International Journal of High Speed Electronics and Systems
Vol. 23, Nos. 1 & 2 (2014) 1420008 (7 pages)

DOI: 10.1142/S0129156414200080

World Scientific
www.worldscientific.com

Designing Filtration Systems to Remove Heavy Metals from Water

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The electronics industry uses high volumes of heavy metals in its production processes. Many of these heavy metals can end up in water and can be very difficult to remove due to the different forms that the heavy metal can exist in. Special design characteristics should be used to produce filters to remove heavy metals. In this study, we identify the different species of heavy metals and describe a method that has been tested for removing all types of species for heavy metals from water. This filtration technique utilizes multiple layers to ensure the removal of soluble, insoluble and complex species of heavy metals in water. The testing was done with a complex solution of lead according to NSF/American National Standards Institute (ANSI) standard 53 for the removal of lead at pH 8.5, using a combination of soluble, particulate and semi-insoluble lead. Filters were compared to standard, commercially available, gravity pitcher filters. The testing showed that the newly designed filter removed over 80 gallons of lead below the drinking water limit, compared to a standard filter which failed immediately. When trying to remove heavy metals from water, special care needs to be used in the design of the system to ensure the removal of all species of heavy metals.

Keywords: Heavy Metals; e-waste; complex solutions; filtration.

1. Background

The electronics industry uses high volumes of heavy metals in the manufacturing of different components, such as printed circuit boards and monitors. While the Environmental Protection Agency(EPA) guides the levels of toxins that can be discharged from these processes at production facilities within the US, these computer and electronic parts often get discarded after their effective life and can end up in domestic landfills, or shipped overseas. In 2005, it was approximated that 8% of municipal waste was considered electrical and electronic equipment. This electronic waste is estimated to be one of the fastest growing waste fractions and approximately 70% of the heavy metals found in landfills are due to e-waste.[1] A Cathode Ray Tube (CRT) style monitor or television contains, on average, four pounds of lead. These CRT style monitors are quickly becoming obsolete and being replaced with Liquid Crystal Display(LCD) and Light Emitting Diode(LED) monitors creating an excess of obsolete

TV's and CRT's that are being disposed in landfills.[2] These heavy metals can leach out of the landfills into the surrounding ground water, and then contaminate the drinking water for the neighboring communities.

Accordingly, we sought to address this gap in technology and develop a filter that could remove the many different species of heavy metals in drinking water.

2. Heavy Metal Species

Filtration of these heavy metals in the drinking water can prove somewhat complex, as the species of the material can vary wildly depending on concentration, pH, oxidation reduction potential, or other ions and chemicals in the water itself. Many technologies exist to remove soluble forms of these heavy metals. Molecular sieves, zeolites or cationic exchange resins can be used to remove soluble heavy metal contaminants. Insoluble heavy metals pose a more difficult challenge to remove because there can be tremendous variation in the size of the particles. The most difficult solution to filter, however, is complex combinations of soluble and insoluble forms of these heavy metals. For example, lead salts such as lead nitrate or lead chloride can be completely soluble at a pH of 6.5 and easily removed by adsorbents or ion exchange, but at a pH of 8.5 these lead species switch to partially insoluble forms.[3] These insoluble or partially insoluble forms can range in particle size from colloidal to hundreds of microns. Figure 1 shows very small particles of lead on the surface of a filter.

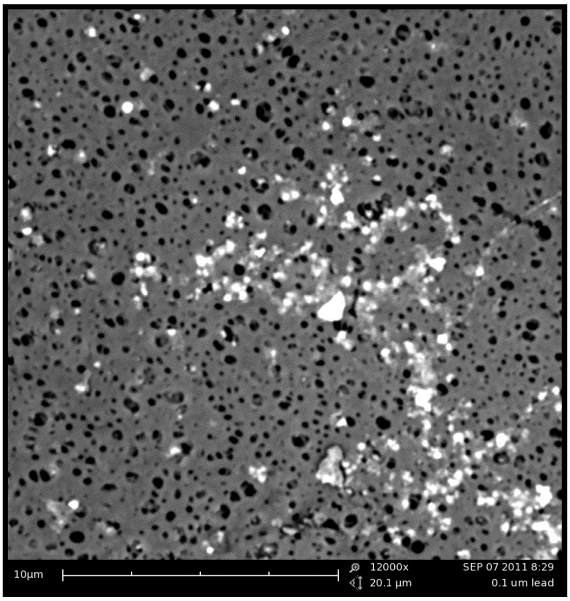

Fig. 1. SEM of particulate lead filtered through a 0.1 micron syringe filter to show size. Lead was precipitated according to NSF/ANSI 53.

