



Silver withdrawal from X-Ray waste via leaching and sorption techniques: Appraisal ideal treatment factors



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Abstract

The principal goal of this exploration is to inspect the withdrawal of silver from X-ray waste. Firstly, the impact of some operating parameters on the silver leaching from x-ray utilizing nitric acid as leaching agent such as leaching temperature, incitation speed (rpm), leaching time, and leaching agent concentration was inspected utilizing practical method and mathematical and statistical method. Outcomes acquired detected that, utmost silver ion concentration in leaching solution was 9284.7 mg/kg films (61.9 %) at an ideal conditions of leaching agent concentration, incitation velocity, leaching time, and temperature of 3 M, 400 rpm, 180 minutes, and 75 °C. Multiple regression analysis technique will be applied in an attempt to acquire correlation ($R^2 = 96.17\%$). Results demonstrated that there is a complete cohesion between the practical values of silver leaching percentage and expected values. After the leaching process, the sorption technique was applied to treat the silver from leaching solution utilizing sugarcane bagasse as a sorbent treated with sulfuric acid. The sorption technique optimization of silver recovery from the leaching solution was elucidated also using practical method and statistical analysis. Factors influencing the sorption process are sorption time, solution pH, mixing velocity, and a sorbent quantity. The optimal pH value, mixing velocity, and sorbent quantity were 5.37, 200 rpm, and 5 gm, respectively at 60 min. sorption time. Under above ideal factors the sorption silver percent was 96.68%. Kinetic of a sorption were effectively depicted using a pseudo second order model with elevated correlation coefficient ($R^2 = 99.09\%$). Adsorbed silver on sugarcane bagasse surface were explored via SEM-EDX analysis. Finally, Multiple regression analysis technique will be applied in an attempt to acquire correlation for predicting the silver recovery percent. R^2 of the attained correlation was 95.56%.

Keywords: X-ray waste, Leaching, Sorption, Recovery, Sugarcane bagasse

1. Introduction

Diminishing natural sources of silver caused the cost of obtaining pure silver to rise. Environmental problems arising from radiographic waste discarding are a major driver for increased recovery, refurbishment and recycling processes. Brilliant sources utilized to recover silver are radiographs, stationary wastes and motion industry wastes. Almost 2 billion radiographs are captured annually worldwide which contains chest X-rays, mammograms and computed tomography [1]. In medical disciplines, nearly 94-98% of X-rays are captured that produce photographic chemicals and scrap sheets as waste [2]. Films of radiographic utilized in the medicinal domain are polyester slips covered on all faces with

photosensitive radioactive materials [2]. X-ray sheets comprise around, 1.5 – 2 % (wt/wt) of silver metal in gelatine- covered film crafted from polyester film [3, 4, 5]. This silver weight percent can be an important source of secondary silver potential [6]. Abdel-Aal and Farghaly, [7] stated that 1kg of improved x-ray encloses 14-17g of silver. Furthermost of photographic chemicals utilized to make x-ray films are produced from silver salt. Almost 8.3% of silver is utilized in photography as a result of its high sensitivity to silver halide light [8]. the silver content from x-ray film effluent treatment facilities can be approximately 1 to 12 g/l [8]. Recovery of silver from photographic wastes has economic value and also importance from environmental point of view. Techniques applied to recover the silver from x-ray wastes can be categorized into direct burning of films,

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Receive Date: 19 April 2023, Revise Date: 25 May 2023, Accept Date: 31 May 2023

DOI: 10.21608/ejchem.2023.206887.7889

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silver metal oxidation followed by electrolysis, and degelatinization of silver layer utilizing diverse leaching agents [9].

The latter two techniques have been applied more widely than the first technique [9]. This is in consequence of the silver obtained from burning x-ray films will be capped with a carbon layer, making the recovery of silver complicated [10]. On the whole, the mentioned techniques for recovering silver from x-ray waste comprise two stages: the initial comprises leaching of the silver from the x-ray and the second is the sorption of silver from leaching solution. The initial step is generally leaching, which may be either microbiological or chemical [11, 12]. Chemical leaching agents earlier utilized in the silver dissolution from x-ray films involve cyanide [13, 14], NaOH [15, 16], nitric acid [17, 18], oxalic acid [19], thiosulphate [20, 21], as so on.

Diverse performances have been improved to recover the silver as ion-exchange [22, 23], precipitation [24], solid phase extraction [25], coagulation [26], biosorption [27], metal replacement [28], electrolysis [28], sorption [29] and so on. The sorption technique is broad applied owing to new kinds of material obtainable for the recovery process. Numerous literatures have concentrated on the application of natural sorbents that are extricated from agriculture waste and seafood side products [30, 31, 32] as a result of their biodegradability and environmentally friendly characteristics. Midst these natural substances, sugarcane bagasse has been evidenced to be appropriate sorbent for removing the metal ions from simulated solution [33, 34].

This exploration firstly highlights the optimization of leaching conditions using nitric acid as leaching agent such as leaching temperature, incitation speed (rpm), leaching time, and leaching agent concentration utilizing practical method and statistic method such as response surface methodology. Multiple regression analysis technique will be applied in an attempt to acquire the arithmetical correlation that can obvious the influence of the leaching conditions on leaching efficacy. After that, recovery of silver from leaching solution via the sorption process using sugarcane bagasse as a sorbent. In the sorption trials, a sorbent quantity, mixing velocity, sorption time, and pH solution were optimized. A kinetic study has been fulfilled to ensure the influence of numerous processing variables on silver recovery from leaching

solution. Also, Multiple regression analysis technique will be applied in an attempt to acquire the arithmetical correlation that can obvious the influence of the silver recover percent.

