

Silver deposition on wetted materials used in the potable water systems of the International Space Station

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Silver is used as the biocide for potable water on the Russian Segment of the International Space Station and is also intended to be used for NASA Orion spacecraft. Studies on the stability of water quality containing silver have demonstrated the depletion of silver from water even after short term storage in water tanks, implying potential microbial water contamination or proliferation. This paper investigates the loss of silver ions from water bulk when water is in contact with various materials typically used in water systems in space applications. Silver ions concentration was equal to 10 or 0.5 mg Ag⁺/L. Water was brought in contact with various materials at surface-to-volume ratio 5.0 cm⁻¹ at 30°C, and was then stored either for 7d (for 10 mg Ag⁺/L) or 28 d (for 0.5 mg Ag⁺/L). Stored surfaces were either leached, in order to estimate the amount of deposited silver onto the surfaces, or subjected to XPS analysis to investigate the chemical state of the deposited silver. Silver losses from water containing 10 mg Ag⁺/L followed the order: PTFE (7.4%) < FEP (14.7%) < SS 316L NASA/JSC PRC-5002 passivated & electropolished (21%) < EPR Parker E0798-70 (63.2%) < SS 15-5 pH, H1025 (78.4%) < 316L with GTAW welding (84.2%) < SS316L NASA/JSC SS PRC-5002 passivated (94.7%) < SS316L (96.8%) ~ Titanium 6AL-4V(96.8%). On the other hand, silver was completely, 100%, depleted from water containing 0.5 mg Ag⁺/L after contact with all metallic surfaces. For this low Ag⁺ concentration, silver was partially (~65%) removed when water was brought in contact with polymeric surfaces FEP and PTFE. Leaching of surfaces verified the deposition of silver onto materials, with the silver mass balance closing to better than 90% in all cases. XPS results showed that the chemical state of deposited silver varies with the type of the solid surface.

Nomenclature

<i>AFM</i>	= Atomic Force Microscopy
<i>ASTM</i>	= American Society for Testing and Material
<i>ATV</i>	= Automated Transfer Vehicle
<i>CW</i>	= Conditioning Water

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<i>EPR</i>	= Ethylene Propylene Rubber
<i>ESA</i>	= European Space Agency
<i>FEP</i>	= Fluorinated Ethylene Propylene
<i>HAS</i>	= Hemispherical Sector Analyzer
<i>ICP-MS</i>	= Inductively Coupled Plasma- Mass spectra
<i>ISS</i>	= International Space Station
<i>JSC</i>	= Johnson Space Center
<i>M</i>	= number of height values (nm) obtained from the height image or the number of phase values (o) obtained from the phase image
<i>NASA</i>	= National Aeronautics and Space Administration
<i>OCP</i>	= Open Circuit Potential
<i>P</i>	= Passivated
<i>P&E</i>	= Passivated and Electropolished
<i>PP</i>	= Polypropylene
<i>PTFE</i>	= Polytetrafluoroethylene
<i>PW</i>	= Potable Water
R_a	= Roughness
<i>SCE</i>	= Saturated Calomel Electrode
<i>SS</i>	= Stainless Steel
<i>S/V</i>	= Surface to Volume
<i>XPS</i>	= X-ray Photoelectron Spectroscopy
<i>WW</i>	= With Welds
z_i	= height or number of phase value of point i

I. Introduction

THERE are two water quality standards defined for water consumption by the International Space Station (ISS) crew: US potable water and Russian potable water¹. There are some major differences between the two types of water: a) the disinfection agent is silver for the Russian type of water and iodine for the US type of water, b) TOC maximum acceptable levels are significantly higher according to the Russian water quality standards (20 mg/L for Russian standards and 0.5 mg/L for US standards), c) Russian standards permit more minerals, up to 1000 mg/L of total dissolved solids after mineralization whereas the US standards foresee 100 mg/L of total dissolved solids, and d) the maximum allowable total chromium level is significantly higher in the Russian type of water, up to 100 µg/L, compared to the US type of water, up to 50 µg/L. Although NASA currently uses iodine as water biocide on the American Segment of the ISS, it plans using silver as a biocide for potable water in future manned space missions.

The incompatibility of silver and iodine provoked the transport of a single type of water per campaign by the Automated Transfer Vehicle (ATV) developed by ESA. Already, four ATV launch campaigns have been successfully completed delivering the Russian type of water to the ISS. Despite slight modifications in the process of ATV loading, silver concentration fluctuations were observed in both campaigns. However, the results of chemical and microbiological analyses still conformed to the Russian water quality standards. Likewise, chemical characteristics of Russian water delivered by Progress vehicle to ISS complied with ISS water quality specifications during Expeditions 21 through 25².

This work is part of a project supported by ESA (European Space Agency) to examine the phenomena responsible for biocide concentration fluctuations in water systems for space crew usage. ESA interest stems from the need to provide the ISS crew with potable water of long term microbial control, in order to exclude any potential threat in crew health related to water quality degradation. The scope of this work is to investigate the decrease of biocidal Ag⁺ concentration in water exposed to different types of materials and assess the chemical state of deposited Ag on these materials. On this account, specific objectives of the work are: (i) to investigate the types of materials that are prone to silver deposition, (ii) to verify silver deposition by closing the silver mass balance and (iii) to identify the chemical state of Ag deposits.

