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Binary Metal Ions Adsorption of Manganese and Silver from Aqueous Solution using Tea Leaf and Tea Fibre: Kinetics, Thermodynamics, and Isotherm Studies

***ETIM, EE; MATHIAS, D; SAMUEL, HS; YAKUBU, S; NWEKE-MARAIZU, U**

Department of Chemical Sciences, Federal University Wukari, Taraba State, Nigeria

**Corresponding Author Email: emmaetim@gmail.com*
**ORCID: https://orcid.org/0000-0001-8304-9771*
**Tel: +2349079192231*

Co-Authors Email: humphreysedeke@gmail.com; shedrachyakubu1@gmail.com; nwekemaraizuugo@gmail.com

ABSTRACT: The adsorption behavior of tea leaves and tea fiber (*Camellia sinensis*) as low-cost adsorbent with respect to manganese and silver was investigated to justify its usage in wastewater treatment. The FTIR results of tea leaves exhibit N-H at 3697.5 cm^{-1} indicating the presence of primary amine; O-H band at 3615.6 cm^{-1} corresponding to alcohol, carbohydrate, proteins and phenols; C-H band at 2918.5 cm^{-1} an indicative of alkane; P-band at 2322.1 cm^{-1} corresponding to phosphine and C=O signaling an aromatic ketone. The FTIR results of tea fibre exhibit O-H stretch band at 3276.3 cm^{-1} corresponding to alcohol, carbohydrate, proteins and phenols; C-H band at 2918.5 cm^{-1} indicating an Alkane; a –C=O band at 1625.1 cm^{-1} correspond to the amide; while a C-O band at 1144.2 cm^{-1} correspond to secondary alcohol and C-O band at 1017.6 indicates an ether or/and primary alcohol. Adsorption study was performed by the batch adsorption method by varying different parameters including pH, adsorbent dosage, temperature, initial concentration and contact time to find best suited conditions for the removal silver and manganese from aqueous media. The Langmuir isotherm gives R^2 values of 0.5444 and 0.5795, 0.5444 and 0.5795 for both silver and manganese using tea leaves and tea fiber and Freundlich isotherm gives 0.5637 and 0.5795, 0.5637 and 0.5795 values for tea leaves and tea fiber correspondingly with the Langmuir isotherm having higher R^2 values considered the most suitable. R2 for the second order of both silver and manganese was 1.00 and 1.00 for tea leaves and tea fibre respectively, which both agrees well with the experiment data.

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The accumulation of metalloids and heavy metals through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition are of a reported increase (Tchounwou *et al.*, 2012). Heavy metals consists of a group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni) whereas in water resourced areas Copper, Zinc, Manganese, Silver and Lead could still be detected (GWRTAC, 2023). Environmental pollution by these metals has been a growing global public health and ecological problem in recent years (Ayawei *et al.*, 2015; GWRTAC, 2023; Weber and Morris, 1963). Additionally, because to the exponential growth in the number of industrial,

**Corresponding Author Email: emmaetim@gmail.com*
**ORCID: https://orcid.org/0000-0001-8304-9771*
**Tel: +2349079192231*

agricultural, home, and technical applications of these substances, human exposure has increased considerably. Geogenic, industrial, agricultural, pharmacological, household effluents, and atmospheric sources have all been documented as sources of heavy metal pollution in the past (Singh *et al.,* 2007). Point source areas, including foundries, smelters, mining, and other metal-based industrial processes, are major sources of environmental pollution (Etim *et al.,* 2019a). Manganese and silver are elements that impact environmental and human health when found in high concentrations in water systems. High levels of manganese in water can be harmful to aquatic organisms, affecting their reproduction, growth, and survival. It can also cause changes in the biological community of streams, rivers, and lakes (Deng and Chen, 2019). Neurological problems, especially in children, can result from prolonged high manganese consumption. Silver is a poisonous metal for aquatic species, and even tiny concentrations of silver in water can kill freshwater invertebrates like crabs. Manganese, on the other hand, can also generate respiratory issues including chronic bronchitis and pneumonia. Moreover, it can build up in the soil and harm microorganisms and plants (Wuana and Okieimen, 2011; Elmorsi, 2011; Abass *et al.,* 2016). Grey-blue skin known as argyria is a disorder that can be brought on by prolonged use of water with high quantities of silver. Intestinal organs like the liver and kidneys may also sustain harm from it (Fu and Wang, 2011; Samuel *et al.,* 2024; Cheng *et al.,* 2012).

Heavy metal ions from wastewater can be removed using a variety of techniques, including solvent extraction, chemical precipitation, chelating and ion exchange, adsorption, membrane separation, and electrochemical processes. The best and most technically possible way to remove metal from aqueous solutions is by adsorption (Ghasemi *et al.,* 2015). A wide range of adsorbing materials is used as adsorbents in the treatment of contaminated water by heavy metal ions. These materials include activated carbon (in granular or powder form), various clays, fly ash, activated sludge, inorganic–organic nanocomposite, carbon nanotube, graphite oxide, cellulose, chitosan, and chelating fibers. Because of its high removal effectiveness, ease of use, and low cost, biosorption has become the preferred method for removing heavy metals from aqueous solutions and wastewater (Ahmaruzzaman, 2011; Edet *et al.,* 2024).

