

Study On the Possibility of Extraction Silver from Radiographic
Films

<http://www.doi.org/10.62341/istj-vol38-2-irego06>

Received	2026/05/01	تم استلام الورقة العلمية في
Accepted	2026/05/18	تم قبول الورقة العلمية في
Published	2026/05/19	تم نشر الورقة العلمية في

Study on the Possibility of Extraction Silver from Radiographic Films

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Abstract

This study focused on the possibility of extracting silver from radiographic films and developer solution used in their processing. Among the methods discussed were the precipitation method using sodium chloride and sodium hydroxide, as well as the metal replacement using aluminum metal. The results showed that extracting silver from radiographic films, after dissolved using nitric acid solution and precipitating it with sodium hydroxide was the most effective, yielding 16.66 gram of silver with a purity of 92.5%, as confirmed by XRF analysis. Regarding the developer solution, the results showed that silver extraction from a long-used solution through metal replacement was the most effective, yielding 3 grams of silver with a purity of 50.3%, according to XRF analysis. The method of precipitation and replacement of metals has been shown to be practical, economical and environmentally friendly.

**This scientific manuscript was presented at the sessions of the
International Renewable Energy, Gas, Oil and Climate**

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**Change Conference "iREGO" in the period of April 25-27,
2026. Tripoli - Libya**

Keywords: Silver Extraction, Radiographic films, Chemical
Reactions, Environmentally Friendly Solutions, XRF Analysis.

دراسة عن إمكانية استخلاص الفضة من أفلام التصوير الاشعاعي
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ملخص

تناولت الدراسة بعض عمليات استخلاص الفضة من أفلام التصوير الاشعاعي والمحلل المُظهر المستخدم في معالجتها، من ضمن الطرق المعتمدة طريقة الترسيب باستخدام كلوريد الصوديوم وهيدروكسيد الصوديوم، وكذلك طريقة استبدال المعادن باستخدام معدن الألومنيوم. حيث أظهرت النتائج العملية أن استخلاص الفضة من أفلام التصوير الاشعاعي بعد إذابة الفضة منها بواسطة محلول حمض النيتريك وترسيبها بواسطة هيدروكسيد الصوديوم، كان الأكثر فعالية حيث تم الحصول على 16.666 جرام من الفضة بنسبة نقاء بلغت 92.5% وفق تحليل جهاز (XRF). فيما يتعلق بالمحلل المُظهر، أظهرت النتائج أن المحلول المستخدم لفترة طويلة كان الأفضل لاستخلاص الفضة باستخدام طريقة استبدال المعادن، حيث تم الحصول على 3 جرامات من الفضة بنسبة نقاء بلغت 50.3% وفق تحليل جهاز (XRF). أظهرت طريقة الترسيب واستبدال المعادن أنها عملية ومناسبة من الناحية الاقتصادية والحافظ على البيئة من مخلفات الفضة.

وقد تم عرض هذه الورقة العلمية في جلسات المؤتمر الدولي للطاقة المتجددة والنفط والغاز وتغير المناخ "أيريغو" في الفترة 25-27 ابريل 2026م. طرابلس - ليبيا

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الكلمات المفتاحية: استخلاص الفضة – الأفلام الشعاعية – التفاعلات الكيميائية –
الحلول الصديقة للبيئة – تحليل الأشعة السينية الفلورية.