II. Materials and Methods

Different types of materials, that have been already used or are compatible with space potable systems, were exposed to water containing either 0.5 mg/L or 10 mg/L silver ions concentration. Potable water (PW) consumed by the crew aboard ISS contains 0.5 mg/L silver ions. Before final loading of ATV water tanks with PW, water tanks are treated with water containing 10 mg/L silver that is called “conditioning water” (CW) . Accordingly, in this

study PW refers to water containing 0.5 mg/L silver, while CW refers to water containing 10 mg/L silver. The examined exposure conditions of materials to water (e.g., high surface-to-volume ratio S/V, high temperature, etc.) were selected so as to intensify silver deposition kinetics. After the exposure period, water samples were subjected to chemical analysis for silver determination. Experiments were performed in triplicate and descriptive statistical analysis of the results of chemical analyses was conducted using SPSS v.17 software. Solid materials were either leached, in order to estimate silver recovery in the leachates, or subjected to microscopic analysis. The latter included Atomic Force Microscopy (AFM) for the determination of the topography and roughness of the surfaces and X-ray Photoelectron Spectroscopy (XPS) for the estimation of the chemical state of silver on the materials' surfaces. In addition, Open Circuit Potential (OCP) measurements were conducted at specific interface of metal/electrolyte, so as to investigate electrochemically the corrosion potential of such systems.

A. Water preparation

Water was produced in the lab according to the Russian water standards¹ containing either 0.5 mg Ag/L (PW) or 10 mg Ag/L (CW). The produced water complied with the quality determined during ATV missions^{3,4,5}. Water was freshly prepared, before each experiment, in 1 L volumetric flasks. All hardware items (glassware, plastic ware, etc) were sterilized prior to use and covered by aluminium foil. The basis for either type of water (CW, PW), was ultrapure water (Direct-Q 3 UV, Millipore). Adequate quantities from stock solutions of various salts were introduced to ultrapure water, so as to comply with the water quality standards. Next, silver ions were added using a silver ionization unit (CSG-1, UK) equipped with silver electrodes of high silver purity (99.99%). Water was subjected to several ionization cycles, in order to achieve the required final silver concentration (either 0.5 or 10 mg/L Ag). Water was then filtered through a 0.2 µm filter (Pall Corporations, USA) and silver concentration was measured spectrophotometrically (LCK354, Hach Lange). The composition of CW and PW is presented in Table 1.

Table 1. Composition of conditioning (10 mg Ag/L) and potable (0.5 mg Ag/L) water.

Parameter	Concentration		Parameter	Concentration	
	Conditioning water (CW)	Potable water (PW)		Conditioning water (CW)	Potable water (PW)
Silver (mg/L)	10	0.5	TOC (mg/L)	0.5	0.5
pH	8.14	8.10	TDS (mg/L)	235	235
Conductivity (µS/cm)	338	310	Ammonium (mg/L)	<0.05	<0.05
Calcium (mg/L)	41.8	42.7	Color (Pt-Co)	0.0	0.0
Magnesium (mg/L)	12.5	12.8	Chromium (µg/L)	6.0	6.0
Turbidity (NTU)	0.23	0.10	Nickel (µg/L)	3.0	3.0
Nitrate (mg/L)	13.4	18	Barium (µg/L)	6.0	6.0
Chloride (mg/L)	<0.05	0.8	Zinc (µg/L)	3.0	3.0
Fluoride (mg/L)	1.0	1.0	Total coliforms (CFU)	0	0

B. Solid materials

Flat strip coupons of solid materials (Length x Width x Depth: 76 x 12.7 x 1.6 mm) were obtained from Metal Samples (Alabama, USA). The manufacturing process and types of tested coupons are presented in Table 2.

Prior to experiments (about 24h before) coupons were meticulously cleaned, according to JRP5322.1G (NASA) and ASTM G1 protocols (JSC, 2008; ASTM, 1999). After cleaning, all coupons were dried and stored under nitrogen atmosphere until the performance of the experiments.

Table 2. Examined materials

MATERIAL	SPECIFICATIONS/ MANUFACTURING
Teflon FEP 500L 160	ASTM D 2116 – 02
Teflon PTFE	ASTM D 1710
EPR Parker E0798-70	0.62" DURO/ rubber
SS 316L	ASTM A-480-12/ Finish: 120 Grit sanded
SS 15-5 pH	AMS H 6875B/ Heated to 551.7°C for 4 h & air cooled
SS 316L/ WW	ASTM A-480-12A/ SS316L with autogenously Gas Tungsten Arch Welding (GTAW) across the width
SS 316L/ P	ASTM A-480-12A/ Passivation with nitric acid: AMS-QQ-P-35C, Type VI in accordance with ATF-SOP-1010 Rev008/ Finish according to NASA/JSC PRC-5002
SS 316L/ P&E	ASTM A-480-12A/ Passivation with nitric acid: AMS-QQ-P-35C, Type VI in accordance with ATF-SOP-1010 Rev008/ Finish according to NASA/JSC PRC-5002/ Electropolishing
Titanium Alloy 6Al4V	AMS 4911J, AMS 4911H

