Lithium removal with household water purification devices

Report for Whylome, Inc. — September 26, 2022

Special thanks to Sarah C. Jantzi (Plasma Chemistry Laboratory at the Center for Applied Isotope Studies, University of Georgia) for analytical support.

This research was funded by anonymous donors and the Tiny Foundation.

Background

Trace amounts of lithium are often found in drinking water. Levels range from a few micrograms per liter, to over 100 μg/L in the case of water contaminated by mine waste or coal ash. Large quantities of lithium, such as clinical doses used for treatment of bipolar disorder, are pharmacologically active, and can impact mood, clarity of thought, and body weight. The effects of trace doses are less well-understood, but trace doses may have pharmacological effects as well — an extensive body of research dating back to the 1970s has found relationships between trace levels of lithium in drinking water and public health outcomes like crime rates, suicide rates, and mental hospital admissions.

Despite this, little research exists regarding how lithium can be cost-effectively removed from drinking water. This study tested three different types of water purification devices to evaluate their ability to remove lithium from water: activated carbon filters, distillation machines, and reverse osmosis filtration (RO). The mechanism of action for each type is summarized below.

Activated carbon filtration

Carbon filters remove contaminants from water using adsorption. Water flows over a bed of carbon particles with a large surface area, which has a strong affinity for hydrophobic molecules. These compounds bind irreversibly to the surface of the carbon, removing them from the water. In addition, the carbon acts as an ion exchange medium, binding heavy metals (such as lead) in exchange for innocuous ions such as sodium. Carbon filtration is relatively inexpensive and widely used at a household scale.

Distillation machines

Distillation machines, or “stills”, purify water by bringing it to a boil, condensing the water vapor onto a cool surface, and collecting the purified condensate (distillate). In a household distillation machine, heat is usually applied by electric resistive heating, and condensing is usually accomplished by blowing air over a coil of heat-conductive tubing to cool it. Salts and other non-volatile compounds in the water do not vaporize, and are left in the still, rather than collected as distillate. Although effective at removing ionic compounds, distillation is energy-intensive due to the need to boil water.

Reverse osmosis
Reverse osmosis (RO) is a filtration technique that uses pressure to push water through a semi-permeable membrane. The pore size of this membrane allows the passage of water but excludes most organic compounds and salts. Filtration is performed in “tangential flow” configuration, where the liquid to be filtered is passed parallel to the membrane surface to sweep away compounds rejected by the membrane and minimize clogging. In practice, the membrane is usually polymeric and the RO filtration is usually preceded by pre-filters and carbon filters to remove larger particles and organic compounds that would clog the membrane and reduce the effective lifetime. For convenience, household RO devices usually operate using the water pressure of the water supply to the house, so that a pump is not necessary. However, only a fraction of the water supplied to the filter exits with the treated water (permeate). Typically 10-30% of the water passes through the filter to be collected as clean water, and the remainder is rejected to the sewer, along with the contaminants that were blocked by the membrane.

Methods

Selection of purification devices
The purification devices selected were all commercially-available devices intended for household use. All were purchased between December 2021 and January 2022 through normal retail channels. The devices were chosen in order to provide multiple examples of each purification technique, and to demonstrate the effectiveness of devices that are commercially popular. Table 1 summarizes the devices tested.[1] Some devices had a model number or stock-keeping unit (SKU), while others had only a general product name.

Table 1. Water purification devices tested in this study

Name	Type	Manufacturer	Notes
Brita 18-Cup Filter Pitcher	Carbon filter	Brita	Gravity-powered
Brondell Coral UC300	Carbon filter	Brondell	Uses household water pressure
Waterdrop 15UA	Carbon filter	Waterdrop	Uses household water pressure
PUR PLUS Faucet Mount PFM350V	Carbon filter	PUR	Uses household water pressure
Culligan Faucet Mount FM-15A	Carbon filter	Culligan	Uses household water pressure
Brita 7540545 On Tap Faucet Water Filter	Carbon filter	Brita	Uses household water pressure

