

Performance of Treated and Untreated Spent Coffee Ground on the Removal of Cu (II) in Aqueous Solution: A Comparative Study

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Abstract The performance of two types of spent coffee ground (SCG), (i) untreated spent coffee ground (USCG) and (ii) acid-treated spent coffee ground (TSCG) on the Cu (II) removal from aqueous solution was investigated and compared in this study. The effects of operating parameters such as pH, contact time and initial Cu (II) concentration on the adsorption rate were studied in batch adsorption mode. The USCG showed better results than the TSCG. The highest removal efficiency of Cu (II) (50 mg/L) by USCG was 91.03% with an adsorption capacity of 45.52 mg/g, which was achieved at pH 6 and 90 min of contact time. The TSCG showed lower performance with a removal efficiency of 44.18% and adsorption capacity of 37.06 mg/g. This may be due to the flushed off in the functional groups of SCG that used for metal binding in the adsorption during acid treatment and the existence of Cl⁻ ions on the TSCG surface, interfering the Cu (II) adsorption and reduces its adsorption capacity. Freundlich fitted well with the equilibrium data for copper (II) removal, as indicated by the R² coefficient, for USCG and TSCG were 0.9912 and 0.9622, respectively. These data indicate that both USCG and TSCG have high sorption capacity and affinity for metal ions. The USCG showed a better Cu (II) removal than the TSCG, indicating a promising function as a low-cost natural adsorbent for Cu (II) and also other heavy metals removals.

Keywords Spent Coffee Ground, Copper, Adsorption,

Wastewater

1. Introduction

Environmental problems have been classified as the biggest crisis arising due to rapid urbanization and industrialization due to the increase of pollutions. These pollutions spread when industrial productions operate without satisfactory respect towards the environment that led to adverse effects on health and lives, soil degradation as well as global impacts [1]. One of the major environmental issues worldwide is the degradation of water quality due to the contamination of harmful substances such as chemicals, heavy metals or microorganisms in the stream, river, lake, ocean, aquifer or other water bodies. Heavy metals, namely arsenic, lead, cadmium, nickel, mercury, chromium, cobalt, zinc and selenium that are usually discharged from industrial activities such as electroplating, ceramic, glass and textiles are highly toxic, even at low concentrations [2].

Toxic metal pollutants are non-biodegradable and remain persistent in the environment for a very long time, thus, resulting in bioaccumulation in aquatic lives when they polluted water bodies [3]. A high concentration of copper (Cu) discharges from industries such as smelting, mining, electroplating and fertilizer industries will affect

the physical and chemical characteristics of water and the ecological balance of aquatic lives [4]. Industrial activity, such as ammoniacal etching in the electronic industry discharges of Cu (II) ion up to 160 mg/L [35]. Cu concentrations between 1 and 10 µg/L (ppb) can seriously affect a large number of marine organisms such as scallops, clams and isopod. The ingestion of high doses of copper (> 1300 ppb, USEPA) will cause gastrointestinal bleeding, haematuria, intravascular haemolysis, methemoglobinemia, hepatocellular toxicity, acute renal failure and oliguria [5]. Lower doses of copper consumption will cause health problems such as vomiting, diarrhoea, jaundice and nausea.

Many technologies have been used to treat heavy metals, including coagulation and flocculation, precipitation, ultrafiltration, ion exchange and reverse osmosis [4]. The disadvantages of these methods are high operational costs due to the chemicals used, high-energy consumption and handling costs for toxic sludge disposal [6]. Hence, adsorption is one of the effective methods to remove heavy metals due to its removal efficiency, simplicity of the design and ease of operation [7]. Low-cost adsorbent alternatives such as agriculture residues, forestry wastes and mineral wastes have been actively explored as activated carbon and ion-exchange resins are expensive adsorbent materials [8].

The reuse of natural-based wastes is one of the sustainable alternatives due to its environmentally and economically-friendly approaches and waste reduction. Spent coffee ground is one of the largest produced in the world with approximately 6 million tonnes yearly in domestic, restaurant and coffee industries [9]. The spent coffee ground (SCG) is beneficial for fertilizer, animal feed materials, biodiesel source and metal ion adsorbent due to its chemical content such as fatty acids, lignin, cellulose, hemicellulose and polyphenols [10]. The SCG becomes an alternative for activated carbon as an adsorbent to treat heavy metals [11]. The existence of functional groups such as -OH, -COOH and phenolic in SCG help in metal binding capacity in the adsorption process [8]. It has been emphasized that SCG also contains a high amount of micropores and mesopores with a large surface area for a high adsorption capacity [6].