C. Exposure of surfaces to conditioning and potable water

Exposure of various types of surfaces to CW and PW took place inside polypropylene containers (HJ-Bioanalytik, Germany) at surface-to-volume ratio (S/V) equal to 5.0 cm⁻¹. As shown in Figure 1, four flat strip coupons of each material (of total surface area about 78 cm²) were introduced into the wells of the container. Each set of four coupons was hanging from a polypropylene rod passing through a small hole near the top edge of coupons. Coupons are hanging apart using small o-rings at the polypropylene rods to separate them. This separation distance was deemed important to avoid contact and overlap of coupons. The exposure period of coupons to CW was 7d, while the exposure period to PW was 28d. Multiwell plates were placed into Plexiglas containers and then were filled with nitrogen. Preparation of experiments was performed under low light conditions. Finally, Plexiglas containers were placed inside an Environmental Test Chamber (Termacks, Series 6000) at 30°C for the entire experimental period (in dark). Tests were implemented in triplicate, while in each series of tests, there was also a blank sample (without exposed metal) in order to examine possible deposition of silver on the polypropylene (PP) walls of the experimental container (multiwell plate). The experimental setup is shown in Figure 1.



Figure 1. Experimental test setup.

At the end of the experimental (exposure) period, all water samples were stored in PP tubes in the presence of HNO₃ at a final concentration of 5%. Water samples were subjected to Ag concentration determination and to trace metals analysis. In addition, coupons were withdrawn from test wells and were dried inside the Plexiglas containers under continuous nitrogen gas flow. After drying, coupons were stored in PP tubes in nitrogen atmosphere. Coupons were then subjected to leaching, in order to recover the silver deposited on their surface and perform total Ag mass balance. 5N nitric acid solution was used as leaching medium. Leaching experiments were carried out in 50 mL PP tubes. Initially, the tubes were immersed into a heated ultrasonic cleaner and were sonicated for 30 min at 60°C. Then, the tubes were placed on an orbital shaker and were agitated at about 200 rpm for 24 h (room temperature). Afterwards, the test coupons were removed and leachates were subjected to chemical analysis for silver determination.

In order to examine whether the water produced in the lab demonstrates the same or altered behavior compared to water used by ESA during the ATV missions, a special set of experiments was conducted. In these experiments, a specific batch of coupons was exposed simultaneously to conditioning water provided by ESA (courtesy of SMAT SpA, Torino) and to conditioning water produced in the lab.

D. Analysis methods

Silver was determined spectrophotometrically by the LCK 354 method (Hach Lange). Several dilutions of the water samples were applied, when silver concentration in the samples was higher than 0.8 mg Ag/L (upper concentration limit of the method). In addition, major cations, such as Ca^{2+} , Mg^{2+} etc., as well as trace metals (including silver) were analyzed by ICP-MS (Agilent, 7700 Series).

The topography and roughness of surfaces at micron and submicron range was examined with a commercial AFM device (NT-MDT SOLVER-PRO). AFM scans were performed in air, in the contact-mode, using a silicon NT-MDT cantilever (CSG30 Series) with a nominal spring constant of 0.6 N/m and a tip of a 10 nm radius of curvature. 256×256 data points were acquired at a 0.6 Hz scan rate. Sample tilt correction and noise filtering was applied to the data as required, using the NT-MDT image analysis component of the NoVA 1.1.0.1912 software. At least three different $10\mu\text{m} \times 10\mu\text{m}$ areas of the sample were scanned and the average roughness values (R_a) of height images was calculated by the image processing software. R_a values quantify how much does the real surface deviate from an ideal flat plane. It sums up the modulus of all variations from the calculated mean value and averages them to their number. R_a is defined as the mean of the absolute values of surface deviations measured from the mean plane at z_0 , according to Equation 1:

$$R_a = 1/M \sum |z_i - z_0| \quad (1)$$

where $z_0 = 1/M \sum z_i$, M is the number of height values (nm) obtained from the height image or the number of phase values (ϕ) obtained from the phase image and z_i is the height or the number of phase value of point i .

X-ray photoelectron spectroscopy (XPS) analysis of the coupons surface layers was carried out in an Axis Ultra DLD system (Kratos Analytical) using a monochromated Al-Ka1 X-ray beam as the excitation source, a hemispherical sector analyzer (HSA) and a 128-channel detector. The analyzed area had an elliptical shape with the two axis being about 400 and 700 μm , respectively. The pass energy resulted in a broadening (FWHM) of less than 500 meV for the Ag-3d line. The studied surfaces were cleaned of adventitious carbon by using a 4 kV Ar^+ ion beam; the same procedure was employed for sputter-etching of the sample in cases that an XPS depth profile was sought (a 10s sputter time resulted in the removal of ca 1 nm of material). The spectra were calibrated in terms of charging-induced shifts by considering either the C1s peak (originating from adventitious carbon) to be located at 284.6 eV or the Ar2p peak originating from the soft surface cleaning by Ar^+ ion sputtering. Data interpretation was performed with the Kratos-Vision software.

E. Open Circuit Potential (OCP)

This type of electrochemical measurement was applied only to an SS 316L coupon with weldings as this material would be representative of corrosion phenomena. The metallic coupon was cleaned with isopropanol and rinsed with water before the experiment. The coupon was then immersed in a single-compartment cell containing 130 ml of deionized and doubly-distilled H_2O , resulting in a system with S/V ratio about 0.09 cm^{-1} . The open-circuit potential was monitored against a saturated calomel electrode (SCE) inserted into the cell via a 0.1 M KNO_3 salt bridge contained in a glass tube and ending to a frit made from a filter tip filled with Nafion[®] solid polymer electrolyte. The tip was placed opposite the center of the specimen at a fixed distance of 3 mm.

