Water Filtration using Plant Xylem in Northern India

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Abstract. Currently, the world is facing scarcity of clean and potable drinking water. We have investigated whether the xylem (a porous conducting tissue) of a plant could be used as a filter to obtain drinking water. Firstly, we chose the appropriate plant for filtration based on our experimentation. Secondly, we used xylem to make a simple water filter and carried out experiments under the pressure head of the pump. Experiments were conducted using xylems of both angiosperms and gymnosperms. Freshly cut xylems of Ashoka tree, Silver Oak, Neem, Mango and Guava trees were screened for filtration. Filtration rate was measured for each plant and they were simultaneously checked for filterability of blue dye water solution. We found that sharp-edged, waxy leaf trees such as Ashoka and Silver Oak can filter water. These belong to the class of gymnosperms. Trees that bloom and give fruit (such as Neem) cannot purify water and remove impurities. The measured flow rate under a pressure of 2.5 psi was about 0.083 ml/s, which corresponds to a filtration rate of 7 litres per day or more and is sufficient for two people.

Key Words: Xylem; Filtration rate; gymnosperms; flow rate

1. Introduction
Potable water has been a human's major concern for decades. The increase in freshwater scarcity is leading scientists and environmentalists to develop large-scale economical water filtration technologies. Potable water or drinking water is defined as having acceptable quality in terms of its physical, chemical and bacteriological parameters and can be used safely in drinking and cooking [1]. According to Mekonnen et al., people are at systemic risks of freshwater scarcity worldwide. Two-thirds of the world's population (4 billion people) is vulnerable to severe water shortages for at least a month during the year. Of these people, 500 million live in India and China [2].

The metabolism of the body and the transport of nutrients depend on water. Water pollution interferes with metabolism and causes long-term or short-term illness. Sharma et al. published a review article, explaining hybrid technologies as well as technologies that have been awaited, types of contaminants and existing water filtration technologies. The awareness of water conservation and safe drinking is very important. Research on the area of water treatment technology is required to have a sustainable solution to such problem [3].

Frederiksen reported that there is an urgent need for international organizations to help developing nations solve the water crisis. The solution must be in consideration of time, money and management [4]. According to Gunn et al., there are two potential silent sources: ground water and virtual water. These aid countries in dealing with problem of water scarcity. In addition, it has been reported that
virtual water transactions can eliminate the global crisis and provide science and technology with cheap and superior solutions [5].

2. Materials and Methods

2.1. Construction of Xylem Water Filter
The preparation of water filter using plant xylem is shown in Fig. 1. Initially, the branches of the tree are cut and the pieces are prepared using clamps that can be fixed to the pipe. Small suitable parts of the branches of the tree are cut into 1-inch diameter pieces. The bark of the branch was removed and the piece of wood was inserted into one end of the pipe.

2.2. Materials selection
Xylem were obtained by cutting branches from various trees (Ashoka, Neem, Mango, Silver Oak and Guava) growing in Aligarh. Throughout the experiment, tap water was used. Separate tests were conducted by dissolving blue ink (Chelpark fountain pen ink) and mud in tap water. Branch sections were fixed at the end of rubber tubing, secured with clamps and sealed by hot-glue.

2.3. Fabrication of Experimental Setup
Schematic layout of the experimental setup is shown in Fig. 2. A submersible pump of 20 W capacity is placed at the bottom of the bucket. The outlet of the pump is connected to a pressure gauge through a restriction valve. The other end of the gauge is connected to a rubber tubing at the end of which xylem is fastened.

![Figure 1. Preparation of xylem filter.](image1)

![Figure 2. Schematic layout of the experimental setup.](image2)
2.4. Measurement of flow rate
Approximately, 10 litres of tap water was filled in the container. 60 ml of blue ink was dissolved in it and the solution was made to flow through the rubber tubing by applying pressure through a pump. The pump pressure varied from 0.5 psi to 2.5 psi for each set of readings. Before measuring the flow rate, the solution in the bucket was stirred to ensure proper mixed solution. For each reading, time taken to collect 50 ml of filtrate was observed using a stopwatch.

2.5. Check for filterability of Ashoka xylem
50 gm of mud was mixed in about 10 liters of tap water to obtain a turbid solution. This solution was passed through plant Xylem under a constant pump pressure of 2.5 psi. 50 ml of filtrate was collected and carefully observed.

3. Results and discussion
Xylem structures include small conduits aligned parallel in a way that can withstand cavitation [6,7]. The woody plants (gymnosperms) are formed from a single dead cell known as tracheids, the largest tracheids have a diameter of 80 mm and a length of up to 10 mm. Flowering plants (angiosperms) have xylem conduit called vessels derived from several cells, arranged in a single file, up to 0.5 mm in diameter and few millimetres to several meters in length [7,8].