1- Introduction

Increasing demand for precious metals in industrial activities has increased the need of intensive studies to extract the precious metals from every form of waste and ores [1]. Industries produce large amounts of solid and liquid waste which are necessary for two components; organic and inorganic. Inorganic waste consists of metallic and non- metallic components. The metallic part consists of some precious metals such as silver, the recovery of which is of interest to this study, and other forms of heavy metals. Silver (Ag), a precious metal, is generally obtained from natural sources also as a by-product of metallurgical and industrial processes and has been applied in different forms including electronic, pulp, jewelry and radiographic industries. Silver is used in radiographic industries due to its high photosensitivity characteristics [1]. Worldwide silver production was reported to be insufficient to meet the demand which is steadily increasing by ~2-2.5% yearly [2]. The ecological problems caused by the disposal of silver enriched effluent is driving factor for increased recovery, regeneration and recycling of this effluent and other industrial waste. Radiographs, still and motion industry wastes are excellent sources for silver recovery. Approximately 2 billion radiographs per year are taken around the world which include chest X-rays, mammograms and CT scans. 94-98% of the X-rays are taken in the medical fields producing photographic chemicals and scrap films as waste [2]. Radiographic films used in the medical field are polyester sheets coated on both sides by radioactive materials which are sensitive to light. Abdel-Aal and Farghaly reported that 1kg of developed X-ray film contains 14-17g of silver [3]. Most photographic chemicals for developing X-ray films are made from silver salt. Due to the high photosensitivity of silver halide, about 8.3% of silver is used in photography [1]. The effluent of X-ray films processing facilities can reach a silver content of 1-12g/l. [1] Silver recovery methods from radiographic waste can be classified into chemical, biological, and conventional approaches. Chemical methods

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involve precipitation, ion exchange, and metallic replacement using reducing agents such as iron or zinc [4]. Biological recovery, a more environmentally friendly approach, employs silver-resistant bacteria or fungi to bio-reduce for bio-reducing silver ions to elemental silver [5]. Conventional methods such as pyro metallurgy involve high-temperature incineration or smelting, are energy-intensive and may emit pollutants [6]. In contrast, modern chemical and biological methods can achieve over 95% silver recovery with lower environmental impact and energy requirements. The recovery of silver from radiographic films are used developer solutions represents an environmentally sustainable approach to managing hazardous medical waste. Improper disposal of such waste can lead to the accumulation of toxic heavy metals in soil and water systems, posing significant ecological and health risks [7]. Silver recovery not only mitigates these environmental impacts but also allows for the reclamation of a valuable resource that can be reused in various industrial and medical applications [8]. Modern recovery technologies have been proven to be effective in reducing pollution compared to conventional treatment methods, while also enhancing the overall efficiency of waste management systems [9].

In this study the recovery of silver from radiographic films and use developer solutions by using chemical precipitation and metal replacement methods. The performance of each method was evaluated by analyzing extraction efficiency and silver purity using XRF. Due to the complexity of silver recovery from different waste matrices, a plausible recovery mechanism was suggested for each method for proper understanding of the process.

2. MATERIALS and METHODS.

2.1 Materials.

In this study, three different chemical methods were applied to treat radiographic films for the purpose of silver recovery. After film processing, two techniques were applied to recover silver from the resulting solutions: chemical precipitation and metal replacement using aluminum.

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2.1.1 Chemical Precipitation: it is a chemical reaction occurring in an aqueous solution where two ionic bonds combine, resulting in the formation of an insoluble salt. These insoluble salts that are formed in precipitation reactions are called precipitates. Precipitation reactions are usually double the displacement reactions involving the production of a solid form residue called the precipitate. These reactions also occur when two or more solutions with different salts are combined, resulting in the formation of insoluble salts that precipitate out of the solution [105].

2.1.2 Metal Replacement Methods: The metal replacement method is a technique that employs metals that are more electropositive than silver. In this method silver ions are reduced by various metals to form the element silver. The advantage of this method is that it is economical and can yield silver with a purity ranging from 95% to 99 %. The most common metals used in this process are zinc and aluminum. The choice of the appropriate metal depends on several factors such as the cost of the chemicals used, the efficiency of silver extraction, and the ease of handling the metal [10].

2.2 Materials and Tools and devices.

- Radiography film (collected from local medical facilities).
- Nitric acid (HNO₃) purity of 65%, density of 1.4 g/ml .
- Sodium chloride.
- Sodium hydroxide.
- Distilled water.
- Developer solution from Non-Destructive Testing (NDT) labs.
- Beaker (500ml)
- Balance.
- Water bath device.
- Oven.
- Evaporating dish.
- Filter funnel.
- Filter paper
- XRF device.
- Aluminum plate.

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3.Methods.

