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Effect of water pre-activation on the activity of silver-containing colloidal solutions

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ABSTRACT

Silver has long been used for disinfection, water and food neutralization, and medicinal applications. The introduction of metallic micro-dispersed and nano-dispersed forms of silver, such as nullvalent and cluster silver, marks a significant advancement in the market. These modern formulations offer high efficacy and reduced toxicity compared to traditional cationic silver, addressing critical health concerns with innovative approaches. However, their limited shelf life due to silver's photosensitivity poses ongoing challenges. Enhancing the stability and longevity of these silver-based preparations is crucial, with substantial implications for public health and safety. This study explored the effect of various water activation methods on the activity of silver-containing colloidal solutions. Activation involved short-term microwave exposure and the extraction of molecular carbon (fullerene) from shungite. The findings revealed that microwave-treated water accelerates the degradation of cationic silver preparations, while fullerene-treated water stabilizes them effectively. The experiments demonstrated that these methods could significantly enhance the practical effectiveness and shelf life of colloidal solutions, offering controlled improvements in stability for practical and production use.

Keywords: Halides, Opalescence, Electromagnetic Radiation, Fullerene, Activated Water.

INTRODUCTION

Currently, medical, cosmetic, and food preparations containing silver are widely represented on the Russian market. The beneficial properties of silver have been known for many centuries (Toure et al. 2023). It was used for disinfection, neutralization of water and food, and medicinal purposes (Aka et al. 2022). It has been scientifically proven that silver directly affects bacteria by inhibiting their growth. Therefore, the use of silver-containing preparations is justified (N'Guettia et al. 2019). Recently, preparations of the so-called metallic micro-dispersed or nano-dispersed silver (cluster silver) have appeared on the market (Sene et al. 2021), where the main amount of silver is in the low-toxic metallic form Ag. These include:

Nullvalent silver: KND-C, KND-C-K, KND-SP, etc. (Biologicheski aktivnaya pishchevaya dobavka "Aregona" [Aregona nutritional supplement], 2011; OOO NIFTI, OOO NPP Sentoza Faktoring, 2008). These preparations, according to the manufacturers' descriptions, have high efficacy and significantly lower toxicity to humans than cationic silver (Kuderina et al., 2021).

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Colloidal (cationic) silver: Serebryanaya voda, Tinosan SDS, Argolaif.

Cluster silver: AdBion-2, Argovit Poviargol, Argonica.

In practice, two forms of silver-containing preparations are currently used, which have silver cations and metallic silver in their composition. However, these types of preparations have disadvantages related to shelf life due to the high photosensitivity of silver compounds. Therefore, the search for methods to manage the shelf life of such preparations is currently relevant.

It is in that light that this work aimed to determine the effect of the method of preliminary water activation on the activity of silver-containing colloidal solutions obtained based on it.

MATERIALS AND METHODS

Materials

1. Dry salt samples: $AgNO_3$, KCl, KBr, KI.
2. Distilled water (GOST R 58144-2018) (Rosstandart, 2018).
3. Fullerene C_{60}.

Devices

1. Photometer KFK 3-01-30MZ manufactured by Zagorsky Optiko-Mekhanicheskii Zavod (ZOMZ) (Russia).
2. Menumaster RMS510TS microwave system manufactured by Menumaster (USA).

Methods

Silver halides (chlorides, bromides, iodides) obtained by merging an excess solution of silver nitrate with corresponding solutions of potassium halides were used as colloidal systems. The solutions were prepared using various types of water (distilled without treatment, distilled with preliminary microwave treatment for 5 seconds at a frequency of 2.45 GHz, water extract with fullerene). In this case, colloidal opalescent solutions of cationic silver were formed with the general micelle formula: **$\{mAdH\ nAg+(n-x)\ NO_3^-\}^+ x\ NO_3^-$**, where H is halogen ions.

The observed opalescence indicates the presence of cationic silver. These solutions, due to photophobia, are destroyed over a short time to form metallic silver with the simultaneous disappearance of opalescence. The disappearance of this phenomenon indicates the destruction of the initial micelles of cationic silver. The proposed methods of pre-activation of water were chosen deliberately.