2. Materials and methods

2.1. Reagents

All used reagents such as nitric acid (HNO_3) with 65-69 % purity, 95 % purity of Ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$), sulphuric acid (H_2SO_4) with 98 % purity, sodium hydroxide (NaOH) with 98% purity, 30-34 % purity of hydrochloric acid (HCl), and sodium carbonate (Na_2CO_3) with 99 % purity were analytical grade and sourced from Merck (Darmstadt, Germany). Sugarcane bagasse was assembled from the local market.

2.2. Recovery process

2.2.1. Leaching process with HNO_3

The initial step was the leaching of x-ray sheets utilizing nitric acid to release silver metal from the sheets into the solution. The films were rinsed with ionized water, erased with a piece of cloth impregnated with ethyl alcohol, and then dried. The dried films were cut manually into small pieces with scissors and 50 gm were placed in a glass beaker with capacity of 1 L. Then (1M) nitric acid solution (500 mL) was added. The contents of the beaker were heated to specified temperature, (25, 40, 60, 75, and 85 °C and agitated at 600 rpm by magnetic agitator for 2 hours. During the dissolving of silver, evaporation takes place, so, a reflux system is utilized. The contents were filtered to separate the remained solid from the clear solution (silver nitrate). The concentration of silver existing in the solutions were assessed with an atomic absorption spectrophotometer (AAS) (Perkin Elmer 2280). There are some operating factors impacting on the leaching process such as nitric acid concentration (0.5-4 M), incitation speed (200-800 rpm), temperature (25-85 °C), and leaching time (30-210 minutes) was investigated.

2.2.2. A sorption process of silver ions from leaching solution

The second step was the sorption of silver found in leaching solution utilizing sugarcane bagasse as a sorbent.

2.2.2.1. A sorbent preparation

The bagasse was first cleaned with distilled water, then contaminates on it were washed and then cut into small pieces to be dried in the sunlight till all the moisture had evaporated. Next, the material was milled into a smooth powder to increase the surface

area by using the mill and transfer it through the sieves with mesh size with the size range of 80-230 mesh. The powder was rinsed with water. To fix the color and water-soluble materials, the milled powder was treated with 40% H₂SO₄ and warmed inside a muffle furnace for 24 hours at 150 °C. The heated material was dowsed in ionized water for few minutes and then soaked in 1% Na₂CO₃ solution overnight to get rid of the residual acid. The material was dried in an oven at 105-110 °C until constant weight was reached (approximately after 24 hours) and utilized for the more study.

2.2.2.2. A sorption procedure

A sorption runs were fulfilled in a batch process at room temperature (25 °C). For each a sorption run the specific weight of a sorbent material was placed into 20 mL of the silver solution leached from X-ray films placed in a 250 mL conical flask. The solution pH was regulated with HCl or NaOH diluted solutions. The solution pH was measured with a digitally calibrated pH-meter (model 3505 made by JENWAY Instruments, with a resolution of 0.01 and accuracy of ± 0.02). Subsequently, the contents were agitated by magnetic agitator at fixed rate and then nominated at specific intervals. The final deposit is separated from solution by filtration and then analyzed via atomic absorption spectroscopy (AAS). The impact of both, pH solution, a sorption time (minute), mixing velocity (rpm), and a sorbent quantity (gm) on the silver elimination percentage was decided in the range of (2-7), (20-80), (50-200), and (1-5), respectively. The quantity of metal ion adsorbed at balance q_e (mg/gm) was estimated through the equation mentioned below:

$$q_e = [C_o - C_e] \cdot V/m \quad (1)$$

Where: V is the solution treated volume (L), C_o and C_e are the initial and balance concentration of silver ions (mg/L), and m is the sorbent quantity utilized (gm). The silver sorption percentage was estimated by means of the below equation:

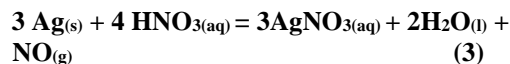
$$\% \text{ A sorption} = [C_o - C_e] / C_o \quad (2)$$

After the sorption of silver ion from leaching solution, the mix was filtrated to separate the sugarcane bagasse from the liquid phase via filter paper that was then dried at 100 °C and analysed at ambient temperature via SEM-EDX analyses to inquiry the microstructure and silver dispersal on sugarcane bagasse after the sorption.

3. Results and Discussion

3.1. Leaching process optimization

The dissolution of silver in HNO₃ to produce silver nitrate solution occurs easily [11, 35]. The next reaction occurs:



3.2. Impact of processing factors on leaching of silver from x-ray sheets

The silver concentration leached from x-ray sheets should be smaller than 15,000 mg_{Ag} / kg_{films} estimated from the silver weight percentage 1.5% (wt/wt) mentioned above. The following factors were inspected to acquire the ideal factors to leach silver from waste x-ray sheets.

3.2.1. Impact of leaching temperature on silver extracted from x-ray sheets

The temperature plays a significant factor throughout the leaching of silver from the x-ray sheets. The impact of temperature on the leaching of silver from waste x-ray sheets is elucidated with fixed other factors (600 rpm, 1M nitric acid, and 120 minutes leaching time). Figure 1 exhibits the impact of temperature on the dissolution of silver. It is obvious that the dissolution of silver rises with raising the temperature to be 75 °C. After that temperature, there was no change in leaching of silver. Thus, the temperature of 75 °C was considered as an ideal degree. It is observed that higher temperature increases the exposure of surface area to the leaching solution. In spite of this, it is not exhorted to leach the silver from x-ray films at high temperature above 100 °C, as there is tendency to disintegrate the stacked gluten used to make x-ray films. The maximum adequate leaching temperature range (70 – 80 °C) for silver leaching from used photographic film was determined by N. Nakiboğlu et al. [9], whilst an ideal leaching temperature (70 °C) was determined by S. Aktas et al. [11], and Gilbert U. Adie, et al., [3] stated that 80 °C is the utmost leaching temperature for silver leaching utilizing both NaOH and HNO₃ solutions. Our outcomes are consistent with those observed from these studies.