3.1 Silver Leaching from Radiographic Films Using Nitric Acid.

Nitric acid Treatment Radiographic films were initially cut into uniform squares of approximately 4 cm² and weighed to obtain 50 g of sample. The pieces were then washed with distilled water followed by alcohol to remove surface impurities. A 500 mL solution of diluted nitric acid (14.4 M) was prepared by mixing 34.6 mL of concentrated nitric acid with distilled water. The cut films were submerged in this solution inside a beaker and placed in a water bath at temperature 80°C for 4 hours as shown in figure (1). After the reaction, the solution was separated and filtered. This method targeted the silver halides present in the emulsion layer. The chemical reaction for silver halide dissolution using nitric acid is shown in equation (1).



Fig. (1) The solution after the reaction is over.

3.2 Extracting silver from previously prepared solution:

3.2.1 The first Method Chemical precipitation

a-Sodium chloride

To recover silver from the prepared solution, a chemical precipitation method using sodium chloride was applied. A volume of 50 mL from pretreated solution was mixed with 50 mL of sodium chloride solution in a beaker. The mixtures were stirred thoroughly and left undisturbed for 15 minutes, during which a

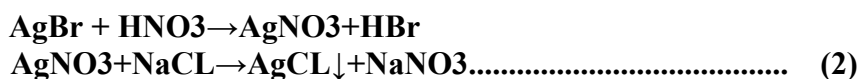
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white precipitate began to form. The resulting precipitate was filtered, placed in an evaporating dish, and dried in an oven at 90°C for 30 minutes.

The precipitation of silver ions in the form of silver chloride (AgCl) is governed by a set of chemical reactions that vary depending on the pretreatment reagent used. The corresponding reactions are shown in Equation (2):

- solution prepared using nitric acid.



b-Sodium Hydroxide:

The same steps of the previous method were repeated, using sodium hydroxide.

Following Equation Shows Reaction:

- Solution prepared using nitric acid.



3.2.2 The Second Method by Metal Replacement:

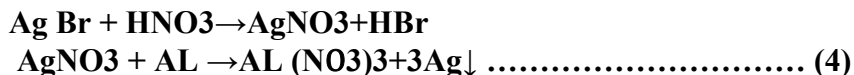
To extract silver from the prepared solutions, a metal replacement technique was applied using aluminum. In this method, 50 mL of each solution was transferred into a beaker, and a small piece of aluminum was added. A few drops of nitric acid were introduced to accelerate the dissolution of aluminum and initiate the displacement reaction. The mixture was stirred well and left to react for 15 minutes, during which a silver precipitate formed. The precipitation was filtered, dried in an oven at 90°C for 30 minutes.

The chemical reactions involved in this method differ based on the reagent used for pretreatment. The silver ions were reduced by aluminum metal through single displacement reaction, as shown in Equation (4):

- Solution prepared using nitric acid.

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4. Extracting silver from the developer solution:

A used developer solution from (NDT) labs was used to develop the films employed for detecting defects such as cracks and fractures in metals.

Table (1) Analysis of some chemical Properties of used developer solutions.

Chemical properties	Lightly used	Moderately used	Heavily used
PH	5.45	10.8	9.71
ES	407.38 ms/cm	79.4 ms/cm	72.8 ms/l
TDS	264800 mg/l	59550 mg/l	43700 mg/l
Density	1.097ml/g	1.07ml/g	0.9514ml/g

The same steps of the previous methods for extracting silver from developer solution.

5. Results and discussion.

5.1. Results and discussion of silver extraction from radiographic films:

Among the tested methods, sodium hydroxide precipitation showed the highest silver recovery (1.01%), while sodium chloride precipitation gave the lowest (0.07%). The metal replacement method achieved a moderate yield (0.288%). These results indicate that the efficiency of silver extraction strongly depends on the reagent used, with sodium hydroxide being the most effective, as illustrated in Figure 2.

