Leaching of Silver from Silver-Impregnated Food Storage Containers

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ABSTRACT: The use of silver in commercial products has proliferated in recent years owing to its antibacterial properties. Food containers impregnated with micro-sized silver promise long food life, but there is some concern because silver can leach out of the plastic and into the stored food. This laboratory experiment gives students the opportunity to design their own study to measure the leached silver via graphite furnace atomic absorption spectrophotometry. In this experiment, students stored deionized water, tap water, and acetic acid in two styles of silver food containers for a week. The less expensive version of the food container consistently had higher levels of leached silver. The acetic acid samples and microwaved samples also had higher silver levels. Students gained experience with sample design, chemical analysis, and data analysis.


It has long been known that silver has significant toxic properties to bacteria, aquatic organisms, and humans. Companies have begun to take advantage of the antibacterial nature of silver by adding silver (particularly nanoparticle silver) to a wide range of products, including cosmetics, fabrics, and food containers. It has been shown that fabrics impregnated with silver nanoparticles release as much as 100% of the silver in either the wash water or sweat. There have been no published studies as of yet on silver release from food containers. It is important to investigate such a release because silver demonstrates neurotoxicity properties in humans, as well as the potential for ecotoxicity if the metal passes through a wastewater treatment plant and is released into a water body.

EXPERIMENTAL OBJECTIVES

This laboratory experiment is intended for an upper-division environmental chemistry or analytical chemistry course. The students are asked to investigate multiple variables that could increase the release of silver from food containers. This experiment has been sequenced such that students already have some experience in investigating multiple controlling variables on metal concentration from previous experiments. The experiment is flexible in that instructors and students can choose different solvents or time frames than those presented in this experiment or even investigate other factors not presented, such as a comparison control of a nonsilver impregnated food container. The primary learning objective is for the students to gain experience in designing an experimental protocol to answer the relatively open-ended question of whether silver leaches from the food storage containers. Secondary objectives are to give the students additional exposure to the analytical techniques used in the experiment (i.e., pipets and graphite furnace atomic absorption spectroscopy).

In the experiment, students evaluate the influence of multiple variables (extraction solvent, container type, and container treatment) on the quantity of silver leached from the container. The ANOVA technique is used to identify significant differences in leached silver between the solvents and treatments. The rapid analysis provided by the graphite furnace atomic absorption spectrometer (GF-AAS) allows sufficient data to be collected for a two-way ANOVA with replication. If desired, the procedure may be simplified by eliminating the replicate samples or only collecting data for a one-way ANOVA.

EXPERIMENTAL OVERVIEW

This experiment spans a two-week period with silver quantified during the second week. The quantities of silver that leach from two different styles of food containers (oso*fresh brand) were examined. The commercial food containers had been impregnated with microsized silver by the manufacturer. The two styles seen in Figure 1 are the original containers (OC), which are thicker and more expensive, and the everyday containers (EC), which are cheaper and thinner. The silver content in the two container styles is not known.

Extraction and Heating

The 14.2 oz (420 mL) OC and 15.5 oz (458 mL) EC were used as the oso*fresh sets included several of these sizes. The students filled each of the containers with 250 mL of each...
of the solvents (tap water, deionized water, and 5% acetic acid). Students collected 10 mL at each sampling event. Heating was done for 2 min in a microwave oven at high power.

Analysis

A 5 μg/L silver standard solution was prepared by serial dilution of a commercial silver standard solution (Acrors Organics, 1 mg/mL Ag in 0.5 M HNO₃ with 3% HNO₃ (Aristar Plus Trace Metal grade). A combined matrix modifier solution was prepared by 1:10 dilution of 10,000 mg/L Pd stock solution (Perkin-Elmer) and 1:100 dilution of 10,000 mg/L Mg stock solution (Perkin-Elmer) to give 0.1% Pd and 0.06% Mg(NO₃)₂. All dilutions were prepared with 18 MΩ deionized water using Eppendorf pipets and polypropylene volumetric flasks.

Graphite furnace atomic absorbance analyses were performed using a Perkin-Elmer AAnalyst 600 spectrometer equipped with an AS 800 autosampler and Perkin-Elmer Lumina silver hollow cathode lamp. Analyses were performed at 328.1 nm using a lamp current of 10 mA. Given the concentrations of silver found in this experiment, other methods of analysis such as inductively coupled plasma mass spectroscopy (ICP-MS) are possible. All calibration and sample analyses were performed in triplicate using injections of 20 μL with 5 μL of matrix modifier solution. Calibration standards were prepared by diluting 5 μg/L silver standard solution to 5, 4, 3, 2, 1, and 0.5 μg/L with deionized water using the AS 800 autosampler. Ten replicate measurements of a deionized water blank were performed to calculate the instrument detection limit for the analysis.