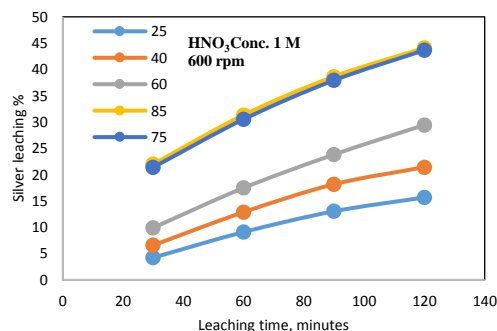


Figure 1: Impact of temperature on the leaching of silver

3.2.2. Impact of incitation velocity on silver extracted from x-ray sheets

The mixing velocity influence on the leaching process was elucidated by varying the mixing velocity from 200 rpm to 800 rpm as displayed in Figure 2. The final results evidently reveal that the concentration of silver leached raised with rising the mixing speed up to 400 rpm under the processing factors of 75 °C of leaching temperature, and 1 M of HNO₃ at 120 minutes. After this value of mixing velocity, a decrease in the silver leaching % was noticed owing to the reality that sheets aggregate with each other. as a result, nitric acid does not get inadequate contact with the sheets [11].

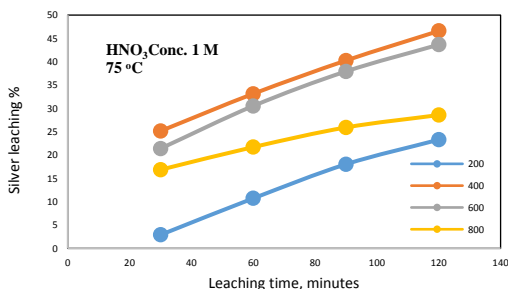


Figure 2: Impact of incitation velocity on the leaching of silver

3.2.3. Impact of nitric acid concentration on silver extracted from x-ray films

Figure 3 depicts the result of influence of nitric acid concentration on leaching of silver from films. The silver leaching % was raised when acid concentration was raised at fixed other variables (400 rpm, 75 °C and 120 minutes). The utmost silver leaching % (53.74%) was acquired when chopped x-ray films were leached with 3M concentration of HNO₃. This % decreases as the HNO₃ concentration reduces owing to the gelatinous silver halide coat remain unstripped from the polyester base sheet. This may denote that the concentration of acid was extremely depressed to properly begin the leaching technique [3]. At 4 M HNO₃ concentration, there was no change in silver leaching percent (54.07 %). Thus, the HNO₃ concentration of 3 M was considered as an ideal concentration. The utmost concentration range of HNO₃ (4 M) was chosen on the suspicion that higher concentrations would be more turbulent and serious to act with, uneconomical and could lead to an occasional detonation [3].

The silver leaching from x-ray sheets was occurred utilizing several leaching agents as (HNO₃/cyanide

solution) [35], (H₂O₂ solution) [36], HNO₃/NaOH solutions [3], and (Oxalic acid solution) [37]. The rising leaching capacity of nitric acid was definitely owing to the dissolution metals in solutions with lower/ acidic pH values.

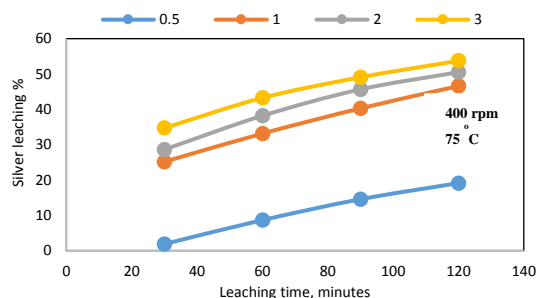


Figure 3: Impact of nitric acid concentration on the leaching of silver

3.2.4. Impact of leaching time on silver extracted from x-ray films

Figure 4 exhibits the impact of leaching time on the silver leaching % with nitric acid solution under the ideal factors (400 rpm, 75 °C, and 1 M HNO₃ concentration). It was perceived that the utmost silver concentration in the leaching solution progressively raises to more than 9284.7 mg/kg (61.9 %) at 180 minutes. After this time, a reduction in the leaching percent is noticed. this reduction may be owing to the complete leaching of silver from the x-ray waste. The growing concentration and temperature provided the faster time desired to leach the silver from utilized x-ray sheets [27]. Table 1 summarizes the ideal conditions under which the maximum concentration (9284.7 mg/kg (61.9 %) of silver was leached from x-ray films.

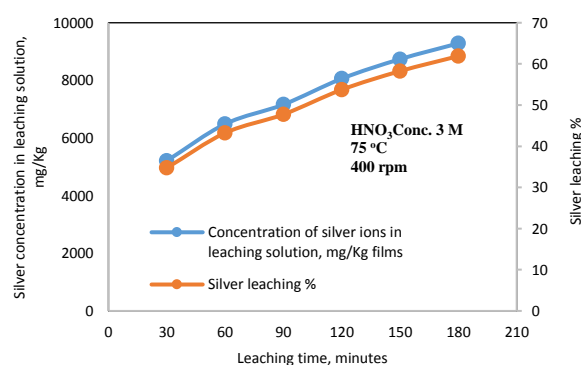


Figure 4: Impact of leaching time on the leaching of silver

Table 1: Ideal leaching conditions of leaching process of silver from x-ray waste

Conditions: 400 rpm, Temperature = 75 °C, 3 M HNO ₃			
Time, minutes	Concentration of silver ions in leaching solution, mg/L	Concentration of silver ions in leaching solution, mg/kg films	Silver leaching %
30	520.92	5209.2	34.73
60	648.52	6485.2	43.23
90	716.16	7161.6	47.74
120	806.08	8060.8	53.74
150	873.74	8737.4	58.25
180 (Ideal time)	928.47	9284.7	61.9
210	904.761	9047.61	60.34

3.3. Static investigation

To clarify the impact of the processing factors on the silver leaching percent, a mathematical relation should be proposed. Multivariate statistical and square regression analyses are widely applied to model and analyse of problems in which the response of interested dependent variable is impacted by several independent variables. This model was utilized in an attempt to discover the mathematical relationship that can elucidate the impact of the processing factors on the silver leaching percent (ANOVA).