Because of their comparable efficiency, ease of availability, and high cost-effectiveness, bio-wastes have lately gained relevance as sorbents. Ion exchange or complex formation between metal ions and the functional groups on the cell surface is the primary mechanism via which heavy metals are biosynthesized (Asuquo *et al.,* 2017). Various functional groups involved are phosphate, carboxyl, amine and amide whose role in metal binding, however, is still not fully understood. There is a considerable potential for adopting a natural, abundant and economical metal adsorption system, and tea leaves generated as waste by-product in cafeterias in large quantities could be used as an adsorbent for the removal of heavy metals from aqueous solution (Bourgeois *et al.,* 2017; Etim *et al.,* 2024; Nweke *et al.,* 2023). Thus, the removal of heavy metals using tea leaf and tea fibre as adsorbent has also been evaluated and justified by study (Magdy *et al.,* 2018; Ori *et al.,* 2024). The biosorption of heavy metals (zinc and lead) using tea leaves (*Cammelia sinensis*) and tea fibre as adsorbents devised to enhance the use of natural available adsorbents such as Camellia sinensis biomass instead of chemicals might give advantages such as lesser cost of production, source of income to the producer, source of revenue to the government as taxes from the sells, less sludge production and readily available materials and enhances sustainable development of agro-based waste (Etim *et al.,* 2019b; Okamoto, 2014; Etim *et al.,* 2019c; Samuel *et al.,* 2023). The objective of this paper was to investigate the adsorption behaviour of manganese and silverfrom aqueous solution using Tea Leaf and Tea Fibre.

MATERIALS AND METHODS

Preparation of 0.1 M Stock Solutions: The stock solution of 0.1 M Silver nitrate ($AgNO_3$), 0.1 M manganese solution, and 0.1 M NaOH were prepared in 1000 mL standard flask using distilled water. The various functional groups present in the tea leaves and fibers were probed using FTIR spectroscopy (Happ-Genezel) in order to account for the active sites present on the biosorbent (Michalak *et al.,* 2013).

Preparation of different concentrations of Metal solutions: Four different metal concentrations was prepared by serial dilution from the metal solution which are 20 mg/L, 30 mg/L, 40 mg/L, and 50 mg/L by measuring appropriately 20 cm^3, 30 cm^3, 40 cm^3, and 50 cm^3, respectively of the stock metal solution into 100 mL volumetric flask and will be shake till homogenize and kept for initial ion concentration determination (Oyedepo, 2011).

Adsorption Studies

Biosorbent collection and Preparation: The tea leaves and fibers were collected from Sardauna local Government area of Taraba State, using the method according to Etim *et al.,* (2019b) for sample collection and preparation. They were washed, rinsed, sun dried for seven days, pulverized, filtered via a 150 mm sieve, and finally stored in an airtight container before experiments. The equilibrium relationship for each effect were accessed accordingly. After the preparation of the biorsorbent, batch adsorption studies were carried out to obtain the rate of adsorption and equilibrium data. This was performed at varying concentration, adsorbent dosage, contact time, pH level and temperature.

Effect of Biosorbent dosage: 1g, 2g, 3g, and 4g of biosorbent were weighed into various conical flasks. Each conical flask held 50ml of the metal solution, which was measured out and labeled. After the flasks were corked and the mixture was shaken for an hour to reach equilibrium, the slurries were filtered using Whatman filter paper and a plastic funnel, the filtrate was stored in containers with clear labels, and the concentrations of the filtrate were then measured using an atomic absorption spectrometer (Pal *et al.*, 2022; Vijayaraghavan and Yun, 2008; Etim *et al.,* 2022a).

Effect of time (Time dependence): 1g of biosorbent was suspended into different conical flasks containing 50 cm^3 metal solutions. Each beaker will be agitated on an electrical shaker/rotatory mixer at 30 rpm with the time difference between each beaker will be 10 minutes, 20 minutes, 30 minutes and 40 minutes. Maintaining these parameters; temperature of 25℃, pH of 6 and concentration of metal 0.1 M constant. Once the spinning is completed, the solute was extracted and place into a plastic centrifuge tube after which it will be centrifuge for 3 minutes at 4000 rpm. This enabled the separation of the biosorbent from the solution,

Effect of initial Concentration: Metal solutions in volumes of 50 cm^3 each, with concentrations of 20 mg/L, 30 mg/L, 40 mg/L, and 50 mg/L, were measured and added to several conical flasks. Each flask was filled with 1 g of the biosorbent, and the mixture was shaken for an hour to reach equilibrium. The slurries were then filtered through Whatman filter paper and a plastic funnel, and the filtrate was stored in containers with clear labels. The concentration of the resulting filtrate was then measured using an atomic adsorption spectrometer (Asuquo *et al.,* 2012).

Effect of pH: 1g of the tea leaves and tea fibre was added in 50 cm^3 of Ag solution in a conical flask. The pH of each of the solutions was be adjusted to the desire value with 0.1 M sodium hydroxide and or 0.1 M nitric acid. The studies were conducted at pH values of 1.0; 3.0; 5.0; and 7.0. The biomass was removed from the solution by decantation and the residual Ag concentration in the solution will be analyzed. They were placed in a mechanical shaker for 1 hour. All studies was conducted in triplicates and the mean value will be determine for each by the AAS machine (Lee *et al.,* 2017; Etim *et al.,* 2023; Pham, *et al.,* 2022; Singh *et al.,* 2012; Asuquo *et al.,* 2012).