Vevor 750W Distilling machine	Distillation	Vevor	Electric heating, fan-cooled
Megahome 580W Distilling machine	Distillation	Megahome	Electric heating, fan-cooled
APEC ROES-50 5-stage RO	Reverse Osmosis	APEC	3 pre-filters (activated carbon), RO, 1 post-filter
GE GXRQ18NBN Reverse Osmosis Filtration System	Reverse Osmosis	GE	1 pre-filter (activated carbon), RO, 1 post-filter

All devices were set up according to the manufacturer's instructions, and used to treat at least 10 liters of tap water (4 liters for the distillation machines) prior to use with lithium-spiked water. This flushed the system and conditioned any membranes or adsorbents prior to use. An additional 10 liters of tap water was passed after each test to ensure that any tubing was thoroughly flushed before moving on to a new condition. Spot checks determined that this was effective at returning the test systems to a clean state.

In the case of carbon filters and reverse osmosis, fresh filters were used for every new concentration. For example, one filter would be used to test performance under the 40 µg/L condition, the system would be flushed, and then a new filter would be installed and used to treat 10L of unspiked water prior to testing the 110 µg/L condition. The exception was the reverse osmosis membrane, which was not replaced every time; the pre-filters and post-filters were replaced but the same RO membrane cartridge was used for all tests (with a flushing equivalent to 10L of permeate performed between every test). Spot checks determined that this was effective at returning the test systems to a clean state, with lithium levels similar to those observed prior to treatment of spiked water.

Water

All water used for testing was treated city water ("tap water"), obtained at the testing location in Golden, Colorado. The water was treated by the City of Golden water treatment plant and is representative of city water distributed in the Golden area. This water has a background lithium concentration of approximately 25 µg/L Li^+. This water was further spiked with a known concentration of lithium in the form of lithium chloride for testing.

Four lithium levels were tested: 40, 110, 170, and 1500 µg/L Li^+. These concentrations represent moderate to high Li^+ levels in drinking water. These concentrations are also high enough that Li^+ remains detectable by analytical methods even if a relatively large fraction of the Li^+ is removed, enabling high resolution for the degree of removal. Testing on each device was always performed in ascending order of Li+ concentration (40µg/L, then 110µg/L, then 170µg/L, etc.) to minimize risk of cross-contamination.

Prior to each test (a single concentration treated by a single purification device), a volume of lithium-spiked city water large enough for the entire test was prepared in a single well-mixed container using volumetric flasks and stock solutions prepared using an analytical balance. This ensured that the feed to the device was consistent throughout the test. A control sample was also taken from this well-mixed container, which was not treated or purified and was analyzed directly for Li+. In each test, samples were taken at two different timepoints after a set volume of lithium-spiked water had been purified.

The carbon filters and reverse osmosis devices were tested at 10 liters and 20 liters. In all cases, this was a small fraction of the estimated filter lifetime as estimated by the manufacturer. The distillation machines were tested at 2 liters and 4 liters, owing to the much slower rate of water purification.

Each sample was 0.5L of treated water, taken immediately after the timepoint was reached. For example, a 10-liter timepoint for an RO device was 500mL taken immediately after a total of 10.0L of purified permeate had been purified by the device. This 500mL sample was mixed well in a clean polyethylene bottle, and smaller aliquots were transferred to polypropylene sample tubes for analysis. Samples were stored at room temperature.

An additional test was performed to operate a reverse osmosis filtration unit for a longer period and observe any longer-term trends. The GE RO device and a feed concentration of 170 ug/L were chosen for this longer-term study. In this case, a total of 100L of water were treated, rather than the 20L treated in other tests. The feed water was batched 100L at a time, with control samples tested from each 100L batch of feed water to ensure a consistent feed concentration (each 100L of feed water yielded approximately 20-25L of clean filtered water).