III. Results and Discussion

First, a comparison was made between the performance of CW produced in the lab and CW provided by ESA. A specific batch of all available materials were exposed to CW provided by ESA for 7d duration at temperature 30°C and S/V ratio equal to 5.0 cm^{-1} . Leaching and further measurement of silver in the leachates was used to estimate the deposited silver mass. Results shown in Figure 2 demonstrate that silver mass balance closed sufficiently well in this case. Closure of silver mass balance refers to the sum of the remaining silver mass in the bulk water at the end of the exposure period plus the recovered (leached) silver mass from SS coupons and PP container walls. The latter refers to 5% of the silver deposited onto the PP container (horizontal dotted line in the plot).

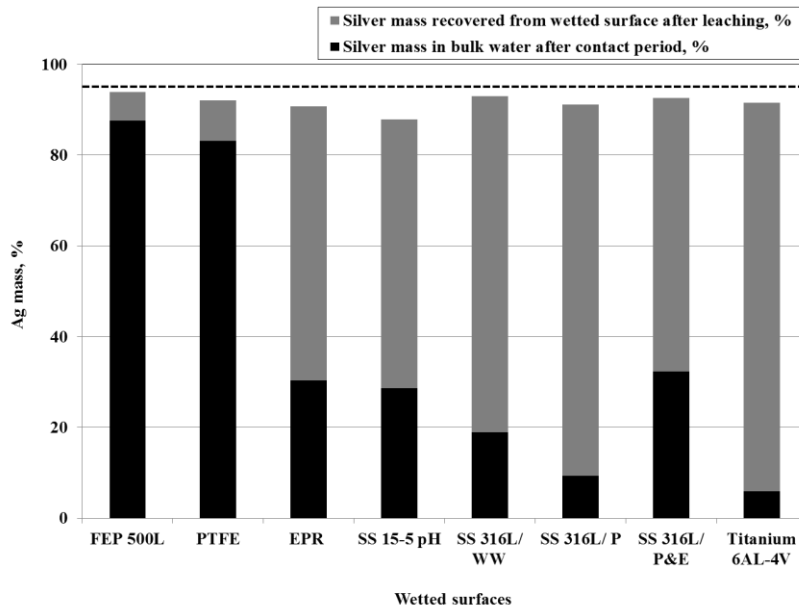


Figure 2. Silver mass balance closure with respect to the initial silver concentration in the bulk (for the experiments with CW provided by ESA).

Figure 3 shows the results of silver depletion in the CW provided by ESA and in the CW produced in the lab. In all cases, results are alike with differences not being statistically significant. Therefore, it is assumed that the results reported below on silver removal from CW and PW produced in the lab yield valid information on silver removal from water used in ATV campaigns.

Analysis of silver in the water samples and leachates led to a reasonable closure of silver mass balance. Figure 4 shows that in all the examined cases the silver mass balance closed to better than 90%. Again, the silver deposited onto the PP container was determined as 5%; hence maximum recovery of silver from all surfaces and the water bulk was expected to be about 95% (dotted line in Figure 4). The sufficient closure of silver mass balance confirmed that silver was indeed deposited on the surfaces causing reduction of silver concentration in the water bulk.

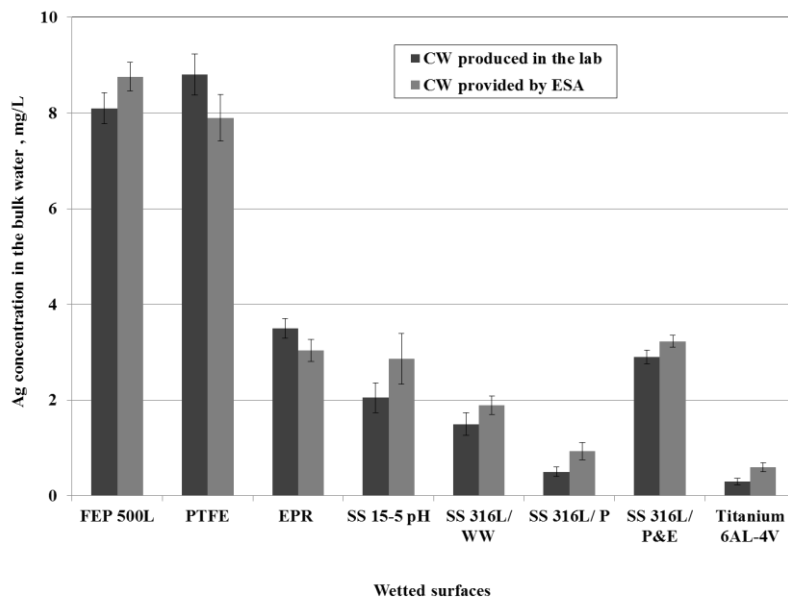


Figure 3. Silver removal from CW provided by ESA and CW produced in the lab after the 7-day exposure period.