The performance standard used to evaluate filtration products, NSF/ANSI 53 Standard for the removal of lead at pH 8.5, demonstrates this complex partially insoluble solution of heavy metals, specifically for lead. Similar filtration standards should be used to test other heavy metals individually with care to make sure that the challenge solutions are complex and contain soluble, as well as partially insoluble forms of the heavy metal. NSF/ANSI Standard 53-2013: Drinking Water Treatment Units – Health Effects provides testing protocols for evaluating the removal efficiency of lead at pH 8.5 from water. This protocol examines the removal of soluble forms of lead as well as particulate lead ranging in size down below one micron in diameter.[4]

An additional complexity in the filtering process occurs when these partially insoluble heavy metal particles resolubilize over time after they have been physically stopped. A physical filter could potentially remove partially insoluble heavy metal particulates by size exclusion over the course of the life of the filter, collecting large volumes of heavy metal on the surface of the filter. When a change of pH or other water characteristics occurs, the heavy metal can resolubilize, going back into solution at a much higher concentration than was originally in the water. Many filtration systems that are designed to remove soluble heavy metals or strictly particulate heavy metals will not adequately filter in these complex partially insoluble heavy metal solutions.[3]

3. Designing a Filter to Remove Complex Species

To remove these complex species of heavy metals, a special filter design is necessary to address the resolubilization, such as the design in Figure 2.

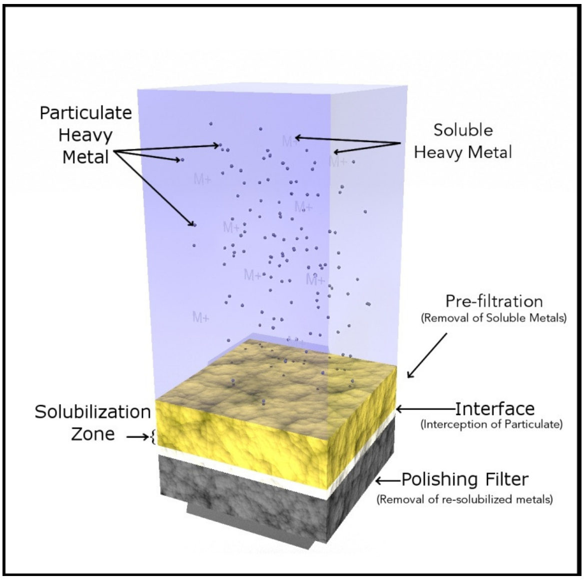

Fig. 2. Diagram showing the system for removing heavy metal solutions that contain soluble and partially insoluble species.

The water needs to first pass through a layer that will remove some portion of the soluble fraction of the heavy metal. A second phase of filtration is necessary to physically remove the particulate portion of the solution. This interface creates a resolubilization zone, allowing the heavy metal to slowly go back into solution over time. After this interface, a second layer is used that will remove the remaining soluble heavy metals that were allowed to resolubilize.[5]

We designed and produced a filter to this specification. The design included two layers of filtration media, with soluble lead adsorbents in each layer and an interface zone that was made to remove particulates down to 0.1 microns. In order to be comparable with current technology available in the market, our filter was designed to fit off-the-shelf, gravity style pitcher housings.

Fig 3. SEM of the surface of one of the two layers showing the immobilized adsorbents and tight pore structure.

4. Testing and Comparison

This filter was then tested to the NSF/ANSI 53 Standard for lead at pH 8.5 and compared to another off-the-shelf product that used ion exchange resin to remove ionic heavy metals. The following tables show the results of the testing:

Table 1. Flow rate, influent lead concentration and effluent lead concentrations levels at different total volume of water filtered with commercially available filters.

New Filter Design pH 8.5 Lead Test Data													
Test Point		Influent Water Data					Filter 1			Filter 2			
#	Gallons Filtered	Total Lead (ppb)	0.1 Filtered (ppb)	1.2 Filtered (ppb)	% Particulate	% Particulate <1.2 um	Flow Rate (ml/s)	Effluent 1 (ppb)	% Reduction 1	Flow Rate (ml/s)	Effluent 2 (ppb)	% Reduction 2
1	0	145.0	100.6	122.5	30.6%	49%	6.5	0.9	99.4%	6.5	1.1	99.1%
5	20	153.4	91.3	143.6	40.5%	84%	5.1	3.8	97.5%	5.5	3.7	97.4%
9	40	154.3	103.6	139.0	32.8%	70%	4.2	2.0	98.7%	4.2	1.6	98.8%
13	60	148.6	91.6	146.9	38.4%	97%	4.3	4.8	96.8%	4.3	5.0	96.6%
15	72	163.4	102.8	154.5	37.1%	85%	4.5	0.5	99.7%	4.3	0.2	99.9%
17	80	141.0	95.8	112.0	32.1%	36%	4.3	0.8	99.4%	4.2	0.4	99.7%

Table 2. Flow rate, influent lead concentration and effluent lead concentrations levels at different total volume of water filtered with new filter design.