Microwave exposure

When water is exposed to a microwave energy stream, the cluster structure of water is destroyed with the simultaneous formation of active oxygen radicals from oxygen molecules dissolved in water (Berdonosov, 2001; Ismailov et al., 2010). The behavior of such water activation was studied using the example of selected colloidal solutions (Potselueva et al., 1998; Hasegawa et al., 2023).

Features of structuring in fullerene water

It is based on the action of molecular carbon (fullerene, C60) (Mosin and Ignatov, 2013), which enters water when it comes into contact with a natural molecular material containing shungite. (Urev, 1988; All-Russian Research Institute for Standardization, 2008). Fullerene forms a complex structure (fullerols) when interacting with water. They absorb up to 24 water molecules on their surface under the action of attractive forces by the electron shell of their conjugated systems. In this case, accelerated dissociation of water with the formation of hydroxide ions on the outer surface of molecular carbon is possible (Landsberg, 2009). Due to such structuring effects, water changes its physical and chemical properties. The features of such water activation and the properties of the resulting activated water were also studied using the example of selected colloidal systems.

RESULTS

Experimentally, based on measurements of the optical density of the obtained colloidal solutions of silver halides with a positive charge of micelles at different wavelengths of transmitted light, the size of colloidal particles was determined using the Geller curve (Tanasyuk et al., 2014). The results are compiled in Tables 1-3, each corresponding to the type of water used: non-activated, microwave-activated, and shungite-activated. . This allowed us to trace the degree of influence of the changed properties of water on the stability of colloidal solutions and the size of colloidal micelles.

It follows from Table 1 that with a decrease in sediment SP and with an increase in molecular weight, the following indicators increase: the size of colloidal micelles, storage time, and the degree of opalescence.

The experimental data for the assessment of the degree of influence of microwave water activation on the properties of colloidal systems are presented below (Table 2).

Table 2 shows that microwave-activated water rapidly destroys colloidal systems, reducing the size of colloidal particles by 4-12% and their storage stability by about 2 times compared with the baseline water (Table 1). This makes it possible, if necessary, to quickly transfer colloidal cationic silver-containing preparations into systems with the formation of metallic silver and the simultaneous disappearance of opalescence. Experimental data on the use of water activated with shungite are presented in Table 3.

It follows from Table 3 that in the presence of shungite water, the size of colloidal particles increases by 11-14% with a simultaneous sharp 5-fold increase in the shelf life of the used colloidal solutions. An increase in solution opalescence is observed. The observed new physical and chemical properties of solutions indicate the presence of specific processes. Thus, the increase in particle size can be explained by the adsorption of large hydrated fullerene particles on them. The optical stability of colloidal solutions increases due to the radioprotective properties of molecular carbon (Lukashov and Kuzaev, 2007). An increase in opalescence proves an increase in the roughness of colloidal particles (Revizskij and Dyblenko, 2003; Egorova and Polenov, 2018). The accessible and simple method of changing the properties of colloidal silver-containing systems described in the paper allows the effective use of these preparations in practice.

Table 1: Physical and chemical properties of colloidal system components in distilled water without activation.

Item No.	Sediment	*SP	Molecular weight	Size of micelles, nm	**Time of retention, hours	Opalescence baseline
1	AgCl	$1.73x10^{-10}$	143.5	0.95	24	Low
2	AgBr	$4.8x10^{-13}$	188	0.97	28	Average
3	AgI	$8.1x10^{-17}$	235	1.03	42	High

*SP is the solubility product, g/dm^3; ** is the storage time until complete decomposition

Table 2: Physical and chemical properties of colloidal system components in distilled water with microwave activation.

Item No.	Sediment	*Size of micelles, nm	Time of retention, hours	Opalescence baseline
1	AgCl	0.91/4%	12	Low
2	AgBr	0.92/5%	14	Average
3	AgI	0.98/12%	15	High

*The degree of reduction in the size of micelles compared to micelles in water without activation, No.

Table 3: Physical and chemical properties of colloidal systems in shungite water.

