was no significant change in the treated and raw water absorbance test by performing wavelength sweeping of 200–350 nm, as shown in Fig. 16.

The test with Al_2SO_4 coagulation, considering removal efficiency in terms of apparent color and turbidity, and volume of filtered water, the values were better in pine than in garapuvu and caixeta (see Fig. 17 and Table 6).

The treated water quality improved, by cleaning the pores of the samples with the water from the public supply system, using the same procedure of dead-end filtration.

In Fig. 17, the difference in samples is the fouling on the wood's surface, which can be explained by the presence of clay in the prepared raw water.

3.4. Helical cross-flow filtration

Following step one, tests were only administered to the pine samples, which obtained better results. Taking into account, the best flow of fibers is in the parallel direction.

In the helical cross-flow filtration without coagulation, there was improvement in the treated water quality, but the results remained outside the required standard, the parameter of apparent color in the order of 37 Pt–Co units and turbidity in the range of 3.3

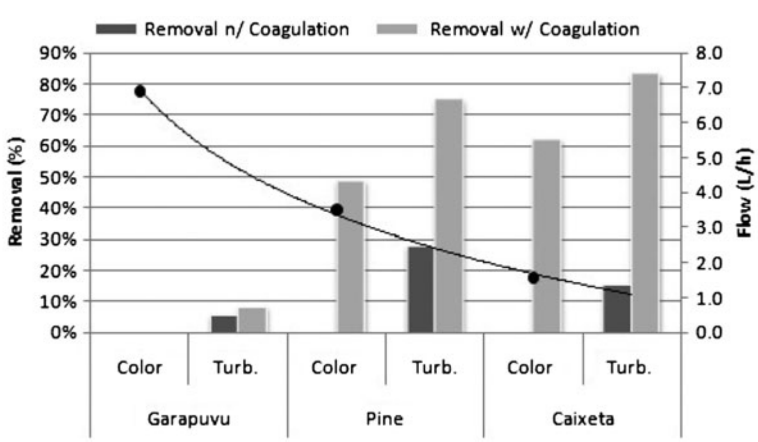

Fig. 15. Removing apparent color and turbidity (%), and average flow rate (L/h) for the analyzed wood (dead-end filtration).

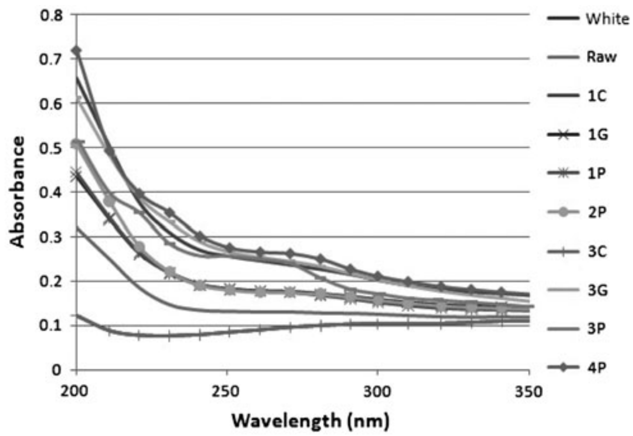

Fig. 16. Absorbance x Wavelength (nm) water samples (without coagulation) in different wood samples.

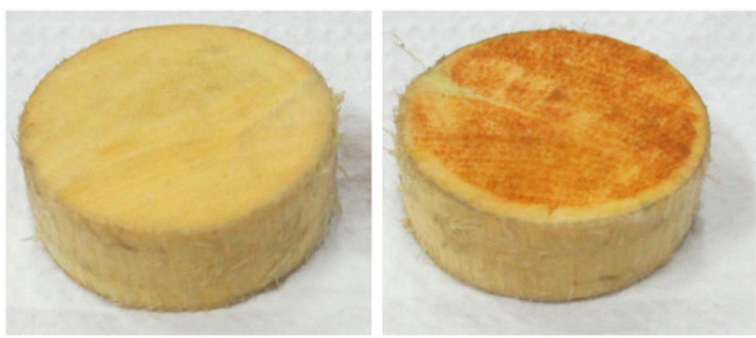

Fig. 17. Caixeta samples before and after the dead-end filtration.

Table 6
Results of the dead-end filtration with and without coagulation (Al_2SO_4)

Wood	Garapuvu		Pine		Caixeta	
Parameter	Color	Turb.	Color	Turb.	Color	Turb.
Removal n/coagulation	*	6%	*	28%	*	16%
Removal w/Coagulation	*	8%	49%	75%	62%	83%
Flow (L/h)	6.9		3.5		1.6	

NOTE: *No removal. Repetition of analysis: 3x [6]

NTU. On observation, the experiment with coagulation obtained positive results for the same parameters, as seen in Fig. 18.