Since angiosperms (flowering plants including hardwood trees) are more effective in transporting the sap, the xylem tissue occupies a small fraction of the cross-section of the stem or branch and is not ideal in the case of filtration. Due to the long length of the xylem vessels, a large thickness (centimetres to meters) of xylem is required to achieve filtration. A filter thinner than the average vessel length allows water to pass through the vessel without filtering it. Contrary to this, gymnospermic plants (including coniferous trees) have short tracheids that forces water to flow through the pit cell membrane even in the small thickness (1 cm) of the xylem tissue. Since the tracheids are smaller in diameter and shorter, they provide higher flow resistance, but a larger portion of the stem cross section is typically used to conduct xylem tissue. For example, in Ashoka tree the branch used in this study, the fluid conductive wood constitutes the bulk of the cross section (blue area in the Fig. 3). These inferences generally lead to the conclusion that the xylem of gymnosperms i.e., the sapwood, is most likely to be the suitable xylem tissue for the fabrication of filtration equipment.

3.1. Variation of flow rate
Filtration of each of the five tree xylems were observed for respective flow rates (rate at which filtrate was collected) by varying the pump pressure. Results show that at maximum pressure, the flow rate for each tree was maximum. Under a constant pressure, flow rate for Ashoka was maximum followed by Silver Oak, Eucalyptus, Neem and lastly Mango tree (results are shown in Fig. 4). Since Ashoka...
and Eucalyptus belong to the class of gymnosperms, consequently they show greater performance. This shows that Ashoka is best suited for quick filtration followed by Silver Oak. Neem, Guava and Mango trees are flowering plants thus, as expected they show poor flow rate and therefore are not suited for filtration.

3.2. Effect of l/d ratio on flow rate
Since Ashoka xylem exhibited highest filtration rate among five trees, it was further studied for filterability by varying the length (l) and diameter (d). Pump pressure was kept constant at 2.5 psi. Firstly, readings were taken by fixing the length of the system and varying its diameter. Secondly, the diameter was kept constant and length was varied. It can be seen from Fig. 5 that flow rate decreased linearly with increasing l/d ratios. However, in the case of diameter kept constant and length being varied, flow rates were considerably higher as compared to the case of varying diameter. Highest filterability was observed for Ashoka xylem with a length of 0.5-inch and diameter of 1-inch while it was least when the length was increased to 3-inches and diameter was reduced.

![Figure 4. Flow rates for different trees at different pump pressures.](image1)

![Figure 5. Variation of flow rate with l/d ratio.](image2)
3.3. Filtration performance of Ashoka xylem for turbid water

The above two results lead to the conclusion that when freshly cut xylem from Ashoka tree (0.5-in. length and 1-in. diameter) was used for filtering water under a pressure of 2.5 psi, the filtration performance and flow rate is highest. Turbid water was made to pass through Ashoka xylem under the aforesaid conditions. It was observed that Ashoka xylem was able to remove the impurity completely (see fig 6). This implies that in conditions of natural disasters such as flood where clean water is scarcely available, Ashoka xylem could act as a potential water filter.

Xylem filter technology could be an attractive option for low-cost point-of-use water filtration. These filters could provide the advantage of reduced human effort requiring only periodic filter replacement. The highest measured flow rate (for Ashoka xylem) under the pressure of 2.5 psi was about 0.083 ml/s which corresponds to a filtration rate of over 7 litres/day, sufficient to meet the drinking need of two persons. Xylem filters could be produced locally and be disposed of due to their biodegradability. While wood is an easily available material, the use of fresh xylem does not preclude its use as a filter material. Thus, it is conceivable that plants could be developed for enhanced filtration characteristics.

![Figure 6. Turbid water (left) and filtrate (right).](image)

4. Conclusions

Trees with pointed and waxy leaves like Ashoka and Silver Oak are able to filter inked water. These belong to the class of gymnosperms. Xylem of the plants are found to show filtration property. Xylem of five different plants were tested for filtration of ink solution to find the best plant for filtration application. Those trees belonged to both gymnosperm and angiosperm families. The trees which flower and give fruits (like Neem) are angiosperms and these fail to purify water and remove impurities. There is a vast scope of tests to be conducted in order to screen different plants to find a correct filter. It was found that Ashoka tree xylem showed best filtration performance among all five plants.

References

[1] Boutilier MSH, Lee J, Chambers V, Venkatesh V, Karnik R (2014) Water Filtration Using Plant Xylem. PLoS ONE 9(2): e89934. doi:10.1371/ journal. pone.0089934.
[2] Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. Science advances, 2(2), e1500323.
[3] Sharma, S., & Bhattacharya, A. (2017). Drinking water contamination and treatment techniques. Applied Water Science, 7(3), 1043-1067.
[4] Frederiksen, H. D. (1996). Water crisis in developing world: misconceptions about solutions. Journal of Water Resources Planning and Management, 122(2), 79-87.
[5] Lopez Gunn, E., & Ramón Llamas, M. (2008, August). Rethinking water scarcity: Can science and technology solve the global water crisis?. In Natural Resources Forum (Vol. 32, No. 3, pp. 228-238). Blackwell Publishing Ltd.
[6] Sperry JS (2003) Evolution of water transport and xylem structure. International Journal of Plant Sciences 164: S115–S127.
[7] Choat B, Cobb AR, Jansen S (2008) Structure and function of bordered pits: new discoveries and impacts on whole-plant hydraulic function. New Phytologist 177: 608–625.
[8] Jansen S, Choat B, Pletsers A (2009) Morphological variation of intervessel pit membranes and implications to xylem function in angiosperms. American Journal of Botany 96: 409–419.