HAZARDS

Nitric acid is corrosive and students should wear appropriate protective clothing. Silver is not considered to be a dermal toxicant, but students should beware of ingestion or eye contact. Both the silver and palladium solutions are prepared in diluted nitric acid and are therefore caustic and should be handled with gloves. Waste material should be disposed according to local, state, and federal environmental regulations.

RESULTS AND DISCUSSION

The analysis data are summarized in Table 1. Students investigated three variables during the experiment: container style, solvent, and treatment (time and heating). Each data point on the table is an average of triplicate measurements performed on a single sample. The original container (OC) consistently had a lower leached silver concentration than the everyday container (EC) for all but the immediate sampling. For both container styles, the deionized and tap water extracted approximately the same concentrations of silver, but the acetic acid had higher concentrations of silver for several samplings. Silver concentration increased slightly due to time and heating with the EC container extracted with tap and deionized water. However, there was a significant increase in silver concentration with heating for both container styles extracted with acetic acid, particularly after an hour post-heating and after the second heating.

ANOVA calculations performed on the OC samples are summarized in Table 2. For both the extraction time and the solvent, the calculated F-value is greater than the critical F-value, which indicates that the observed differences in measured silver content due to these factors are statistically significant. In addition, the F-value for the interaction term is also greater than the critical F-value. This indicates that the more corrosive solvent (acetic acid) and longer waiting and heating times combine to extract more silver than the sum of the two factors alone would predict. Results for the EC samples were similar, but even more pronounced, as expected based on the higher total concentrations of silver extracted from that style of container.

SUMMARY

This experiment has been used successfully in our upper-division environmental chemistry and instrumental analysis courses. The students are interested in the outcome of the experiment because the data are relevant to food storage containers. Students commented that they liked being able to decide which parameters they were going to study. They also gained technical skills with the use of pipets and the GF-AAS and

Table 1. Silver Concentration in Extracted Samples

<table>
<thead>
<tr>
<th>Extraction Time</th>
<th>Silver in Deionized Water/μg L⁻¹</th>
<th>Silver in Tap Water/μg L⁻¹</th>
<th>Silver in Acetic Acid/μg L⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate</td>
<td>OC 0.2</td>
<td>EC 0.2</td>
<td>OC 0.2</td>
</tr>
<tr>
<td>1 Week</td>
<td>OC 0.3</td>
<td>EC 0.6</td>
<td>OC 0.2</td>
</tr>
<tr>
<td>1 Week + Heating</td>
<td>OC 0.4</td>
<td>EC 0.8</td>
<td>OC 0.3</td>
</tr>
<tr>
<td>1 Week + Heating +1 h</td>
<td>OC 0.4</td>
<td>EC 0.3</td>
<td>OC 0.7</td>
</tr>
<tr>
<td>1 Week + 2 Healings</td>
<td>OC 0.4</td>
<td>EC 0.9</td>
<td>OC 1.4</td>
</tr>
</tbody>
</table>

Table 2. Two-Way ANOVA with Interaction on Silver Extraction in the OC Style Container

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>Fcrit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>1.49</td>
<td>4</td>
<td>0.37</td>
<td>58.52</td>
<td>3.06</td>
</tr>
<tr>
<td>Solvent</td>
<td>0.86</td>
<td>2</td>
<td>0.43</td>
<td>67.33</td>
<td>3.68</td>
</tr>
<tr>
<td>Interaction</td>
<td>1.08</td>
<td>8</td>
<td>0.13</td>
<td>21.23</td>
<td>2.64</td>
</tr>
<tr>
<td>Within sample</td>
<td>0.10</td>
<td>15</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
learned valuable experimental design and data-analysis skills. There are a multitude of variations that can be carried out with this experiment for different sections, different semesters of the same course, or if independent projects are part of the course. Among these variations are exploring silver leaching from new versus used containers, leaching from the internal versus external surface of the containers, or the use of nonsilver-impregnated food containers as a control.

ASSOCIATED CONTENT

Supporting Information
Instructor notes, two versions of the student instructions (for one-week or two-week lab exercises), and student data. This material is available via the Internet at http://pubs.acs.org.

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REFERENCES