Effect of temperature: Measured into four separate conical flasks, 50 cm3 of 40 mg/L of the Ag stock metal solution will be adjusted on a temperature scale of 40°C, 50°C, 60°C, and 70°C. The adsorbent will then be weighed and poured into each flask in a volume of 1 g. After one hour of mechanical shaking to bring the slurries to equilibrium, they will be filtered through a plastic funnel and Whatman filter paper. The filtrate will be stored in containers with clear labels, and an atomic absorption spectrometer will be used to measure the concentration of the filtrate (Sivarajasekar and Baskar, 2014).

Kinetics of the adsorption Process: The rate of reaction was determined using the pseudo-first order kinetic model. The kinetic analysis will employ the pseudo-first order and pseudo-second order rate equations, as indicated in the relevant equations below.

$$\mathrm{Log}(q_i - q_t) = \mathrm{log}q_e \frac{k_1}{2.303} \qquad (1)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} \qquad (2)$$

Where; k_1 is the Lagergren rate constant of the biosorption: (min^{-1}) k_2 is the pseudo-second order rate constant (gm g^{-1} min^{-1}); q_e and q_t are the amounts of metal ions sorbed (mg g^{-1}) at equilibrium and at time t, respectively (Etim *et al.*, 2022b).

Thermodynamics of Adsorption: The nature of an adsorption process is co nfirmed by the evaluation of its thermodynamic parameters. Thermodynamic parameters like free energy change (ΔG_{ads}), enthalpy change (ΔH_{ads}), and entropy change (ΔS_{ads}) of adsorption was calculated to evaluate the feasibility and spontaneity of the process (Tan and Hameed, 2017; Asuquo *et al.,* 2012).

The standard free energy change of adsorption (ΔG^o_{ads}) was calculated using the following equation below;

$$\Delta G\mathrm{oads} = -2.303RTlog(bQo) \qquad (3)$$

The maximal Langmuir adsorption capacity is Q_o and the Langmuir isotherm constant is b.
T is the thermodynamic temperature and R is the gas constant (8.314 J mol^{-1} K^{-1}).

The Gibbs free energy of biosorption can be computed as follows

$$\Delta G^o = -RT \ln K_c \qquad \ldots 4$$

Where ΔG^o represents the standard Gibb’s free energy change for the adsorption (J/mol), R represents the universal gas constant (8.314 J/mol/K) and T represents the temperature (K). The adsorbate’s distribution coefficient is Kc. A negative Gibbs free energy value suggests that the adsorption process is feasible and spontaneous (Tighadouini *et al.,* 2021). The plot of ln K_c versus 1/T yields a straight line with values forΔH^o and ΔS^o as the slope and intercept. K_c is the distribution constant and can be written as (Tripathi and Ranjan, 2015; Verma *et al.,* 2017).

$$K_c = C_{ad}/C_e \qquad \ldots 5$$

C_{ad} (mg/l) and C_e (mg/l), respectively, are the concentration of solute adsorbed at equilibrium and the concentration of solute in solution at equilibrium. The following is the relationship between (ΔG^o), enthalpy change (ΔH^o), and entropy change (ΔS^o) of adsorption:

$$\Delta G^o = \Delta H^o - T\Delta S^o \qquad \ldots 6$$

Positive change in enthalpy (ΔH^o) implies that the adsorption is an endothermic process, but positive change in entropy (ΔS^o) reflects enhanced randomness at the solid/ solution interface.

RESULTS AND DISCUSSIONS

FTIR Analysis Result: Fourier transforms infrared spectroscopy of both tea leaves and tea fibres were obtained to analyze the surface functional group. Table 1 and 2 shows the difference in functional group for tea leaves and tea fibre. The FTIR results of tea leaves exhibit N-H at 3697.5 cm^{-1} indicating the presence of primary amine; O-H band at 3615.6 cm^{-1} corresponding to alcohol, carbohydrate, proteins and phenol; C-H band at 2918.5 cm^{-1} an indicative of alkane; P- band at 2322.1 cm^{-1} corresponding to phosphine and C=O signaling an aromatic ketone. The presence of primary amine was fully confirmed with the band at 1606.6 cm^{-1}, also the band at 1364.2 cm-1 is an indicative aromatic amine; a band at 1233.7cm^{-1} signaled the carboxylic acid and 1010.1 cm^{-1} shows the presence of primary alcohol or/ and ether. The FTIR results of tea fibre on the other hand exhibit O-H stretch nand at 3276.3 cm^{-1} corresponding to alcohol, carbohydrate, proteins and phenols; C-H band at 2918.5 cm^{-1} indicating an alkane; a –C=O band at 1625.1 cm^{-1} correspond to the amide; while a C-O band at 1144.2cm^{-1} correspond to secondary alcohol and C-O band at 1017.6 indicates an ether or/and primary alcohol.

Table 1. FTIR analysis for tea leaves

Peak Wavelength	Bond type	Functional group
3697.5	N-H	Primary amine
3615.6	O-H	Carbohydrate; protein; alcohol
2918.5	C-H	Alkane
2322.1	P-	Phosphine
1729.5	C=O	Aromatic Ketone
1606.5	N-H	Primary amine
1461.1	-C=O	Inorganic carbonate
1364.2	C-N	Aromatic amine
1233.7	R-COOH	Carboxylic acid
1010.1	C-O	Primary alcohol

Table 2. FTIR Analysis for tea fibre

Peak wavelength	Bond type	Functional group
3276.2	O-H	Carbohydrate; protein; phenol
2918.5	C-H	Alkane
1625.1	-C=O	Amide band I
1513.1	-C=O	Caboxylic acid
1513.8	C-N	Amide band III
1144.2	C-O	Secondary alcohol
1017.6	R-O-R	Ether