Analysis

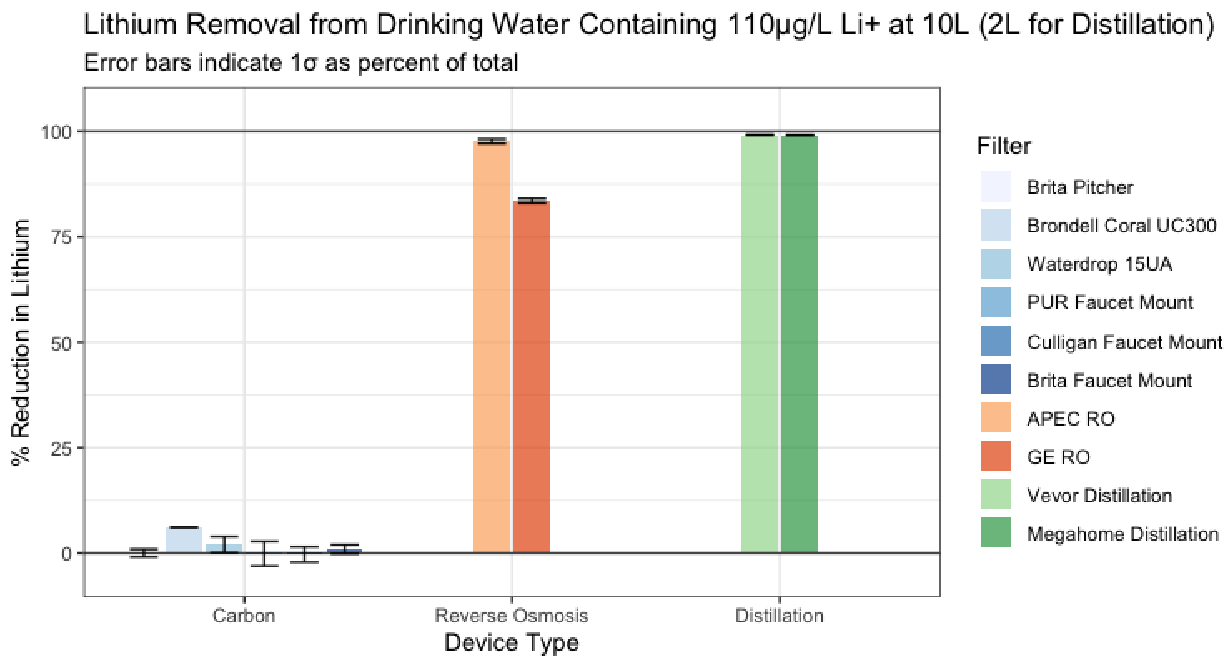
Analysis was performed by ICP-OES. The instrument used was a Perkin Elmer 8300 ICP-OES, and the limit of detection for the analytical method was 1 µg/L. All samples were analyzed in triplicate, with sample order randomized.

Results

Raw data are here and the analysis script is here.

Results are summarized in Table 2, and an overview of the performance of each model at a concentration of 110 µg/L Li+ is shown in Figure 1.

Figure 1.



Carbon filters did little to remove lithium from tap water. In contrast, reverse osmosis devices removed a large percent of the lithium (>90%) in all cases. Distillation machines performed the best, driving the levels of lithium below the limit of detection when treating all but the highest concentrations.

To slightly complicate matters, a mistake occurred with the feed prep in four cases. Too much lithium chloride (exactly double) was added to the feed tanks for the PUR faucet mount at 110 and 170 µg/L, and also Culligan faucet mount 110 and 170 µg/L. For example, when the starting concentrations were supposed to be 110 µg/L for the PUR Faucet Mount, they actually started with 210 µg/L. Then the filter did nothing to remove Li+, and the filtered water was also 210. Percent removal remains close to 0%, consistent with other results, but the starting concentration (and ending concentration) were both much higher than they should have been.

While this mistake is unfortunate, it doesn't change the conclusion, though it does complicate the data because the starting concentrations were different. Carbon filters still don't remove Li+ at concentrations of 210 and 325 µg/L.