The values and p-values of the coefficients are specified in Table 2. The p-values resolves whether or not any factor is critical. The correlation terms with a p-value of less than 0.001 are extremely significant. The R² was 96.17 %; it exposed that the changeability

in the leaching could be expounded via the model, with the cohesion between the practical and expected values being momentous inside the process. The acquired correlation in terms of momentous factors only has the succeeding form:

$$\text{Leaching silver \%} = -87.968 + 45.88 C_{\text{HNO}_3} + 0.173 I.V + 0.1767 t + 0.00468 T^2 - 9.733 C^2_{\text{HNO}_3} - 0.000166 I.V^2 \quad (4)$$

Where: C_{HNO₃} is the nitric acid concentration, I.V incitation velocity, t is the leaching time, and T is the leaching temperature.

Table 2: Value and p-value of all coefficients

	Coefficients	P-value	Significance
Intercept	-87.96784025	0.000160069	
X Variable 1, [C _{HNO₃}]	45.88236489	0.001405936	Significant
X Variable 2, [I.V]	0.173177364	0.001187067	Significant
X Variable 3, [t]	0.176688506	0.0003032	Significant
X Variable 4, [T ²]	0.004677468	6.30393E-05	Significant
X Variable 5, [C ² _{HNO₃}]	-9.733022547	0.001890156	Significant
X Variable 6, [I.V ²]	-0.000165722	0.000653257	Significant

The normal probability of standardized residuals with average correlation errors of zero is displayed in Figure 5. The linear distribution of the residual errors clarifies that the errors are normally distributed indicating that the typical prediction are not influenced.

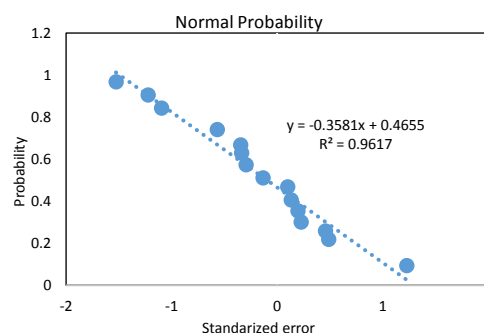
**Figure 5:** Normal probability of standardized errors for silver leaching

Figure 6 reveals the comparison between the practical values of silver leaching percentage and expected values. This figure demonstrates complete cohesion between them. The silver leaching

percentage varied from 15.66 % to 61.9 %. Table 3 clarifies the practical values of silver leaching percentage and expected values for the 16 runs.

Table 3: The practical values of silver leaching percentage and expected values

Runs	Practical observed %	Predicted %
1	15.66	16.55395261
2	21.42	21.11448373
3	29.45	30.46941934
4	43.66	39.94129166
5	44.11	47.42524015
6	19.11	20.80885112
7	50.51	51.1335639
8	53.74	52.35081605
9	23.3	23.7014625
10	46.59	47.45026666
11	28.576	28.1745375
12	34.73	35.44885056
13	43.23	42.74950572
14	47.74	47.05016089
15	58.25	57.65147122
16	61.9	62.95212639

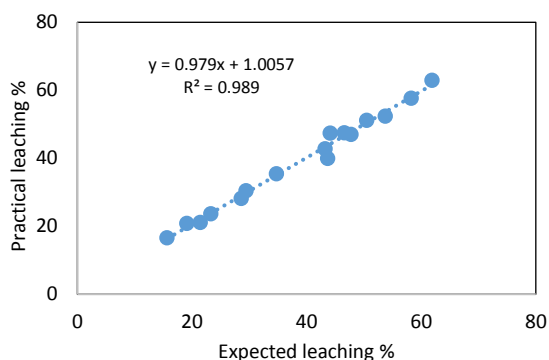


Figure 6: Expected silver leaching % vs. practical silver leaching %

3.4. The sorption process optimization

After the dissolution process of silver into the solution, a sorption technique was utilized to recover silver from leaching solution with treated sugarcane bagasse as a sorbent. 20 mL of silver solution with 928.47 mg/L concentration was employed.

3.5. Characteristics of treated sugarcane bagasse before a sorption

Image of scanning electron microscope (SEM) of the sugarcane bagasse layer treated with sulfuric acid before the sorption is revealed in Figure 7. This analyse point to the pored structure of the bagasse; so, it can be presaged that silver ions can be physically adsorbed into the bagasse thru the Van der Waals forces, and the silver ions can either adsorb on the bagasse surface or can widespread into its pores. The physical sorption force is often considered weakened and may rely on the surface area and pore size. While the Figure 8 exhibits the functional groups in the 300-4000 cm^{-1} wave number range, their formed bonds, and its range for treated sugarcane bagasse analysed by means of IR spectra - Fourier transforms infrared. Around the wavelengths of 3354 cm^{-1} , 1368.14 cm^{-1} , 1160.04 cm^{-1} , 1030 cm^{-1} , and 1200 cm^{-1} were observed bands that are specific to the stretching vibration of the O-H group, vibration of phenolic O-H group, stretching of secondary alcohol O-H, the stretching of primary alcohol O-H, and C-O stretching of phenols, respectively, after that the vibrations specific to the aliphatic group -C-H which happens at 2910 cm^{-1} . At the wavelength 2850, the specific peak is detected for

the methoxyl C-H group vibration and at the wavelength 1104 cm^{-1} , the specific peak is shown for the C-O-C stretching vibrations. At the wavelength 1700 cm^{-1} , a specific peak to the stretching vibrations of the C=O group is noticed and at the wavelength 1631 cm^{-1} , a specific peak is seen for the C=C aromatic skeletal vibration.