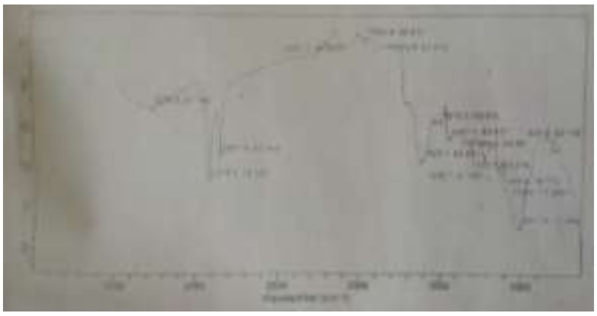

Fig 1. FTIR spectra of tea fibre

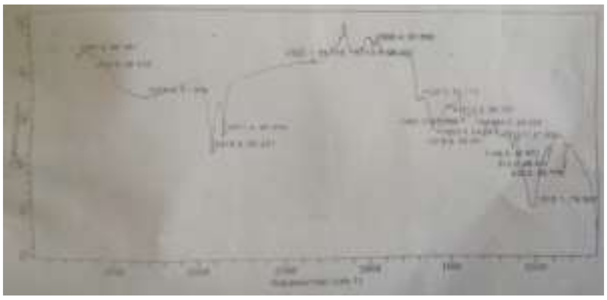

Fig 2. FTIR Spectra of tea leaves

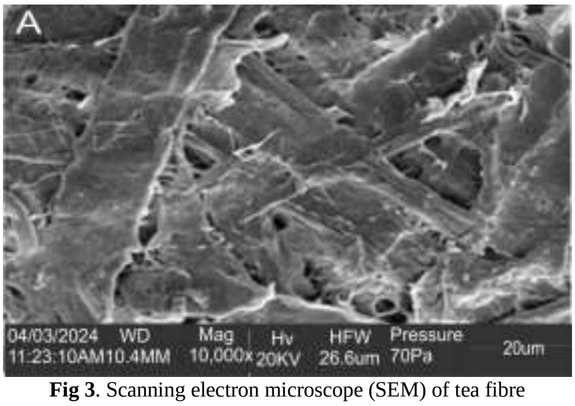

Fig 3. Scanning electron microscope (SEM) of tea fibre

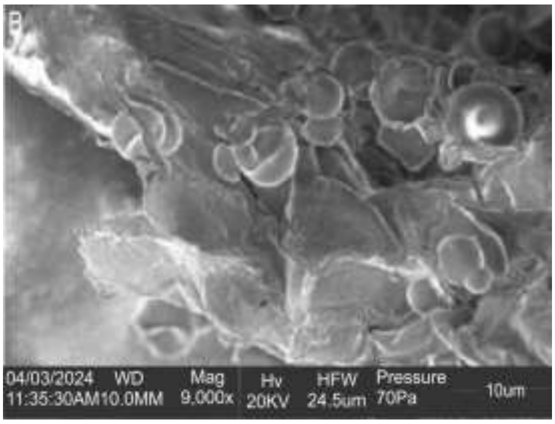

Fig 4. Scanning electron microscope (SEM) of tea leave

SEM Analysis: SEM result shows the distance between the microscope's objective lens and the surface of the sample being observed. Tt is given as 10.0 mm, indicating that the distance between the lens and the sample is 10.0 millimeters. a magnification of 90000x means that the image being observed is magnified 90,000 times compared to its actual size. The high voltage is applied to the electron beam to accelerate electrons towards the sample. Figure 3 it is given as 20 kilovolts (20 kv) and the micrometer is stated as 24.5 micrometers (µm), indicating the width of the observed area on the sample. In SEM, a vacuum environment is required to prevent electron scattering. Here, the pressure is mentioned as 70 pascals (pa). Figure 4 shows 10.4 mm, indicating that the distance between the lens and the sample is 10.4 millimeters. a magnification of 10000x means that the image being observed is magnified 10,000 times compared to its actual size. The high voltage is applied to the electron beam to accelerate electrons towards the sample. Here, it is given as 20 kilovolts (20 kv) and the micrometer is stated as 26.6 micrometers (µm), indicating the width of the observed area on the sample.

Table 3. Thermodynamic result of silver and manganese for tea leave and tea fibre

Adsorbents	Parameters	Temperature	Results
TL	ΔG^O (KJ/mol)	313	19. 1868
		323	19.7998
		333	20.4128
		343	21.0258
	ΔH^O (KJ/mol)		0.00004606
	ΔS^O (KJ/mol)		0.0613
TF	ΔG^O (KJ/mol)	313	10710.2116
		323	11052.3906
		333	11394.5696
		343	11736.7486
	ΔH^O (KJ/mol)		0.0089
	ΔS^O (KJ/mol)		34.2179

Adsorption study: A study on adsorption was conducted using the batch adsorption method, wherein various factors such as pH, adsorbent dosage, temperature, initial concentration, and contact time were varied in order to determine the optimal conditions for the removal of manganese and silver from aqueous media.

Effect of pH: Figures 5 and 6 give plots of pH on the adsorption of both silver and manganese for tea leaves and tea fibre. From the graph it was observed that there was increase in adsorption as the pH decreases from four to eight followed a by a steady increase as the pH decreases further for manganese and increase in adsorption of tea fibre.