As discovered, there was a significant removal in terms of apparent color (70%) and turbidity (93%) for the filtration with coagulation, confirmed in Table 7.

On observing the treated water, the filtration with coagulation had a tendency to result in less fouling; this is most likely due to the penetration of solids into pores. However, the final volume was lower than the filtration without coagulation, as shown in Fig. 19. If there had been a longer filtration time, it could also be interpreted as an inversion of curves resulting in a

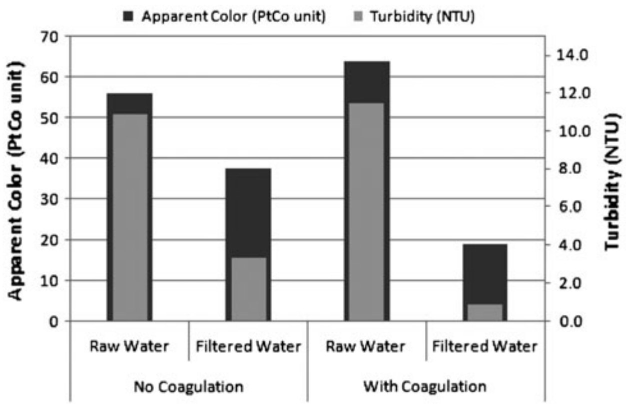

Fig. 18. Comparison between apparent color and turbidity of the raw and treated water, with and without coagulation (average values in helical cross-flow filtration).

Table 7
Removal of turbidity and apparent color, with and without coagulation (helical cross-flow-filtration)

Parameters	NO coagulation			With coagulation		
	Raw	Filtered	Removal	Raw	Filtered	Removal
Apparent color (Pt–Co unit)	56.0	37	33%	64	19	70%
Turbidity (NTU)	10.9	3.3	69%	11.5	0.8	93%

higher water production for the filtration with Al_2SO_4 coagulation.

The equation for the volume of filtration with Al_2SO_4 coagulation: $V_{ac} = 2.96\ T - 0.0933$ ($R^2 = 99.91\%$) and the equation for the volume of filtration without coagulation: $V_{ac} = -0.0004\ T^6 + 0.0139\ T^5 - 0.1873\ T^4 + 1.3024\ T^3 - 5.098T^2 + 11.861\ T + 0.0718$ ($R^2 = 99.94\%$).

Where: V_{ac} = Volume accumulated (L), and T = filtration time (h).

The equations are valid for a time of 10 h. In 5.1 h of filtration, the accumulated volumes are inverted, being higher in filtration with Al_2SO_4 coagulation.

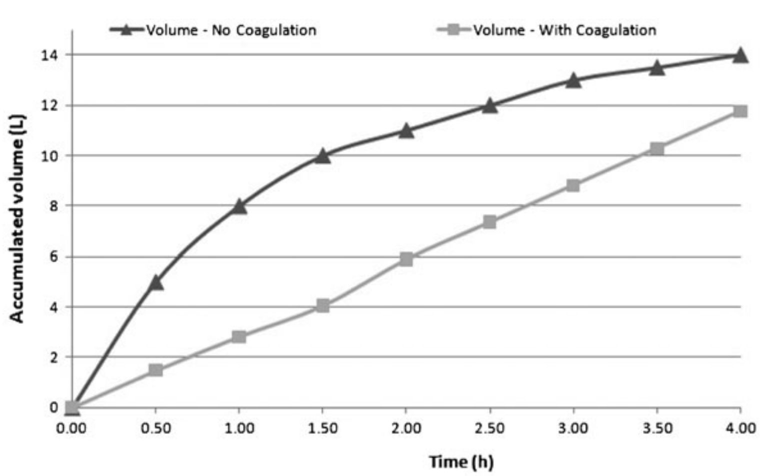

Fig. 19. Accumulated volume during filtration with and without coagulation (helical cross-flow-filtration).

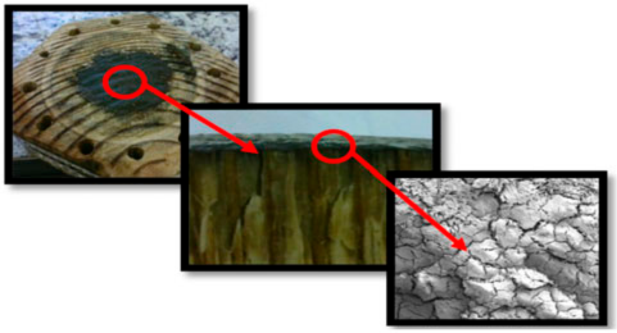

Fig. 20. Fouling of pine surface.