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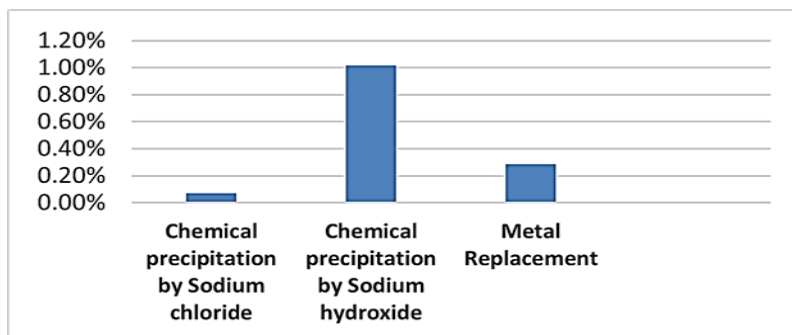


Figure (2): The results of silver extraction from radiographic films.

5.2 Results and discussion of silver extraction from the developer solution:

5.2.1 The method Chemical precipitation by Sodium chloride:

The results showed that silver extraction using the chemical precipitation method by sodium chloride shows variations based on the level of use of the developed solution. The heavily used solution exhibited the highest silver extraction rate at 0.28% as shown in Figure (3). These findings suggest that increasing the intensity of the developed solution slightly enhances the silver extraction percentage.

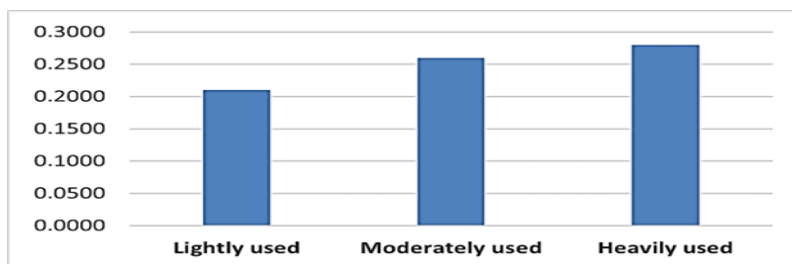


Figure (3) The percentage of silver extracted from developer solution using the chemical precipitation method by sodium chloride.

5.2.2 The method Chemical precipitation by Sodium hydroxide:

The results showed it was found that the highest percentage of silver extracted was from the heavily used solution, with a value of 0.37% as shown in Figure (4). This could be due to the accumulation of silver or other factors such as changes in the chemical composition of the solution due to repeated use.

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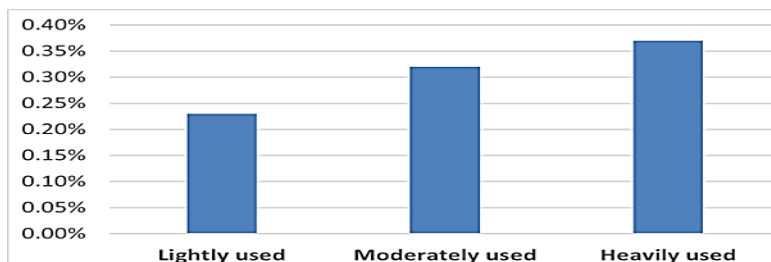


Figure (4) The percentage of silver extracted from the developer solution using the chemical precipitation method by Sodium hydroxide.

5.2.3. The method by Metal Replacement:

The results showed it was found that the heavily used solution showed the highest silver extraction percentage of 0.39%, as shown in Figure (5). This suggests that the intensive use of the solution led to a greater accumulation of silver compared to the other solutions.

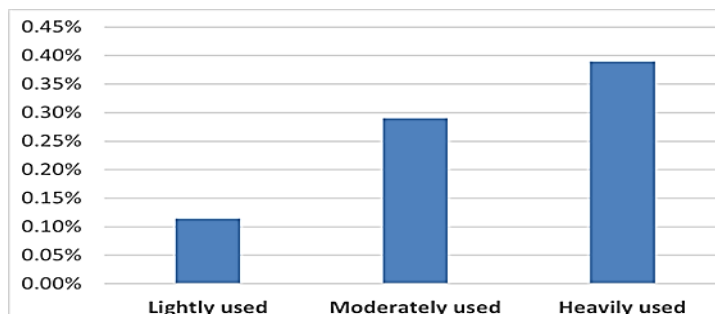


Figure (5) The percentage of silver extracted from developer solution using method metal replacement.