Figure 7: Scanning electron microscopy, SEM for the treated sugarcane bagasse before a sorption

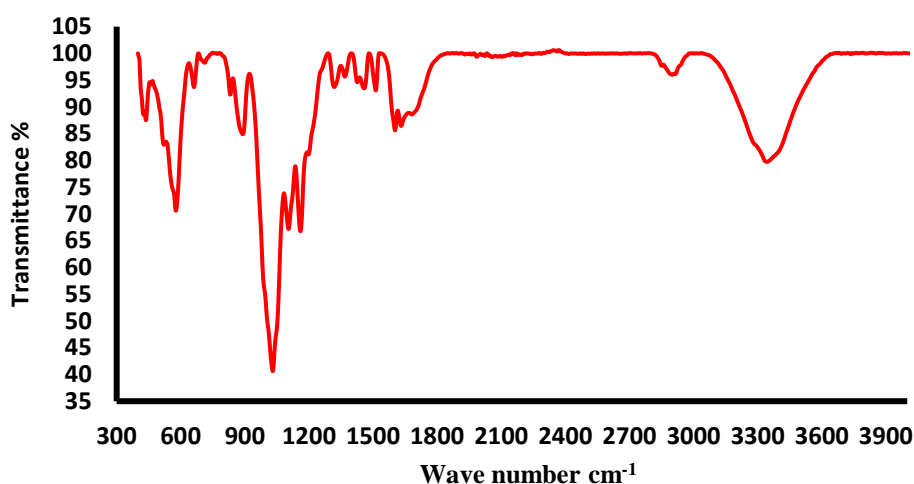
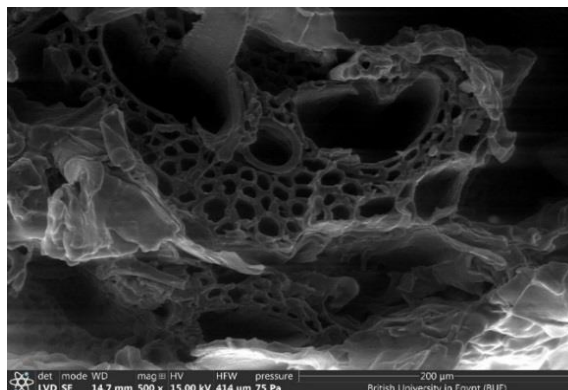


Figure 8: Fourier-transform infrared spectroscopy, FT-IR for the treated sugarcane bagasse

3.6. The factors influenced on the recovery percentage:

3.6.1. pH solution impact

Figure 8 elucidates the impact of pH on the sorption of silver ions on treated sugarcane bagasse under fixed conditions of initial silver ions concentration, a sorbent dose, incitation speed, and a sorption time (928.47 mg/L, 5 gm, 200 rpm, and 60 minutes). It is evidently that the sorption of silver rises with an elevated in the solution pH until it reaches the utmost value around pH 5.37. After this value, there is a slight decrease in the silver ions sorption to an approximately 7 pH and thereafter an intense reduction is acquired. Roughly, this may be owing to the deposition of silver ions in the form of silver hydroxide and the electrostatic repulsion between the sorbent surface sites and silver ions [39, 40]. Ashish Modi, et al. [41] and Thanut Jintakosol et al. [42] reported the same phenomena.

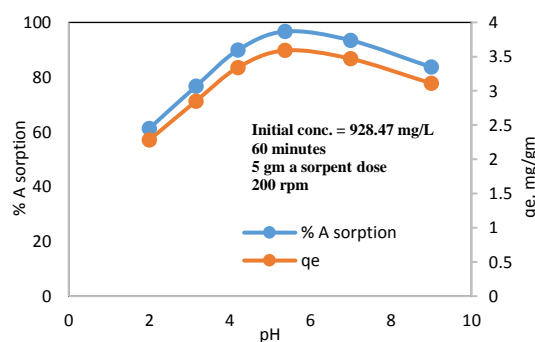


Figure 9: The impact of pH solution on the silver ions sorption

3.6.2. Mixing velocity impact

To verify the impact of mixing velocity on the sorption of silver, trials were performed at the silver concentration of 928.47 mg/L, 5 gm a sorbent dose, 5.37pH, and 60 minutes sorption time. The outcomes are depicted in Figure 10. The outcomes elucidate that the silver sorption percent raised with raising mixing velocity from 50 to 200 rpm; i.e. increased turbulence. Increasing the mixing velocity reduced the diffusion layer thickness that the silver had to pass through to reach the sorbent surface, causing a decrease in the

diffusion resistance and thus an increase in sorption of silver [43].

