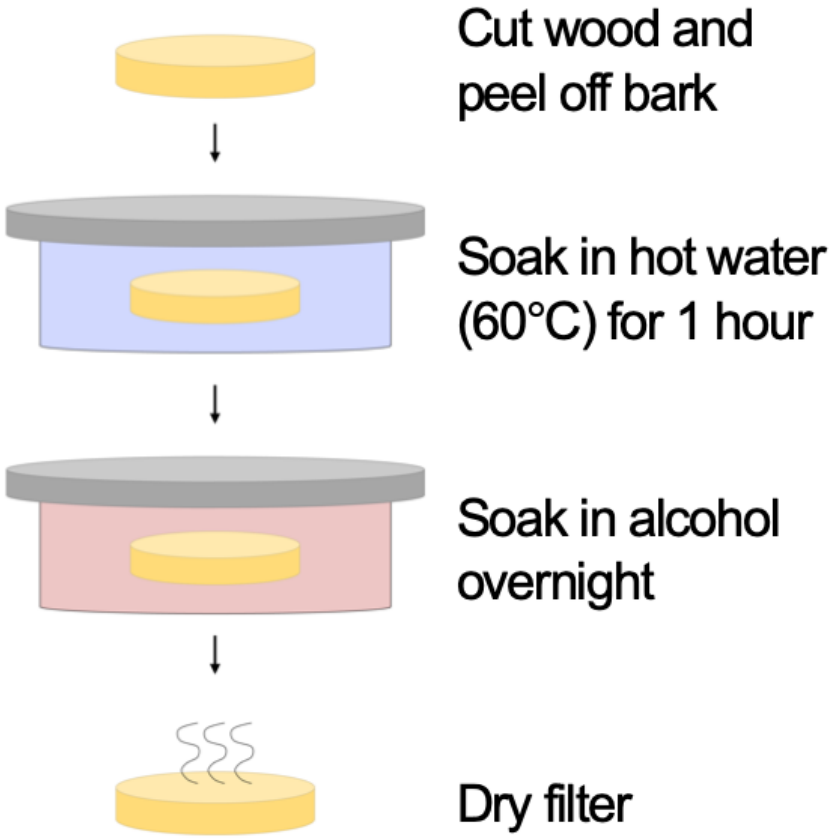
Guide for fabricating xylem filters

Steps involved in xylem filter manufacture

Fabrication of xylem filters involves four simple steps illustrated below. The rationale and further details associated with each of these steps, the effect of design/manufacturing parameters on filter performance, and resources required for fabricating filter cartridge have been provide in subsequent slides.

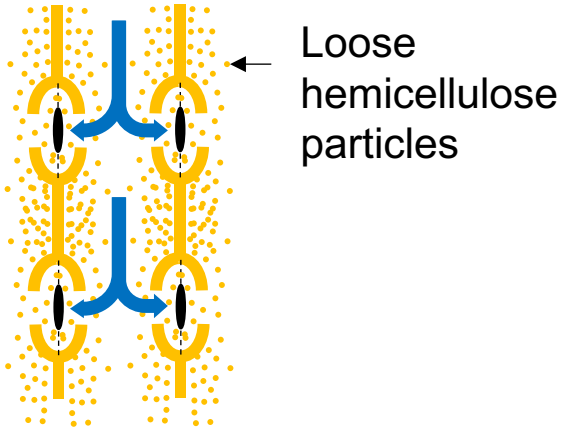


Step 1: Cut wood and peel off bark

1. Wood for creating the filters can be selected based on the ‘Design guide for selecting tree species for making xylem filters’ document in this page.
2. The choice of filter diameter will depend on the target flow rates (since flow rate scales linearly with filter area) and accessibility to wood.
3. Filters should be thicker than the length of a single conduit (typically ~5 mm in gymnosperms) to achieve contaminant rejection. Presence of resin canals in the sapwood can create leakage pathways. Measures to mitigate leakage (such as increasing filter thickness even further, plugging resin canals, etc.) might be needed in such cases. Literature on the conduit length and presence of resin canals for the selected wood species should be reviewed. Preliminary tests should be conducted to identify the appropriate filter thickness to obtain the desired rejection performance.

Step 2: Soaking wood in hot water for 1 hour

- Xylem filters have a unique self-blocking behavior: Xylem is composed of loose hemicellulose fibers that dissolve in the water flowing through the filter and re-deposit on the membranes clogging them. This imposes an intrinsic limit on the filter's shelf life.