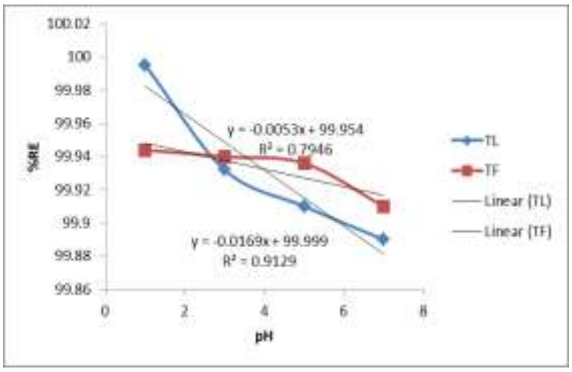

Fig 5. Effect of pH for the removal of silver from tea leave (TL) and tea fibre (TF)

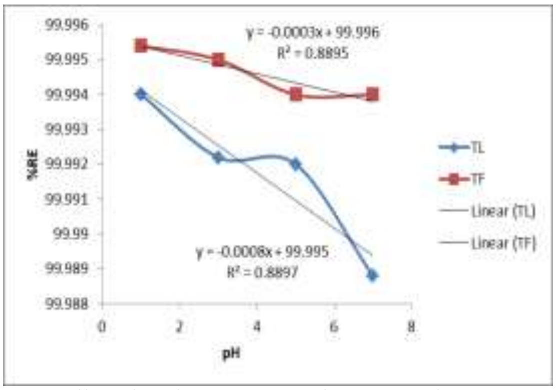

Fig 6. Effect of pH for the removal of manganese from tea leave (TL) and tea fibre (TF)

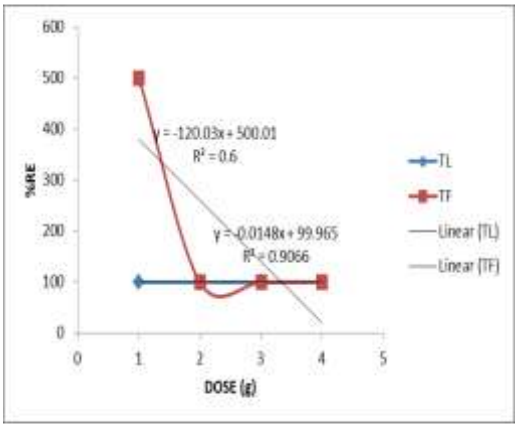

Fig 7. Effect of adsorbent dosage for the removal of silver from tea leave (TL) and tea fibre (TF)

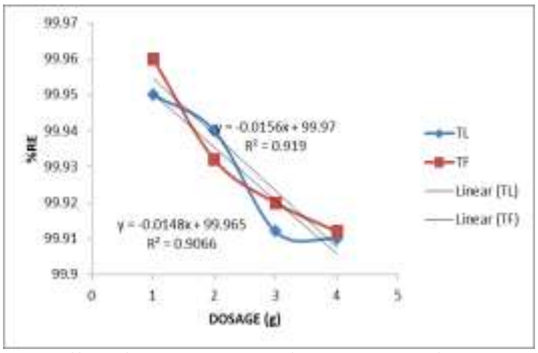

Fig 8. Effect of adsorbent dosage for the removal of manganese from tea leave (TL) and tea fibre (TF)

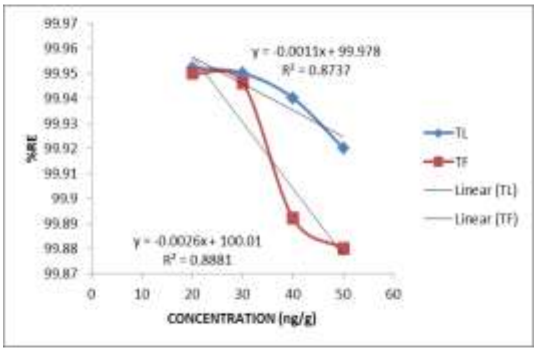

Fig 9. Effect of initial concentration for the removal of silver from tea leave (TL) and tea fibre (TF)

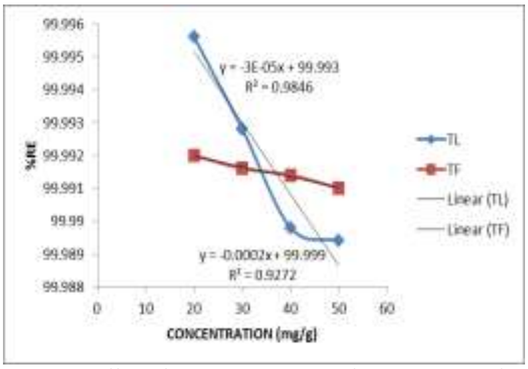

Fig 10. Effect of initial concentration for the removal of manganese from tea leave (TL) and tea fibre (TF)

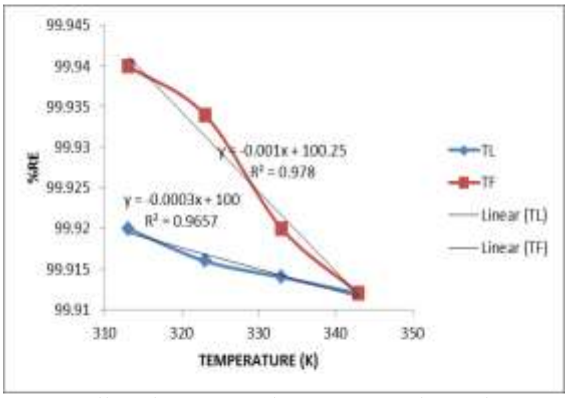

Fig 11. Effect of temperature for the removal of silver from tea leave (TL) and tea fibre (TF)