Manometers between the input and output of the filter measured the head loss of the filtration system. The pressure difference of manometers remained constant during fouling of the filter element (wood). The explanation for this is the input flow was constant, increasing the recirculation flow with a decrease of the permeate water.

Within the limits established for the pressure in the experiments, the filtration rate had an average of 15 m^3/m^2 d.

3.5. SEM—after filtration

Fig. 20 shows a sequence of images to confirm the fouling without zoom and with SEM (with a magnification of 25 × s), showing the retained particles on the surface of the wood.

The image with a magnification of 500 × s by SEM noted that the fouling penetrated the pores of the pine sample (see Fig. 21).

The next images extracted at a depth of 5 mm (see Fig. 21) and at depths of 10 and 15 mm from the surface of the wood seen in Fig. 21 show that fouling continued at a depth of 5 mm because some of the pores were obstructed. There was no penetration of fouling at the depths of 10 and 15 mm.

4. Conclusions

The filtration of fibers in the perpendicular direction proved insignificant because of its extremely low filtration rate, requiring a high working pressure.

In terms of dead-end filtration, pine was confirmed as the most favorable option when considering the quality and production of water.

There is a correlation between wood density and porosity. In this research, the density of 0.50 g/cm^3 and the porosity in the range of 40% showed significance for the water treatment.

For the analyzed wood, the pore diameter with higher performance was about 0.02 mm. The results in helical cross-flow filtration were noteworthy as it demonstrated the viability of this filtration technology. In terms of quality treatment, the results of apparent color were about 10 Pt–Co units (average removal of 70%) and turbidity in the range of 0.50 NTU (average removal 93%).

Concerning the working pressure, the input pressure was 40 psi and the output pressure was 26 psi. It generated a head loss in the pilot system of 14 psi.

The filtration tests involving coagulation showed improved results and higher efficiency. In the helical cross-flow filtration, the fouling on the surface of the pine reached a depth of 5 mm, not found in 10 mm.

In summary, this treatment system demonstrated enhanced results with minimal cost and low-power consumption working at low pressures. Additionally, this study used only renewable and biodegradable materials, benefiting the environment.

It would be valuable to conduct another research with caixeta (*T. cassinoides*), performing the same tests as this species of wood also displayed satisfactory results in the filtration process.

This research has not studied the possibility of reusing the wood filter. Future research could explore methods of cleaning and/or backwashing using clean

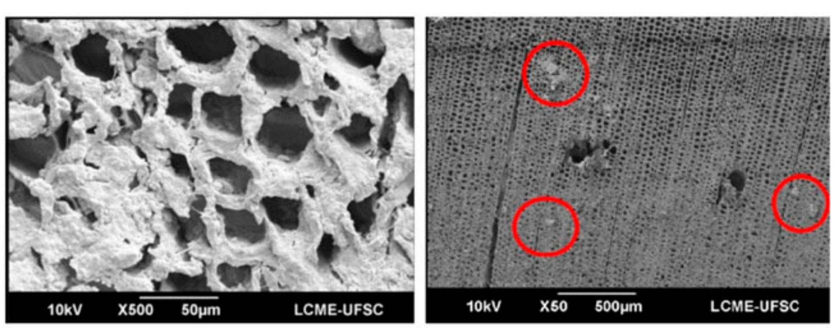

Fig. 21. Fouling in the pores of pine at the surface and at a depth of 5 mm (with zooms of 500 and 50 × s, respectively).

water (public supply system) or a diluted solution of sodium hypochlorite (NaClO).

References

[1] E. Correa, M.L. Sens, Filtração de água em membranas de madeiram, Trabalho de conclusão de curso [Water filtration in wood membrane, Completion of coursework], UFSC, Florianópolis, SC, 2002, pp. 23–30.
[2] A.L. Gonzaga, Madeira: Uso e Conservação. Programa Monumenta—Cadernos Técnicos [Wood: Use and conservation. Monumenta program – technical papers], IPHAN, Monumenta, Brasília, 2006, pp. 36–40.
[3] J. Malevialle et al., Tratamiento del água por procesos de membrana—Princípios, procesos y aplicaciones [Water treatment by membrane processes – Principles, processes and applications], Mc Graw-Hill, Madrid, 1998, pp. 101–110.
[4] U. Klock, G.I.B. Muniz, J.A. Hernandez, A.S. Andrade, Química da Madeira, Apostila. Universidade Federal do Paraná [Wood chemistry, Handbook. UFPR], Curitiba, 2005, pp. 67–70.
[5] D. Andrew, M.A.H. Eaton, Standard methods for the examination of water and wastewater, 21st ed., American Public Health Association, Washington, DC, 2005.