The SCG has shown its potential on the removal of aniline dye and nitrobenzene from wastewater with about 88% and 98% removal, respectively [12, 13]. It has been reported that cadmium removal by SCG was achieved at 72% [14]. The treatments of natural adsorbents by alkali and acid modifications have been carried out using 0.1 M NaOH and saturated hydrochloric acid (HCl) in the previous studies to increase the adsorption capacities of heavy metals [8,15]. In the concern of sustainable development, techniques that give added value to waste should be considered. Therefore, the main objective of this study was to investigate and compare the performance of untreated and acid-treated SCG as adsorbents to

remove Cu (II) from a synthetic aqueous solution. Different operational parameters such as pH, contact time and initial metal concentration were investigated in this study. Langmuir and Freundlich isotherms were examined to establish the most appropriate correlation with the equilibrium curve. Furthermore, the microstructure of the SCG was also analysed.

2. Materials and Method

2.1. Preparation of Cu (II) Solution

The Cu (II) solution of 1000 ppm was prepared by dissolving 3.93g of copper sulphate pentahydrate, CuSO₄.5H₂O (Fluka, 98% purity) in 1L of distilled water as a stock solution [34]. The stock solution was then diluted with deionized water to obtain the required initial concentration of Cu (II) solution.

2.2. Adsorbent Preparation

The SCG was collected from a Starbucks Café in Setia Alam, Selangor, Malaysia. The pre-treatment of SCG was carried out immediately after collection to avoid degradation of SCG and mold formation. Two types of SCG were prepared in this study; (i) untreated SCG (USCG) and (ii) acid-treated SCG (TSCG). USCG was prepared by drying the SCG in the convection oven at 100 °C until the constant weight was achieved. Part of the USCG was then treated using 37% concentrated hydrochloric acid (HCl) with a ratio of one (1) USCG to two (2) concentrated HCl (by weight), which was then placed in the oven at 70 °C for 1-2 hours [15]. After the treatment, the excess acid on the SCG was washed using distilled water five times and was then filtered with filter paper (110 mm diameter). The filtered SCG was dried at 70 °C until a constant weight was achieved and was labelled as TSCG. Both USCG and TSCG were stored at room temperature (25 °C) and in a dry environment before use as an adsorbent in the adsorption experiments.

2.3. Batch Adsorption Experiments

All adsorption experiments in this study were carried out using the batch technique as the amount used was relatively small, as well as simple and a low-cost operation. All experiments were performed at 25 °C, with an adsorbent dosage of 1 g/l and agitation speed at 140 rpm. The effect of various parameters on the adsorption rate and efficiency were observed and measured by varying contact time, *t* (30, 60, 90, 120, 150, 180, 210 and 240 mins), initial concentration of Cu (II) ions (5, 10, 15, 20, 30, 60, 90 mg/L) and initial pH of the aqueous solution (2,3,4,5,6,7,8). The initial pH of Cu (II) aqueous solution was adjusted to the required pH (2-8) by adding

0.1M of HNO₃ and 0.1M NaOH. The investigated parameters and operating conditions of the adsorption process are summarised in Table 1.

Table 1. Summary of different parameters varied in this study

pH	Initial Cu (II) Concentration (mg/L)	Contact time (min)
2,3,4,5,6,7,8	50	1440 (24 hrs)
USCG: pH 6 TSCG: pH 7	50	30, 60, 90, 120, 150, 180, 210 & 240
USCG: pH 6 TSCG: pH 7	5, 10, 15, 20, 30, 60 & 90	30

50 mL of Cu (II) aqueous solution was mixed with 1 g/L adsorbent in a 250 mL Erlenmeyer flask. The mixture was then mixed continuously with a constant agitation speed (140 rpm) for better mass transfer with a higher interfacial area of contact [11]. The experiments were performed using a shaker (Thoth, 6430 Model) at a controlled temperature of 25 °C. The concentrations of Cu (II) before and after the adsorption process for each sample were measured using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES). Prior to ICP analysis, the mixture was filtered to separate the adsorbent and aqueous solution. The Cu (II) concentration in the filtrate was analysed using ICP. The removal efficiency of Cu (II) was calculated using Equation (1).

$$\text{Removal efficiency}(\%) = \left[\frac{C_o - C_e}{C_o} \right] \times 100 \quad (1)$$

Where, C_o and C_e (mg/L) are the initial and equilibrium concentrations, respectively, in the liquid phase.

The amount of metal uptake at equilibrium Q_e (mg/g) was calculated using Equation (2) as below;

$$Q_e = \frac{(C_o - C_e) V}{m} \quad (2)$$

where, C_o and C_e (mg/L) is the initial and equilibrium concentrations of the liquid phase, V (L) is the volume of adsorbate and m (g) is the mass of adsorbent.

2.4. Microstructure Analysis

The microstructure analysis of the adsorbents and used

adsorbents were analyzed using Phenom XL Scanning Electron Microscopy (SEM) operating at 15 kV acceleration voltage. The elemental analysis of the SCG was done using Energy-Dispersive X-ray (EDX) Phenom ProSuite.