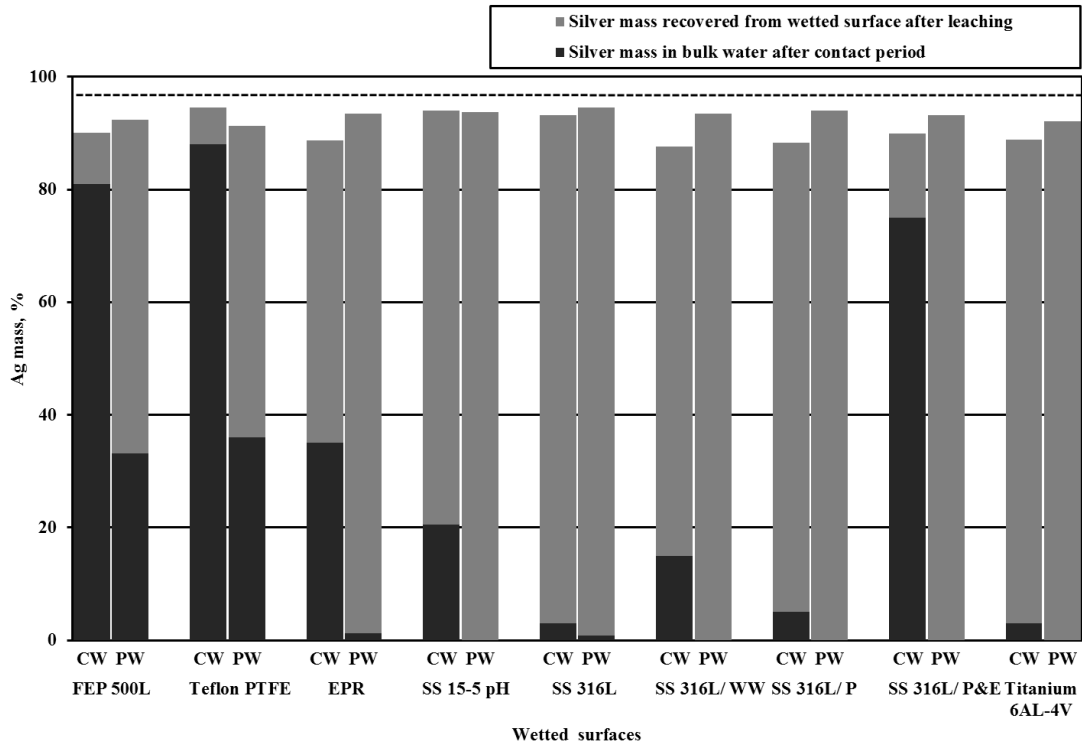


Figure 4. Silver mass balance closure with respect to the initial silver concentration in the bulk (for the experiments with conditioning water, CW, and potable water, PW).

Figure 4 shows that at the end of the exposure period silver was almost fully depleted from PW when the exposed material was either metallic or rubber. So, for PW it was not possible to assess which of these particular materials were more prone to silver deposition. On the contrary, this was possible in the case of CW, where the available silver mass in the water was much higher and silver removal from the bulk occurred more gradually. As shown in Figure 4, titanium alloy and SS316L attracted almost all available silver from the bulk after the 7-day exposure period. On the other hand, materials with an anti-corrosion layer on their top resisted more to silver deposition, e.g., heat passivated SS and electropolished SS316L. Interestingly, Teflon materials, even though they are considered inert, also caused noticeable silver removal from the CW.

The employed experimental matrix and procedures aimed to clarify whether silver loss from the water bulk is related with the deposition of silver on the solid surfaces. Indeed, the results verified that: a) silver is deposited on the examined surfaces and b) silver deposition depends on the type of material (different materials ‘attract’ silver to a different degree) and not on the water chemistry. Microscopic analysis of solid surfaces is required to obtain more details about the deposited silver. On this account, AFM analysis was employed aiming to detect potential differences in the topography of surfaces before and after exposure to the CW. High resolution topography of the SS316L surfaces before and after exposure to CW is shown in Figure 5, as it was obtained through AFM pictures. AFM measurements were carried at 5 different sample locations and 3s variation was ± 0.4 nm. Therefore, the difference (even if subtle) is statistically significant.

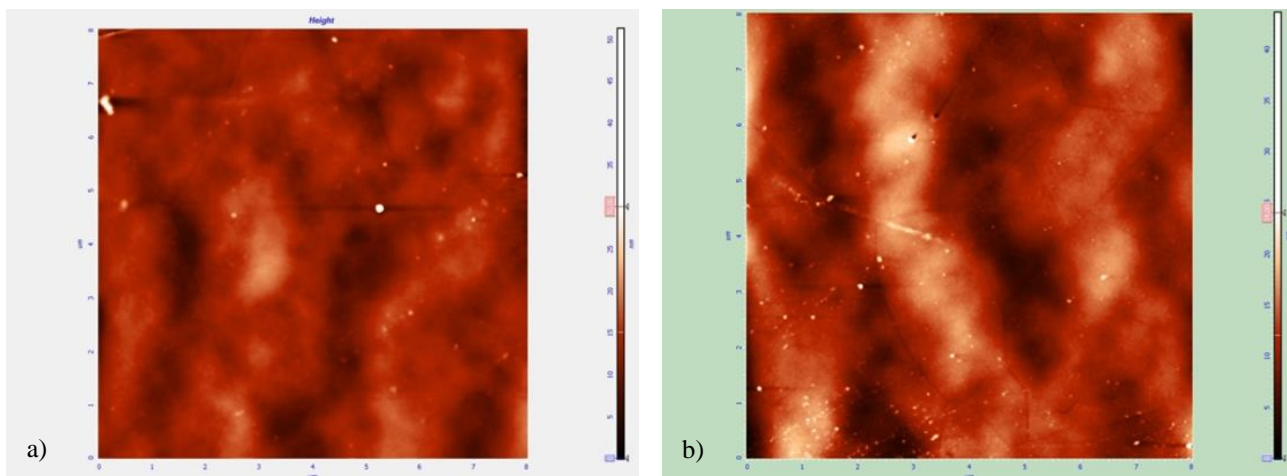


Figure 5. AFM pictures of passivated & electropolished SS316L before (a) and after (b) exposure to CW.