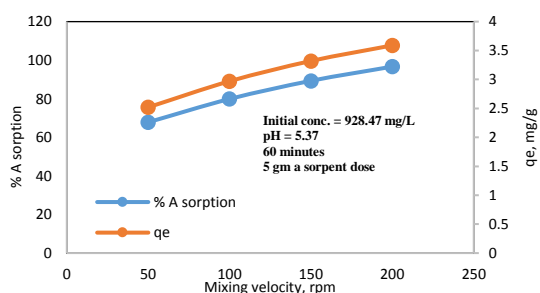


Figure 10: The impact of mixing velocity on the silver ions sorption

3.6.3. A sorption time impact

The sorption time was another significant factor for the sorption process. The impact of sorption time on the sorption of silver ion on sugarcane bagasse was depicted in Figure 11. The remainder of the factors were retained fixed same as enhanced in the prior trials, i.e., 5.37 pH, 928.47 mg/L initial ion concentration, 200 rpm, and 5 gm a sorbent dose. The outcomes indicated that the silver ions were speedily adsorbed in the initial 20 minutes with the enhance of sorption time from 0-20 minutes and the silver ions disposal raised to about 96.68% within 60 minutes. This phenomenon may be in consequence of vacant sites, and silver ions can readily interrelate with these sites [44]. After 60 minutes, there is no clear change in the sorption rate with time and the sorption get to balance.

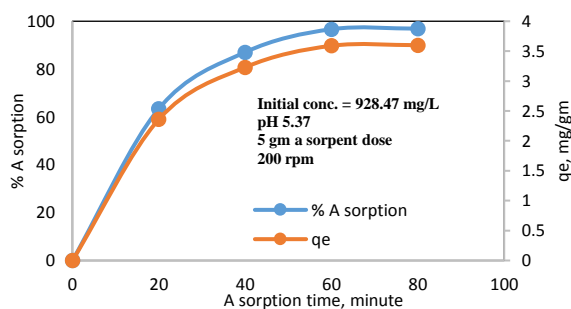


Figure 11: The impact of a sorption time on the silver ions sorption

3.6.4. A sorbent dose impact

The impact of sorbent quantity on the sorption of silver was explored by changing the amount of sorbent (1- 5 gm), conserving the other process factors fixed (928.47 mg/L initial silver concentration, 5.37 pH, 60

minutes, and 200 rpm). According to Figure 12, by increase the sorbent quantity from 1 gm to 5 gm, the sorption percent of silver increased while the sorption capacity decreased. The enhance in the sorption percent is a result of an elevated in the sorbent surface area and obtainability of obtaining further sorption sites [45, 46]. On the other hand, the reason behind decreasing the sorption capacity with increasing a sorbent dose is owing to overlapping of the sorption sites in consequence of excess numbers of sorbent molecules [47]. The sorption time needed to get to balance was reduced with enhance the sorbent amount.

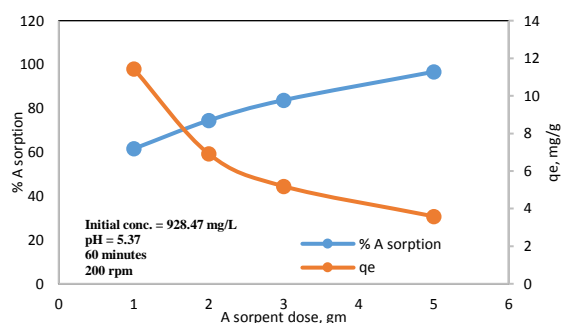


Figure 12: The impact of a sorbent dose on the silver ions sorption

3.7. Characteristics of adsorbed silver on sugarcane bagasse

The morphology of adsorbed silver on sugarcane bagasse was defined via scanning electron microscopy (SEM) as exposed in Figures 13. After sorption of silver from leaching solution, the sorbent surface led to a metallic particles cumulation, which were identified as silver thru the EDx spectra as exposed in Figure 14 and Table 4 with 90.12% by weight purity. The morphology of adsorbed silver on sugarcane bagasse was corroborated a uniform dispersal of silver on the sugarcane bagasse surface. The surface morphology of the formed silver is irregular-shaped.