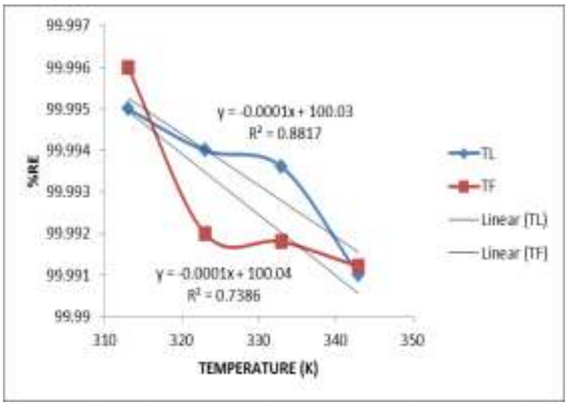

Fig 12. Effect of temperature for the removal of manganese from tea leave (TL) and tea fibre (TF)

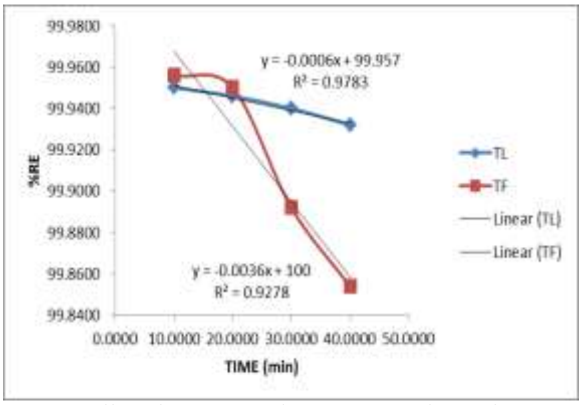

Fig 13. Effect of contact time for the removal of silver from tea leave (TL) and tea fibre (TF)

Hence equilibrium is attained at pH 5. Since H+ ions are present in excess at low pH values, metals must complete their adsorption on the sorbent surface with H+ ions. However, the attraction that forms between the positively charged metal ion and the negatively charged sorbent surface due to -OH groups produces a considerable increase in adsorption when pH levels are raised.

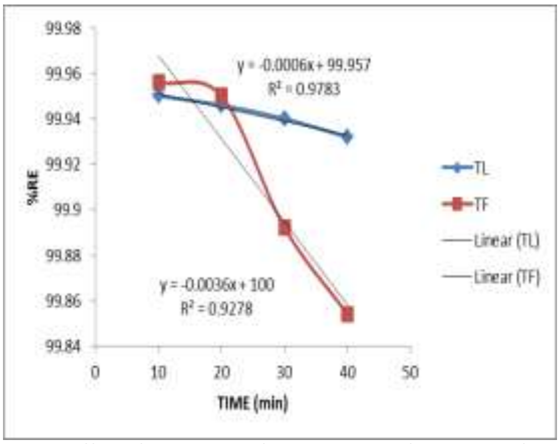

Fig 14. Effect of contact time for the removal of manganese from tea leave (TL) and tea fibre (TF)

Effect of adsorbent dosage: The experimental result on the effect of adsorbent dosage In Figures 7 and 8 shows respectively that equilibrium was attained at an adsorbent dose of 2.0g of silver for tea fibre and 2.0 & 3.0 of tea leave beyond which adsorption dropped below equilibrium. This indicates that the adsorption of manganese and silver increases unto both tea leaves and tea fibre increases steadily and reaches a maximum, then desorption set in.

Effect of initial concentration: The effect of initial concentration of silver and manganese for tea leave and tea fibre in the aqueous solution shows an increase in % removal with an increase in concentration of tea fibre as represented in Figures 9 and 10 This implies that the more binding site will be vacant for complexation of silver and manganese. Rise in concentration also raised adsorption of adsorbate on available site.

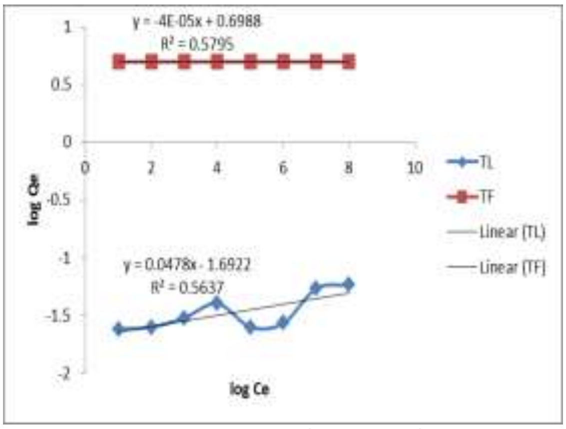

Fig 15. Freundleich isotherm plot of silver (Ag) for tea leaves and tea fibre

Effect of temperature: The experimental results on the effect of temperature on the adsorption of silver and manganese on both tea leaves and tea fibres show a decrease in the adsorption of adsorbate on the adsorbent as the temperature increases from 40°C-80°C as captured in Figures 11 and 12 respectively. This indicates that adsorption reactions are normally exothermic.