Commercially Filter Design pH 8.5 Lead Test Data												
Test Point		Influent Water Data					Filter 1			Filter 2		
#	Gallons Filtered	Total Lead (ppb)	0.1 Filtered (ppb)	1.2 Filtered (ppb)	% Particulate	% Particulate <1.2 um	Flow Rate (ml/s)	Effluent 1 (ppb)	% Reduction 1	Flow Rate (ml/s)	Effluent 2 (ppb)	% Reduction 2
1	1.5	138.9	91.7	122.8	34.0%	66%	2.3	9.3	93.3%	3.3	18.8	84.7%
2	2	138.9	91.7	122.8	34.0%	66%	2.3	10.0	92.8%	3.3	21.5	82.5%
3	3	159.4	106.8	154.1	33.0%	90%	2.3	16.5	89.6%	3.3	27.0	82.5%
4	4	159.4	106.8	154.1	33.0%	90%	2.3	17.7	88.9%	3.3	26.6	82.7%
5	5	151.1	99.7	134.7	34.0%	68%	2.3	15.4	89.8%	3.3	17.0	87.4%

The commercially available filters failed almost immediately, showing greater than the drinking water limit of 10 ppb within 3 gallons of filtered water. The newly designed filter showed effluent concentrations well below the drinking water limit of 10ppb. This system of filtration shows excellent performance for removing complex species of heavy metals from drinking water. In addition, the flow rate was between 2 and 3 times faster than the commercially available filters at the same head height, which decreases wait time for the end user. Figure 4 shows the effluent lead levels versus total gallons filtered for the filters compared. The black line shows the drinking water limit of 10 parts per billion for lead.

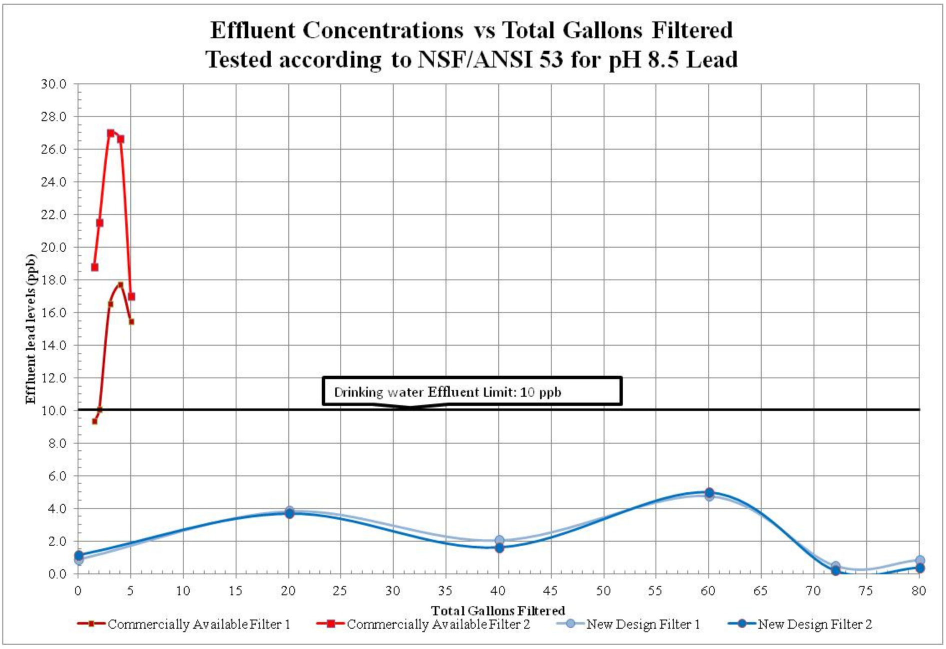

Fig. 4. Testing results when tested to NSF/ANSI 53 for pH 8.5 lead.

Conclusions

As our consumption of electronics increases, the potential for drinking water to be polluted with heavy metals increases drastically. When designing a filter to remove these heavy metals, special care must be taken to remove all types of species of the heavy metals, including the partially soluble portions. Utilizing filtration systems that strictly remove particulate species or strictly soluble heavy metals will not give adequate protection like those commercially available today. This new design is necessary to ensure the removal of all forms of heavy metals from drinking water.

Disclosures

The authors of this publication are employed by KX Technologies LLC which is developing products related to research described in this publication.

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