6. XRF Results of Radiographic Films:

XRF analysis of the recovered precipitate showed a strong characteristic silver peak at 22.163 keV (Ag K α 1), with additional silver peaks at 21.990 keV, 24.942 keV, and 25.145 keV, confirming the presence of silver in the sample, (see figure 6). These results are consistent with the reference study [11], where the main silver peak was also observed around 22 keV with secondary peaks near 25 keV. The similarity in peak positions

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confirms successful silver recovery from X-ray film waste. As shown in the table .2.

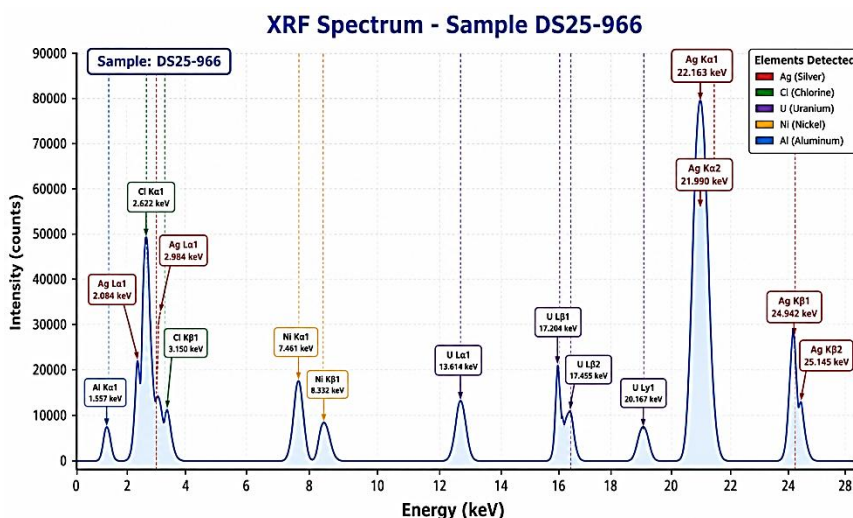


Figure (6) Spectral analysis of silver extracted from radiographic film.

Table (2) Elemental composition of silver extracted from radiographic films analysis by XRF.

Metal	Analyzed value
Ag	92.5
K	1.25
Br	0.25
Al	2.30
Cu	0.12
Fe	1.50
Cl	1.56
Zn	0.42

The results in table (2) indicate that the silver extraction process using sodium hypochlorite is effective, yielding 16.666 grams of silver with a purity of 92.5%, as shown in Table (2). However, the presence of other elements such as aluminum, iron, and chlorine suggest impurities that may affect the quality of the

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extracted silver. Improving the process by adjusting the solution concentration or refining filtration stages could help remove these impurities. Nevertheless, the high silver extraction rate demonstrates the efficiency of the process, making it a promising method for industrial applications.

6.1 XRF Results of Developer:

Table (3) Elemental composition of silver extracted from the developer solution by XRF analysis.

Metal	Analyzed value
Ag	50.3
K	2.3
Br	0.59
Al	29.8
Cu	0.1
Fe	0.87
Cl	0.95
Zn	14.5

The results in table (3) indicate that the silver extraction process using the metal replacement method is effective, as 3 grams were extracted from 3250 mL of a heavily used developer solution, which weighed 3092.27 grams. Analysis using the XRF device showed that silver makes up a significant proportion, reaching 50.3% of the analyzed sample as shown in table (3), highlighting the method's effectiveness in extracting silver. However, high levels of aluminum 29.8% and zinc 14.5% were also detected, indicating the need to improve the process to increase the purity of the extracted silver.

7. Conclusion

In conclusion, this study extracted silver from radiographic films and the developer solution using various chemical methods.

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The results demonstrated that dissolving silver from the films with nitric acid, followed by silver precipitation with sodium hydroxide, was the most effective in terms of the purity of the extracted silver, Additionally, the metal replacement method was found to be effective for silver extraction from the long-used developer solution. These findings contribute to a better understanding of silver extraction techniques and offer practical solutions for recovering silver from consumed materials in medical and industrial fields.

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