Effect of contact time: The effect of contact time on batch adsorption of both silver and manganese for tea leaves and tea fibre shows that adsorption increases steadily from 10 minutes to 20 minutes. This implies that equilibrium time was attained at 20 minutes since adsorption decreases afterward. The adsorption process was found to be very rapid initially and a very large fraction of total concentration of the metals was removed in the first 20 minutes as shown in Figures 13 and 14.

Adsorption Isotherm: The relationship between the amount of adsorbed material at the interface and the concentration of adsorbate in the bulk is described by the adsorption isotherm (Pal et al., 2022). Every adsorption site is assumed to be equal, and whether or not a particle can bond there is unaffected by the occupancy of other sites.

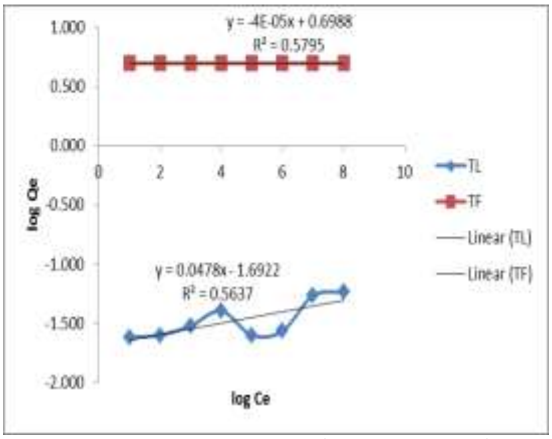

Fig 16. Freundleich isotherm plot of manganese (Mn) for tea leaves and tea fibre

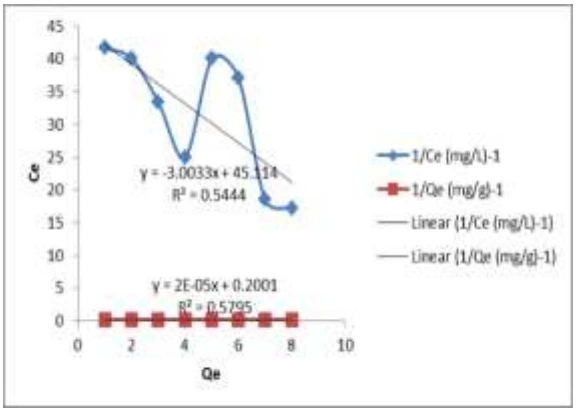

Fig 17. Langmuir adsorption isotherm plot of silver (Ag) for tea leaves and tea fibres

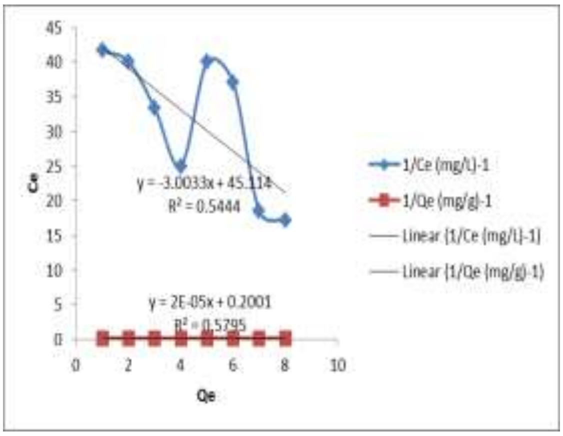

Fig 18. Langmuir adsorption isotherm plot of manganese (Mn) for tea leaves and tea fibres

For the purpose of better understanding the adsorption isotherm of silver and manganese, the Langmuir and Freund isotherm models were utilized in the process simulation. For Langmuir model as shown in Figures 17 and 18, the regression correlation coefficient (R^2) for both tea leaves and tea fibre was found to be 0.5444 and 0.5795 respectively and that of the freundlich as 0.5637 and 0.5795 for both tea leave and tea fibre as shown in Figure 15 and 16.