No significant differences were seen after the exposure (Figure 5), indicating that silver is not deposited as individual large particles but rather as a thin film or islands on the examined metallic surface. The average roughness, S_a , increased from 1.8 nm to 2.7 nm. A closer analysis of surface morphology revealed a 47% change in the roughness of the sample upon its exposure to the Ag^+ solution. This might imply that Ag deposition was accompanied by substrate oxide growth (according to galvanic deposition mechanism). It should be noted though that the so called “silver deposition film” cannot be estimated because the coupons’ surface is not flat and in fact most of the large features observed in the AFM micrographs are due to these undulations.

The form of deposited silver on the surface of various materials was estimated further by performing XPS analysis on several surfaces after exposure to conditioning water. Figure 6 shows the wide XPS analysis spectra of acid passivated and electropolished SS316L material. As can be seen in Figure 6, the presence of Ag was detected on the sample’s surface. In order to scavenge the surface and obtain concentration depth profiles, sputtering with Ar was applied (1 nm per 20 sec). As expected, sputtering of 1 nm from the surface was enough to remove the surface layer, often containing contaminations (e.g. carbon, C). Depth profiles obtained by sputtering revealed Ag, Ni and Fe peaks of increased atomic concentration.

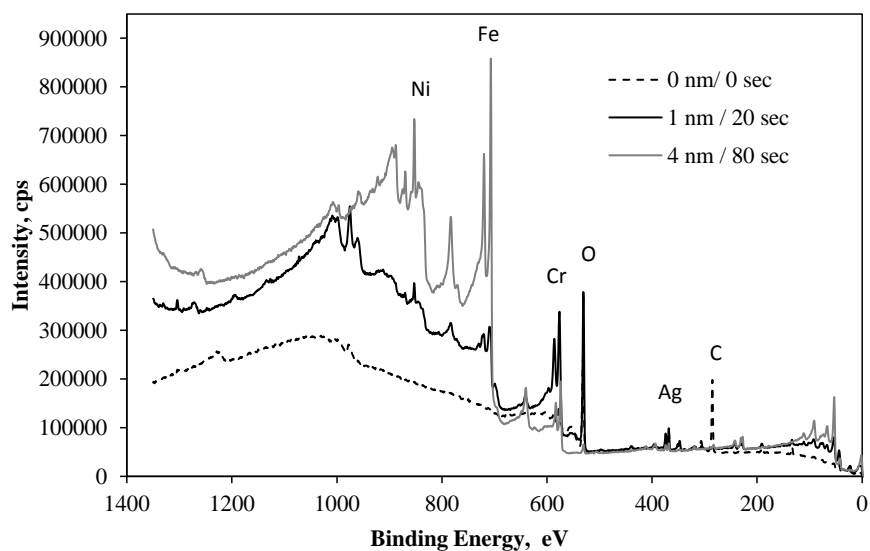


Figure 6. Wide area XPS spectra of a SS 316L passivated & electropolished solid coupon after a 7 day contact period with conditioning water, before and after sputtering of the surface.

To clarify the chemical state of deposited silver, focusing on the Ag 3d binding energy region was needed (Figure 7). Before sputtering, the Ag 3d 5/2 and Ag 3d 3/2 peaks were located at 367.5 eV and 373.5 eV, respectively. This means that Ag was oxidized on the sample's surface, forming Ag₂O oxide. The oxide film proved to be thicker than 1 nm since sputtering of 1 nm moved the peaks to higher binding energies but still between oxide and metallic peaks. The peaks at 367.8 eV and 373.8 eV most likely correspond to a mixture of oxidized and metallic Ag. Finally, when sputtering removed 4 nm from the surface, Ag was found in its metallic form (peaks are located at 368.3 eV and 374.3 eV), as it is displayed in Figure 7.