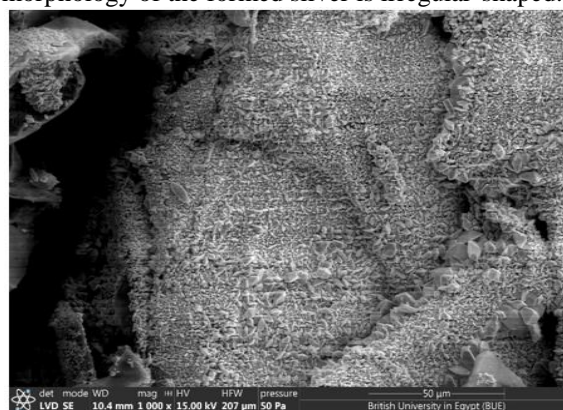


Figure 13: SEM images of adsorbed silver

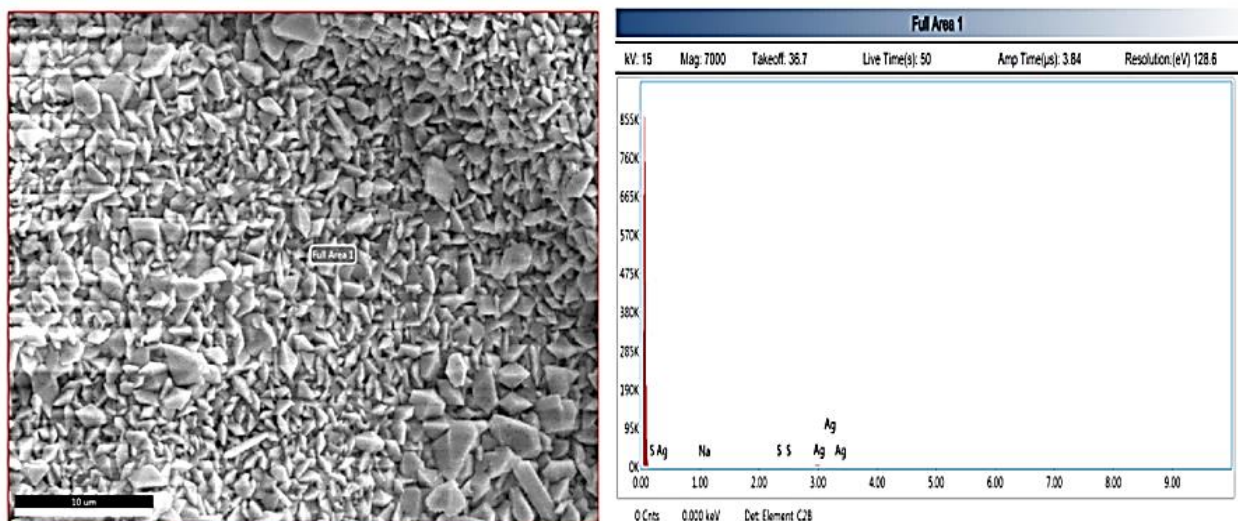


Figure 14: EDX spectra of adsorbed silver

Table 4: Element compositions of formed metallic silver

Element	Sorption method		
	Weight %	Atomic %	Error %
NaK	1.09	3.73	26.57
S K	8.79	28.96	4.65
AgL	90.12	67.31	2.96

3.8. The sorption kinetic models of silver

The sorption kinetic data was probed utilizing pseudo first-order and pseudo second-order kinetic models [36]. The adsorption kinetic experiment was conducted at optimal factors (5.37 pH, 5 gm of sorbent quantity, 200 rpm, and 928.47 mg/L silver ion concentration). The remaining silver concentration was appreciated at various time periods. The sorption

kinetic of silver is elucidated in Figure 15. The values of rate constant of the pseudo first order (K_1) and the quantity of silver ions adsorbed (milli gm/gm) at equilibrium (q_e) were appraised from slope and intercept of the plot of $\ln(q_e - q_t)$ vs. t , whereas the values of rate constant of the pseudo second order (K_2) and q_e were estimated from the intercept and slope of a plot t/q_t vs. t . The corresponding outcomes for the sorption kinetics of silver are summed in Table 5. It can be order noticed that the correlation coefficient R^2 of the pseudo first order kinetic model was superior than that of the pseudo second kinetic model. A similar observation has been revealed before by Thanut Jintakosol et al. [42] and I. Ismi et al. [44], in the silver adsorption from aqueous solution. For that reason, the sorption kinetic of silver is effectively consistent with the pseudo second order model.

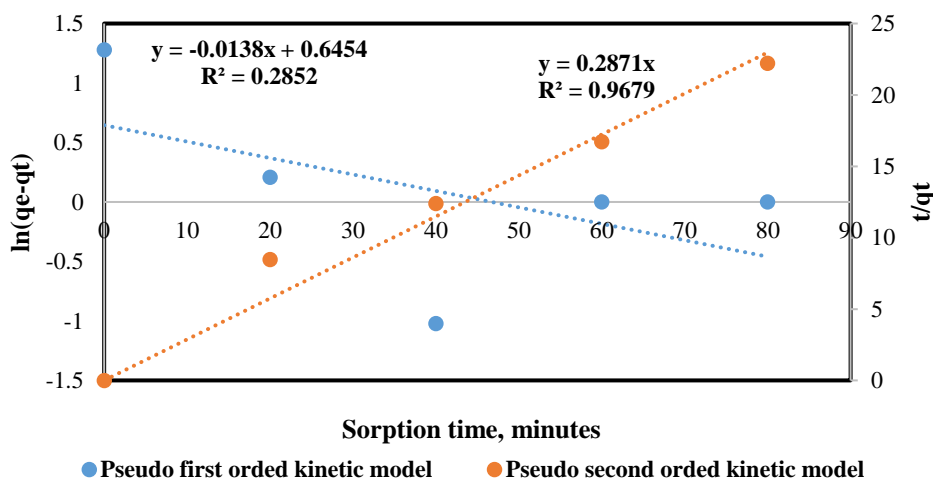


Figure 15: Sorption kinetic models of the sorption of silver at ideal factors

Table 5: Reaction rates of 928.47 mg/L initial silver concentration

Reaction rate equation	Kinetic equation	Rate constant	R ²
First order equation	$\ln q_e - q_t = 0.0138 t$	0.0138 min ⁻¹	0.2852
Second order equation	$t/q_t = 0.2871 t$	0.2871 L.min ⁻¹ .gm ⁻¹	0.9909

3.9. Static investigation

To clarify the impact of the processing factors on the sorption of silver percent, a mathematical relation should be proposed by applying multivariate statistical and square regression analyses as mentioned in the section 1.2. The values and p-values of the coefficients are specified in Table 6. The p-values resolves whether or not any factor is critical. The correlation terms with a p-value of less than 0.001 are extremely significant with R² equal 99.15%. The acquired correlation in

terms of momentous factors only has the succeeding form:

$$\text{Sorption \%} = -136.77 + 25.087 \text{ pH} + 0.3238 \text{ rpm} + 1.837 t + 16.34 \text{ S.Q} - 1.999 \text{ pH}^2 - 0.00055 \text{ rpm}^2 - 0.013 t^2 - 1.298 \text{ S.Q}^2 \quad (5)$$

Where: t is the sorption time, and S.Q is the sorbent quantity.

Table 6: Value and p-value of all coefficients

	Coefficients	P-value	Significance
Intercept	-136.77	8.92957E-06	
X Variable 1	25.08736	3.01937E-06	Significant
X Variable 2	0.323826	0.000583583	Significant
X Variable 3	1.836773	7.81265E-05	Significant
X Variable 4	16.34163	0.00106234	Significant
X Variable 5	-1.99871	5.78959E-06	Significant
X Variable 6	-0.00055	0.135856829	Not significant
X Variable 7	-0.013	0.000538544	Significant
X Variable 8	-1.29753	0.031560117	Not significant

The normal probability of standardized residuals with average correlation errors of zero is displayed in Figure 16. While Figure 17 reveals the comparison between the practical values of sorption percent and expected values. This figure demonstrates complete cohesion between them. Table 7 clarifies the practical values of sorption percent and expected values for the 15 runs.