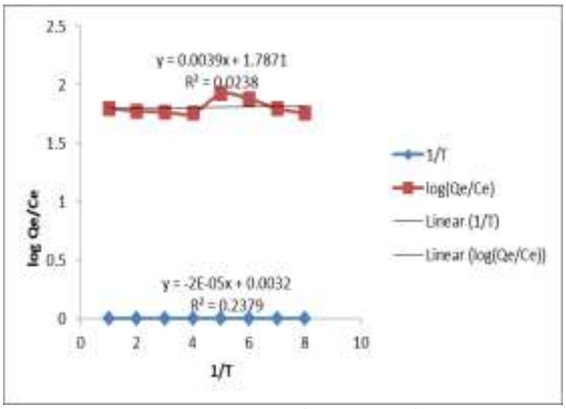

Fig 19. Thermodynamic studies of silver (Ag) for tea leaves and tea fibres

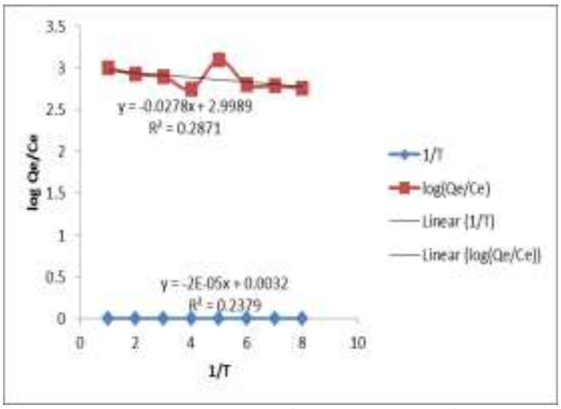

Fig 20. Thermodynamic studies of manganese (Mn) for tea leaves and tea fibres

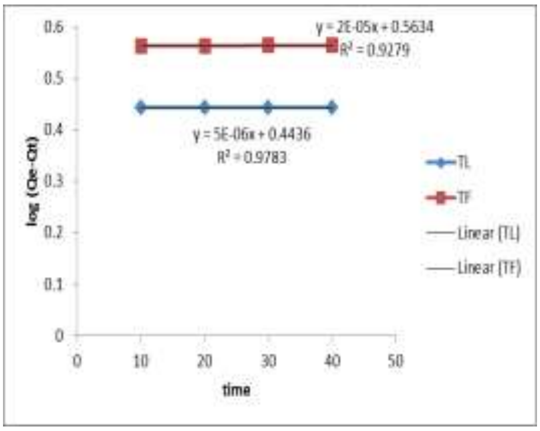

Fig 21. First order kinetic of silver for tea leaves and tea fibre

This implies that the equilibrium data agrees well with Langmuir than freundlich which assumes that a monolayer is formed and the uniform energies of adsorption onto the tea leaves and tea fibre and that no transmigration of silver and manganese on the adjacent binding sites.

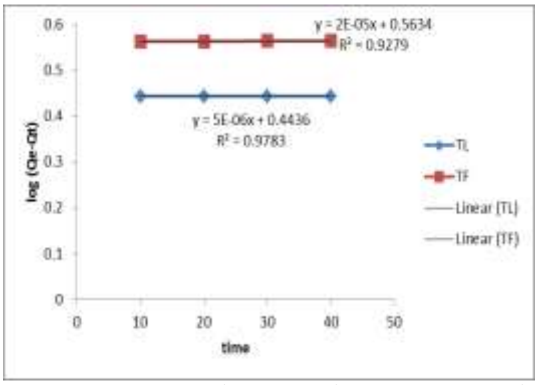

Fig 22. First order kinetic of manganese for tea leaves and tea fibre

Thermodynamic studies: The thermodynamic parameters, as shown in Figures 19 and 20, for the biosorption of manganese and silver on tea leaves and tea fibers indicate that an increase in randomness at the solid/solution interface during the biosorption process is implied by a positive value of change in entropy. An essential need for viability is the Gibbs free energy, which indicates the spontaneity of a chemical reaction.

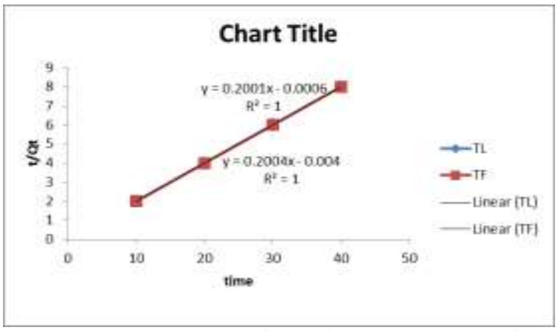

Fig 23 second order kinetic of silver for tea leaves and tea fibre

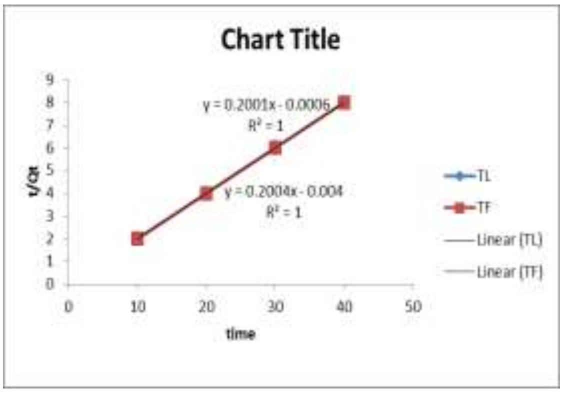

Fig 24 second order kinetic of manganese for tea leaves and tea fibre

Kinetics studies: Two kinetic models which are the first and second order were used to describe the experimental data obtained for the adsorption of silver and manganese onto tea leaves and fibre as shown in Figure 21, 22, 23 and 24 respectively. The correlation coefficient (R^2) was 0.9 and 0.9 for both tea leaves and tea fibres of silver and manganese for the first order. On the other hand the value of R^2 for the second order was 1.00 as shown in Figures 22 and 24, which both agree with the experiment data. The higher the R^2 indicates that the second order kinetic model is suitable to describe the kinetic adsorption process of silver and manganese better than the first order. This implies that they were chemisorptions due to sharing of electron between the adsorbent surface and the adsorbate during the adsorption of antimony.

Conclusion: The adsorption of manganese and silver from aqueous medium was examined in this study, and it was discovered that tea leaves and tea fiber were an efficient biosorbent for removing the metals from simulated waste water. The study also revealed the parameters that affect the adsorption, including temperature, pH, initial concentration, contact time, and adsorbent dose. The Langmuir isotherm gives the following correlation coefficient R^2 values of 0.54444 and 0.5795 for tea leave and tea fibre respectively while freundlich isotherm gives 0.5795 and 0.5637 values for tea leaves and tea fuibre respectively. The thermodynamic study showed that the adsorption process was feasible and spontaneous and endorthemic in nature. The research therefore present tea leaves and tea fibres which is much available and low cost by-product of tea leaves and tea fibre processing as effective biosorbents for the removal of silver and manganese from wastes water.

Declaration of Conflict of Interest: The authors declare no conflict of interest

Data Availability Statement: Data are available upon request from the first author or corresponding author.

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