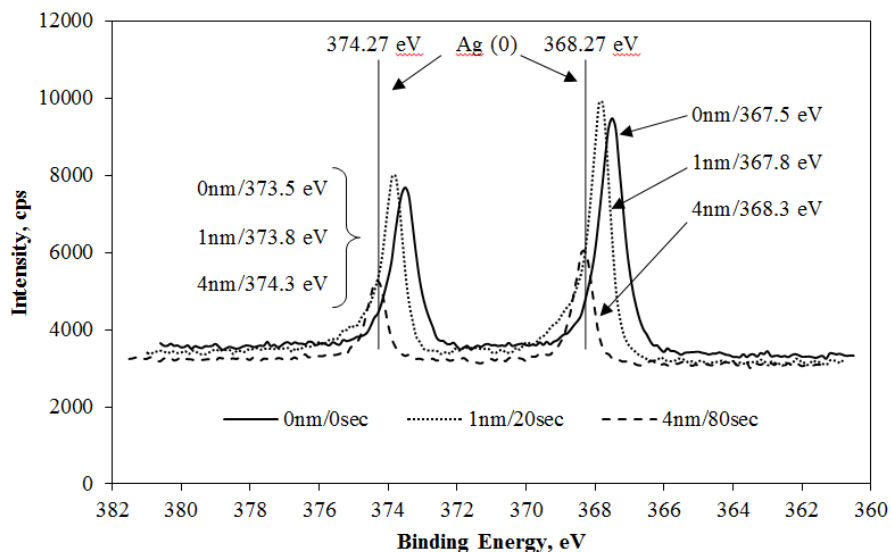


Figure 7. XPS spectra of non-sputtered and gradually sputtered SS 316L passivated & electropolished sample in the Ag 3d binding energy region.

Although the sputtering beam is known to cause chemical changes in some instances (this would imply that Ag₂O on stainless steel is reduced to Ag during sputtering) this is not the case in our work: prolonged sputtering of Ag oxide layers on other samples (Figures 8, 9) did not shift the oxide peak to the position of metallic Ag (as it was the case in Figure 7); hence it is believed that we are dealing indeed with an inherent change in Ag chemical state within the layers of the deposit. As far as the peak position and multiplicity is concerned, a single oxide peak is reported (attributed to both Ag(I) and the unusual Ag(III) state present in Ag₂O and the mixed state AgO oxides⁶); whereas in the co-existence of metallic and oxide forms a convolution rather than separate peaks is expected⁷ and evidence for that is the shoulder/tail in the intermediate-1 nm depth spectrum of Figure 7.

As regards titanium, XPS spectroscopy confirmed the presence of Ag on its top surface layers, too. This was observed in the wide XPS spectra (data not shown) before and after sputtering, as in the case of SS316L. After sputtering, the carbon peak almost disappeared indicating almost total removal of surface contamination. Therefore, the other peaks of the substrate (Ti, Al and V) became clearer. More specifically, Ti attained its characteristic double peak (instead of the mixed with oxides triple peak observed before sputtering) indicating the removal of the native oxide TiO₂ layer. After sputtering peaks were more intense but no shift to binding energies of metallic silver was observed, as it is seen in Figure 8 that focuses on the 3 d binding energy region.

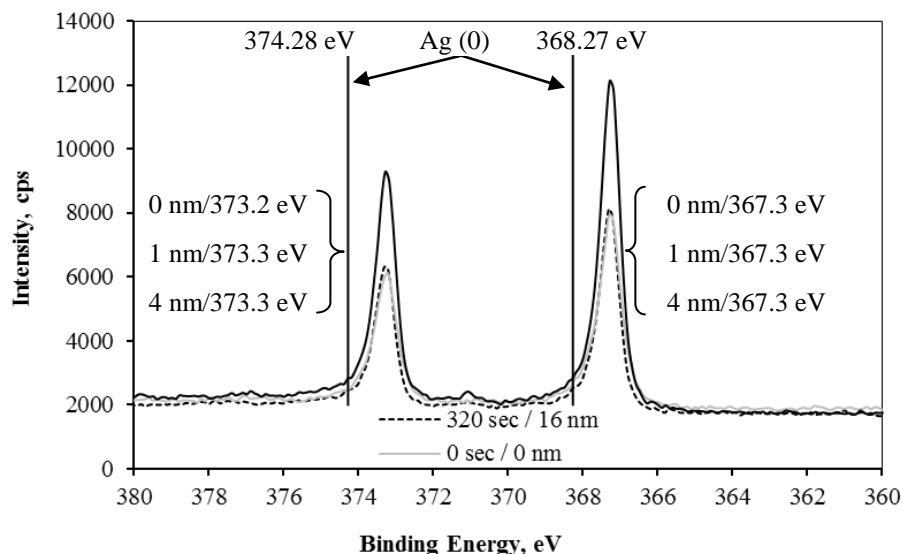


Figure 8. XPS spectra of the non-sputtered and gradually sputtered titanium surface in the Ag 3d binding energy region.

Wide area XPS spectrum of Teflon FEP surface identified the presence of Ag on sample's surface (data not shown). Apart from Ag peaks, C, O and F peaks were also observed. Ag peaks were revealed more clearly when focusing on the Ag 3d binding energy region. Figure 9 shows the XPS spectrum of a FEP surface after the deconvolution. Ag peaks located at 368.0 eV and 374.0 eV, respectively, can be associated with oxidized Ag (Ag_2O oxides).