- To mitigate self-blocking, xylem filters can be soaked in hot water at 60°C for 1 hour. The temperature and duration of treatment has been optimized for removing sufficient fibers to improve capacity, while mitigating damage to pit membranes to preserve rejection for filters made from Eastern white pine and gingko. These parameters might need further adjustment based on the tree species used for creating the filters.
- This step might not be needed if the external contaminant load is high.

Step 3: Soaking of filters in alcohol

- Drying causes the membranes in the xylem to seal against the cell wall and at times, damages them. This results in poor flow rates and rejection performance and thus, short shelf-life of xylem filters.
- To improve shelf-life, two methods for preserving filters in a dry format can be followed:
  - *Alcohol treatment (shown in video)*: Soaking the cut filters in alcohol (ethanol, isopropanol, etc.) before drying preserves the structural integrity of membranes and provides a shelf-life of at least two years. The alcohol should be food-grade and measures should be taken to ensure that the residual alcohol in the filter (if any) conforms to food safety regulations.
  - *Controlling filter thickness (not shown in video, but this involves simply skipping Step 3):* The flow rates of dried filters depends strongly on filter thickness. By maintaining a filter thickness of ~0.25 inches, reasonable flow rates can be obtained. In order to mitigate the leakage of contaminants through damaged pit membranes and improve rejection, multiple thin filters can be stacked in series. This method is useful in areas where access to alcohol is difficult, although quality control might be difficult.

Step 3: Drying

- Filters can be air-dried or dried in an oven at 45°C.
- Filters should be completely dried before packaging.
- Desiccants, like silica gel, can be used during packaging to keep the filters in a dry state.

Effect of filter geometry, fabrication process, and operating conditions or parameters on xylem filter performance.

Performance metrics	Xylem filter geometry		Fabrication methods			Operating conditions/parameters	
			Dry preservation				
	Sapwood area (A)	Thickness (*t*)	Alcohol treatment*	Stacking multiple filters in series*	Hot water treatment**	With cloth or GAC pre-filtration	Pressure used for driving flow (*P*)
Flow rate (*Q*)	$Q \propto A$	$Q \propto 1/t$, if conduits (tracheids) are well-connected, else decreases more rapidly with thickness.	Increases	$Q \propto 1/n$, where n is the number of filters	No significant effect.	Generally increases; depends on water quality and pre-filtration process.	$Q \propto P$
Volumetric capacity (*V*)	$V \propto A$ is expected for the same driving pressures	Unknown	Increases	Unknown; may be comparable to a single filter.	Increases if self-blocking is more dominant than fouling due to contaminants in water, else significant effect is not expected.	Generally increases; depends on water quality and pre-filtration process.	Unknown; depends on how pressure affects fouling.
Rejection: Filtration-based	No effect	Depends on particle size. Typically increases rapidly till thickness exceeds tracheid length; may not increase further if sapwood has resin canals, else theoretically expected to increase with length.	Increases	Increases; theoretically log-additive, if rejection of each filter is identical.	Depends on temperature and duration of treatment; may decrease rejection. Soaking at high temperatures or for long durations compromises rejection performance.	Depends on pre-filtration method used; GAC can augment performance by removal of chemical contaminants.	No significant effect expected.
Rejection: Adsorption-based (viruses)	No significant effect expected if permeate flux is constant	Expected to increase for the same driving pressure. $\tau \propto 1/t^2$, where τ is contact time.	Unknown	Expected to increase; theoretically log-additive, if rejection of each filter is identical.	Unknown		Expected to decrease. $\tau \propto 1/P$, where τ is contact time.

Resources required for filter manufacture

Task	Resources needed
Xylem filter cartridge	
Extraction of branches	A pruner or sickle could be used for cutting branches. A chain saw might be used for cutting trunks.
Peeling of bark	The bark in the branches can be usually peeled by hand. Gloves should be used to avoid contact with resin. Band saws/hand saws might be needed for removing the bark from trunks.
Cutting the wood to desired sizes	Wood can be cut using a band saw, cold saw or hand saw. The surface roughness of the filter will vary with the equipment used. *Smooth surfaces are **required** to prevent leaks while using filters with a face seal holder*, but surface roughness might be a cause of lesser concern when a side sealing mechanism is used. To obtain a smooth surface, filters should be cut with a cold saw.
Hot water treatment	Clean (tap) water, vessels for soaking the filters in water, stove (gas/electric/induction) or just fuel wood for heating the water to 60° C, and a thermometer for monitoring temperature.
Alcohol treatment	Certified, food-grade alcohol (methanol, ethanol, etc.) with >99% purity and alcohol-compatible vessels for soaking the filters. The level of residual alcohol in dried filters should be maintained within the permissible limits for human consumption as prescribed by food safety standards[31].
Drying	Filters could be dried at room/ambient temperatures of 25–40° C or using an oven.