Item No.	Sediment	*Size of micelles, nm	**Time of retention, hours	Opalescence baseline
1	AgCl	1.05/11%	120/5%	High
2	AgBr	1.2/12%	150/5.3%	High
3	AgI	1.4/14%	240/5.7%	High

*The numerator is the particle size, nm, and the denominator is the degree of increase in particle size compared to micelles in water without activation.
**The numerator is the storage time of colloidal particles, hours, and the denominator is the multiplicity of the increase in storage time compared to micelles in water without activation.

DISCUSSION

The primary objective was to determine how different water activation methods impact the stability of colloidal silver solutions. The results indicate that microwave-treated water accelerates the degradation of cationic silver solutions, whereas fullerene-treated water significantly enhances their stability and shelf life. This finding aligns with Lai et al. (2019), who reported the rapid formation of colloidal silver nanoparticles under microwave irradiation, indicating that microwave treatment can significantly alter the properties of silver solutions.

The rapid degradation observed with microwave-treated water is attributed to the formation of active oxygen radicals, which promote the reduction of silver ions and lead to the breakdown of the colloidal structure. This is consistent with the findings of Berdonosov and Ismailov (2001) and Sousa et al. (2020), who emphasized the role of microwave irradiation in altering the properties of colloidal systems. Such rapid degradation can be beneficial for applications requiring quick silver ion reduction but poses a challenge for long-term storage stability.

Nicosia et al. (2020) also discussed the impact of microwave-assisted reactions on silver nanoparticles, noting changes in particle size and antibacterial properties. This supports the study's observations on reduced particle size and stability under microwave treatment. The study's results suggest that microwave activation can be tailored for industrial applications where rapid silver ion availability is advantageous.

Conversely, fullerene-treated water was found to stabilize colloidal silver solutions, significantly extending their shelf life and enhancing physical properties such as opalescence. This stabilization is likely due to the protective layer formed by fullerene complexes around the silver particles, as reported by Mosin and Ignatov (2013) and Landsberg (2009). The increase in particle size and enhanced opalescence observed with fullerene-treated water indicates a protective mechanism that enhances the longevity of colloidal silver solutions.

Barani and Mahltig (2020) discussed the use of microwave irradiation to catalyze the in-situ reduction of silver nanoparticles, noting the improved stability and protective properties of the resulting colloidal systems. This aligns with the study's findings on the enhanced stability and particle size in fullerene-treated water. Additionally, Atta and Abomelka (2021) demonstrated similar effects in their work on the microwave-assisted reduction of silver on cotton fabrics, highlighting the potential for practical applications in textiles and coatings.

The contrasting effects of microwave and fullerene treatments on colloidal systems are crucial for designing tailored applications. The quick degradation properties of microwave-activated water can be leveraged in industrial processes requiring rapid silver ion availability, as suggested by Puthalath et al.

(2021), who explored the synthesis and antibacterial activity of silver-copper nanocomposites formed by microwave-assisted chemical reduction.

On the other hand, the enhanced stability provided by fullerene-treated water is advantageous for applications in pharmaceuticals and medical imaging, where prolonged stability and precise particle size control are essential. This is supported by Adhikari et al. (2018), who discussed the rapid microwave-assisted synthesis of silver nanoparticles in a deep eutectic solvent, emphasizing the importance of chemical stability and protective effects.

Conclusion

The study demonstrated how altering the properties of colloidal solutions with silver-containing preparations can be achieved through activated water samples treated with various external physical influences. The research established that microwave-activated water accelerates the degradation of cationic silver preparations, while fullerene-treated water has a stabilizing effect on these colloidal solutions. These findings offer promising methods for enhancing the stability and practical applications of colloidal systems.

Future research should delve into the molecular dynamics that underlie the stabilization mechanisms of fullerene-treated water, explore alternative microwave treatment parameters to mitigate adverse effects on colloidal stability, and examine the practical applications of these findings in industries such as pharmaceuticals and food production.

Overall, the conducted study underscores the significant role of water activation in managing the properties of colloidal silver solutions, laying a foundation for improved practical applications and further scientific investigation.

COMPETING INTERESTS

The authors declare that they have no competing interests

AUTHORS' CONTRIBUTIONS

TS, YU, EE, GU, and AK conceptualized and designed the study. AK and GU conducted the experiments and performed data analysis. TS, YU, EE, GU, and contributed to drafting the manuscript. All authors reviewed and approved the final version of the manuscript.

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