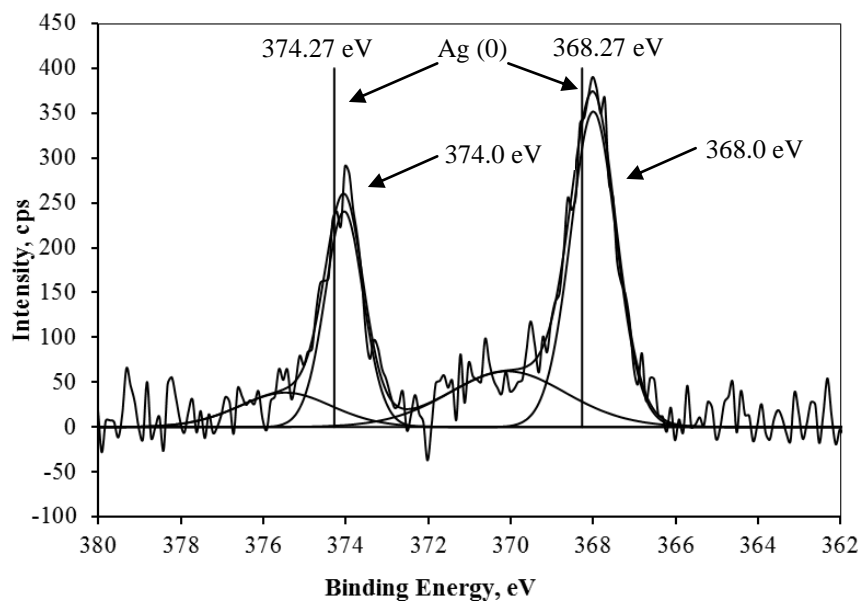


Figure 9. XPS spectrum in Ag 3d binding energy region of a non-sputtered FEP sample after the deconvolution.

The material used in the OCP experiment was SS 316L with welds at its surface. Figure 10 shows the variation of the open-circuit potential of the SS 316L WW coupon with immersion time, before and after silver addition. During the first day of immersion, the potential drops from ca. -160 mV to ca. -200 mV as a result of the slow establishment of the stainless steel coupon rest potential. At that time 0.5 ppm of Ag^+ were added (in the form of AgNO_3). As it can be seen more clearly in the related inset plot, the potential drops rapidly within a few minutes following the Ag^+ addition (by 51 mV in 10 min). During the subsequent hours, the potential continues slightly to decrease resulting in a 78 mV drop after one day.

The fact that the potential drops immediately after the addition of Ag^+ indicates a change in the stainless steel surface composition, most likely by creation of a SS/Ag composite, which has its own rest potential. Such a significant potential change within a short time interval indicates that the formation of the first Ag nuclei or islands on SS surface is very fast. At longer times, the potential is slowly drifting to lower values, a rate that could be explained if the additional Ag (deposited under mass transfer control) is preferentially deposited on top of already formed Ag nuclei or islands, and to a lesser extent on other stainless steel locations; in the latter case, the composition of the surface of the stainless steel/Ag composite in contact with the solution would indeed have changed very slowly.

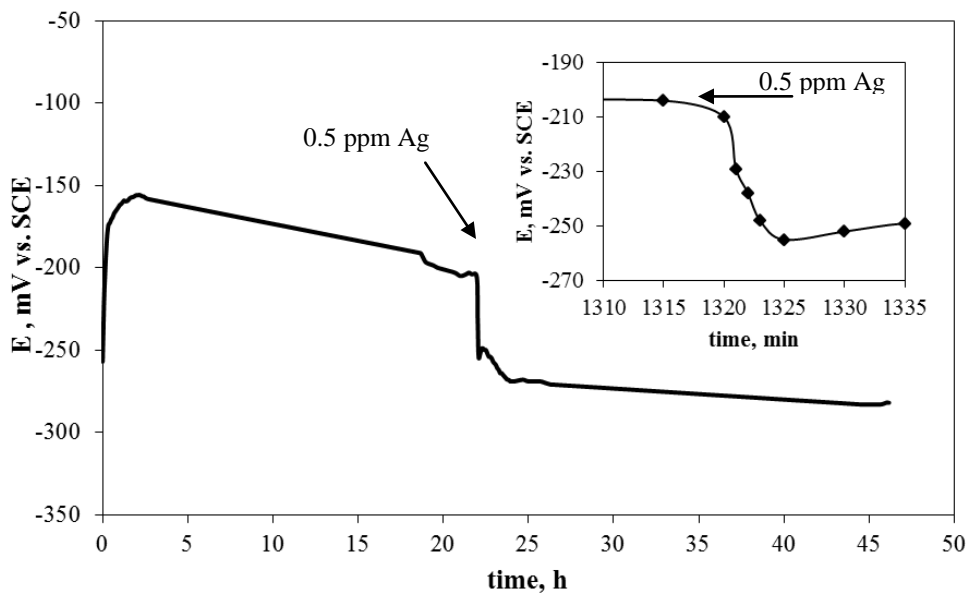


Figure 10. Variation of the open circuit potential of SS 316L/ WW surface immersed in deionized and doubly distilled water with time, before and after the addition of 0.5 mg Ag/L . Inset: Potential drop in the first few minutes after Ag^+ addition.

IV. Conclusions

The results of this study demonstrated that silver contained in water, prepared according to Russian standards, interacts with the solid materials of ATV water systems. Silver was almost fully depleted from water bulk after a 7-day exposure period of metallic surfaces to potable water. On the other hand, exposure of surfaces to conditioning water revealed that non-passivated metallic surfaces along with rubber surface led to significantly higher silver removal from the water bulk compared to the rest of materials. Best performance –less silver removal– was observed for SS electropolished and Teflon materials. Analysis of leachates from the exposed surfaces allowed to close the total silver mass balance reasonably well proving that silver was deposited on the surfaces. Detailed XPS analysis indicated the chemical state of deposited silver on the examined surfaces.

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