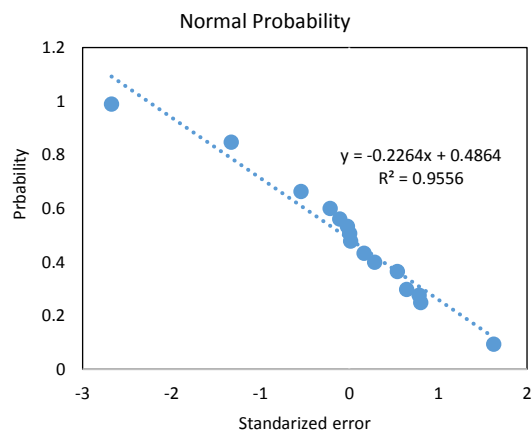
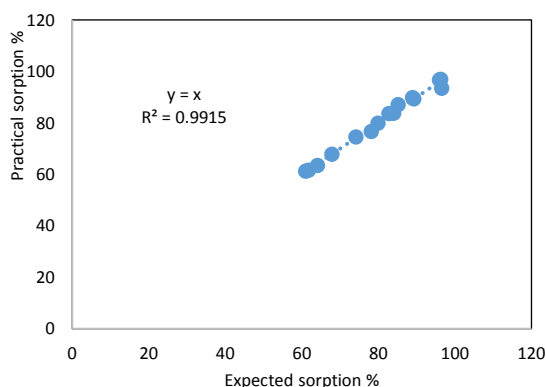
**Figure 16:** Normal probability of standardized errors for sorption of silver

Table 7: The practical values of sorption percent and expected values

Runs	Expected sorption %	Practical sorption %
1	61.035947	61.23
2	78.17383236	76.65
3	88.96579547	89.87
4	95.93870186	96.68
5	96.53100214	93.46
6	82.74715099	83.67
7	96.28782778	96.91
8	85.19348334	87.06
9	64.05217222	63.43
10	84.01598359	83.77
11	74.16202188	74.49
12	61.71299179	61.59
13	89.29926871	89.32
14	79.93073129	79.91
15	67.83308957	67.84

**Figure 7:** Expected sorption % vs. practical sorption %

3.10. Comparison between our outcomes and prior consequences

Comparison of existing outcomes with preceding consequences for the silver recovery from x-ray sheets is depicted in Table 8.

Table 8: Comparison of existing outcomes with preceding consequences

Technique	Ideal conditions of leaching process		Silver concentration in leaching solution	% silver recovery	Reference
Leaching vis NaOH and HNO ₃	NaOH	1.5 M, 30 °C at 900 min	26.6 mg/kg	-	3
	HNO ₃	4 M, 30 °C at 1440 min	9830 mg/kg		
Leaching via NaOCl and HNO ₃	NaOCl	2 %	0.768 gm	-	2
	HNO ₃	1 M, 80 °C at 4 hr			
Leaching via HNO ₃ , cementation & reduction with Fe powder and Zn powder	1 M, 300 rpm, 80 °C at 3 hr		4.5 gm/L	96.15% (using zinc powder), 91.14% (using iron powder)	11
Leaching and precipitation via NaOH and Na ₂ S	NaOH	1.5 M, 80 °C at 7 days	Ag in filtrate = 1140 ppm	-	28
	Na ₂ S	1.5 M, 25 °C at 2 days	Ag in filtrate = 12 ppm		
Leaching via HNO ₃ , and sorption utilizing sugarcane bagasse	3 M, 400 rpm, 75 °C at 180 minutes		9284.7 mg/kg (61.9%)	96.68 %	Current fulfillment

4. Conclusion

As a consequence of the practical methodology, the succeeding inferences were summed up:

- The utmost concentration of leached silver ions was 9284.7 mg/kg films (61.9%) under ideal conditions of 3 M nitric acid concentration, 400 rpm incitation, 75 °C leaching temperature at 180 minutes.

- The acquired correlation in terms of momentous factors only has the succeeding form:

$$\text{Leaching \%} = -87.968 + 45.88 C_{\text{HNO}_3} + 0.173 I. V + 0.1767 t + 0.00468 T^2 - 9.733 C^2_{\text{HNO}_3} - 0.000166 I. V^2$$

- Results clarified that there is a complete cohesion between the practical values of silver leaching percentage and expected values
- After optimizing the leaching conditions, the leached silver with concentration 928.47 mg/L was treated via the sorption of silver from leaching solution on sugarcane bagasse as a sorbent treated via 40 % sulfuric acid. The final outcomes revealed that the utmost silver sorption percent and the sorption capability were 96.68% and 3.59 mg/gm, respectively under optimized conditions of 5.37 pH, 5 gm of sorbent quantity, 200 rpm at 60 minutes a sorption time.
- Adsorbed silver was characterized via SEM-EDX analysis. The Ag purity is 90.12% by weight.
- The outcomes of kinetic modeling exhibited that the sorption of silver is effectively consistent with pseudo second order model with correlation coefficient ($R^2 = 99.09 \%$).
- It was also noticed that the acquired correlation in terms of momentous factors only has the succeeding form:

$$\text{Sorption \%} = -136.77 + 25.087 \text{ pH} + 0.3238 \text{ rpm} + 1.837 t + 16.34 \text{ S.Q} - 1.999 \text{ pH}^2 - 0.00055 \text{ rpm}^2 - 0.013 t^2 - 1.298 \text{ S.Q}^2.$$
- Results also clarified that there is a complete cohesion between the practical values of sorption percent and expected values.

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