For practical purposes, reverse osmosis (RO) requires much less energy input than distillation, and has a much lower cost per unit of volume capacity. Unlike distillation, household RO systems are easy to integrate with existing plumbing and can run entirely using home water pressure, requiring no energy use at the household level and sized to meet typical cooking/washing demand. Given these advantages, it was decided to test RO for a longer period of time, up to 100L of treated water, to evaluate ongoing performance.

In the long-term reverse osmosis test with 170 µg/L feed water, the GE RO device continued to demonstrate effective lithium removal, removing 89% or more of the lithium up to 100L of treated water, though it did show some degradation in performance. At 10L, the device removed about 98% of lithium, while by 100L, it removed only about 89% of lithium. While this shows some decline, we also did not observe a sudden "breakthrough" or failure in the first 100L. Further testing would be needed to evaluate this decline. These results are summarized in Table 3.

Table 2. Lithium Purification Result

	Starting Concentration	*40 µg/L*		*110 µg/L**		*170 µg/L**		*1500 µg/L*	
		10L	**20L**	**10L**	**20L**	**10L**	**20L**	**10L**	**20L**
Carbon Filters	**Brita 18-Cup Filter Pitcher**	36 (1)	36 (2)	108 (1)	107 (2)	167 (1)	166 (2)	1467 (38)	1457 (6)
	Brondell Coral UC300	31 (0)	37 (0)	102 (0)	108 (1)	156 (1)	168 (1)	1440 (10)	1467 (31)
	Waterdrop 15UA	41 (0)	42 (1)	114 (2)	115 (1)	173 (4)	176 (2)	1540 (26)	1560 (17)
	PUR PLUS Faucet Mount PFM350V	41 (1)	42 (1)	209 (3)	210 (3)	323 (7)	326 (3)	1477 (21)	1530 (30)
	Culligan Faucet Mount FM-15A	42 (1)	42 (1)	209 (2)	209 (2)	324 (7)	327 (3)	1500 (40)	1553 (15)
	Brita 7540545 On Tap Faucet Water Filter	40 (1)	39 (0)	109 (1)	111 (2)	165 (1)	166 (2)	1490 (10)	1510 (30)
Reverse Osmosis	**APEC ROES-50 5-stage Reverse Osmosis**	< 1 (0)	1 (0)	3 (1)	3 (0)	4 (0)	6 (0)	36 (1)	45 (1)
	GE GXRQ18NBN Reverse Osmosis	3 (0)	5 (1)	20 (1)	13 (0)	4 (1)	9 (0)	54 (2)	71 (2)
		2L	**4L**	**2L**	**4L**	**2L**	**4L**	**2L**	**4L**
Distillation	**Vevor 750W Distilling machine**	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)	1 (0)	1 (1)	3 (1)	3 (1)
	Megahome 580W Distilling machine	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)	< 1 (0)

Entries: Mean (SD)

** Exactly double the Li+ was added for the PUR and Culligan Filters*

Table 3. Long-Term Reverse Osmosis Test

Starting Concentration	*170 µg/L*							
	Original Study		Long-Term Test					
	10L	**20L**	**30L**	**40L**	**50L**	**60L**	**80L**	**100L**
GE GXRQ18NBN Reverse Osmosis	4 (1)	9 (0)	9 (0)	19 (1)	12 (0)	21 (1)	14 (0)	19 (1)

Entries: Mean (SD)

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[1] : An additional carbon filter tested was the “PUR Plus 7-Cup Pitcher”, which filters water 7 cups at a time via gravity. (This makes it similar to the Brita 18-Cup Filter Pitcher, which is also gravity-powered). When used to filter water under the same conditions as the above filters, lithium concentration was found to be higher in the filtered water than for the feed water, at all concentrations. However, the experiment was repeated with a newly purchased set of filters (purchased several months after the initial set of filters) and this result could not be repeated with the new batch of filters. Due to the discrepant results, and the time and cost required to follow up further, the results for this filter were omitted from the study. One possible cause for the discrepancy could be significant batch-to-batch variation in the lithium content of the filter cartridges.