3. Results and Discussions

3.1. Effect of pH on Cu (II) Removal

The pH of the metal aqueous solution is an important parameter that controls the adsorption process. The pH values of Cu (II) aqueous solutions were varied from acidic to basic (pH 2-8). Figure 1 shows the effect of the initial pH of the Cu (II) solution on the removal efficiency of Cu (II) by USCG and TSCG. At pH 2, the removal efficiency of Cu (II) from the aqueous solution by both USCG and TSCG is at the lowest, which is approximately 23%. This shows that higher concentration and high mobility of H⁺ ions lead to the minimum adsorption of Cu (II) at a low [16]. When the pH increases, the number of H⁺ ions competing is lower and more ligands were exposed to the negative charges, which resulted in extensive adsorption [17]. Hence, increasing the pH solution towards pH 6 – 7 will enhance the negative surface charges, thus, increasing the electrostatic attractions of Cu (II) ions [18]. This leads to higher adsorption of copper. However, further increase of pH contributed to the formation of insoluble copper compounds such as Cu (OH)₂, which limits the interaction and sorption of the adsorbent [19].

The removal efficiency of Cu (II) ions by both USCG and TSCG showed a massive increase between pH 5-7 but decreased with further pH increment to basic conditions. The maximum removal of Cu (II) was observed at pH 6 (78%) and pH 7 (55%) for USCG and TSCG, respectively. This shows that the effective pH for adsorption of Cu (II) by SCG (USCG and TSCG) is approximately at neutral pH. This agrees well with the result presented by Zhuang et al. which showed the highest removal efficiency of Cu (II) ions (95%) by modified pineapple bran cellulose was at pH 7 [17].

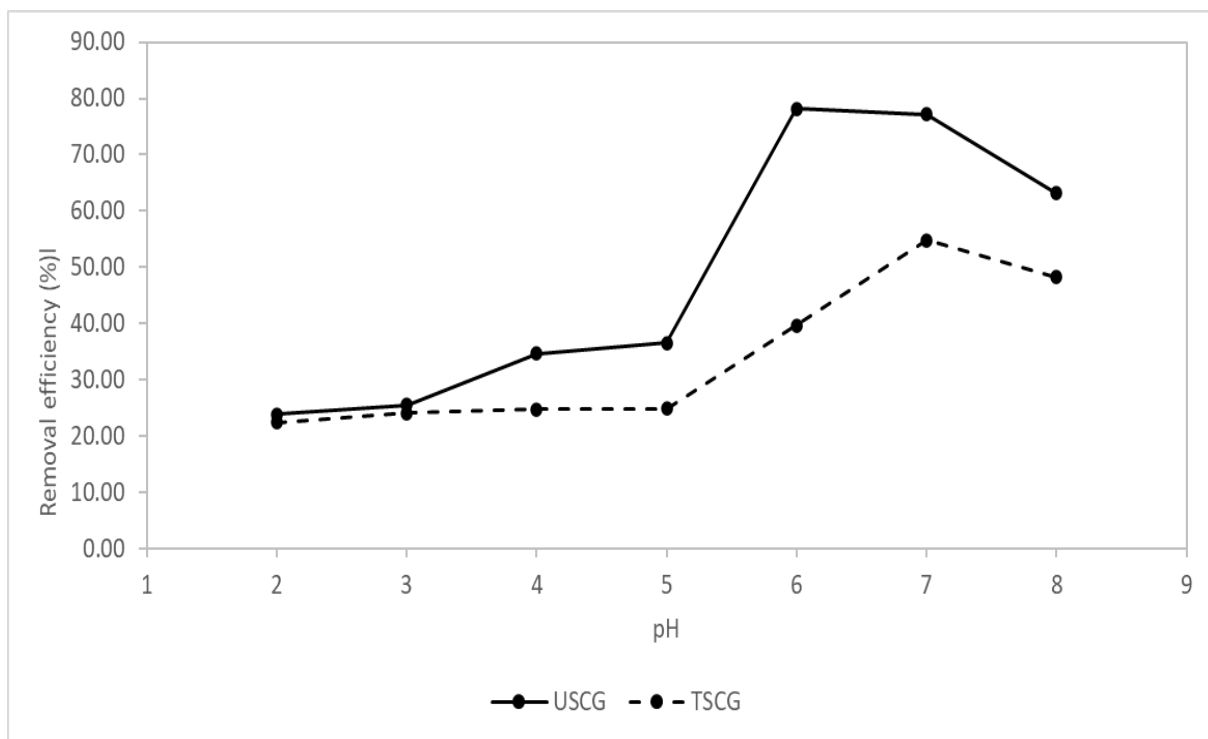


Figure 1. The effect of pH on the removal efficiency of Cu (II) by SCG adsorbents

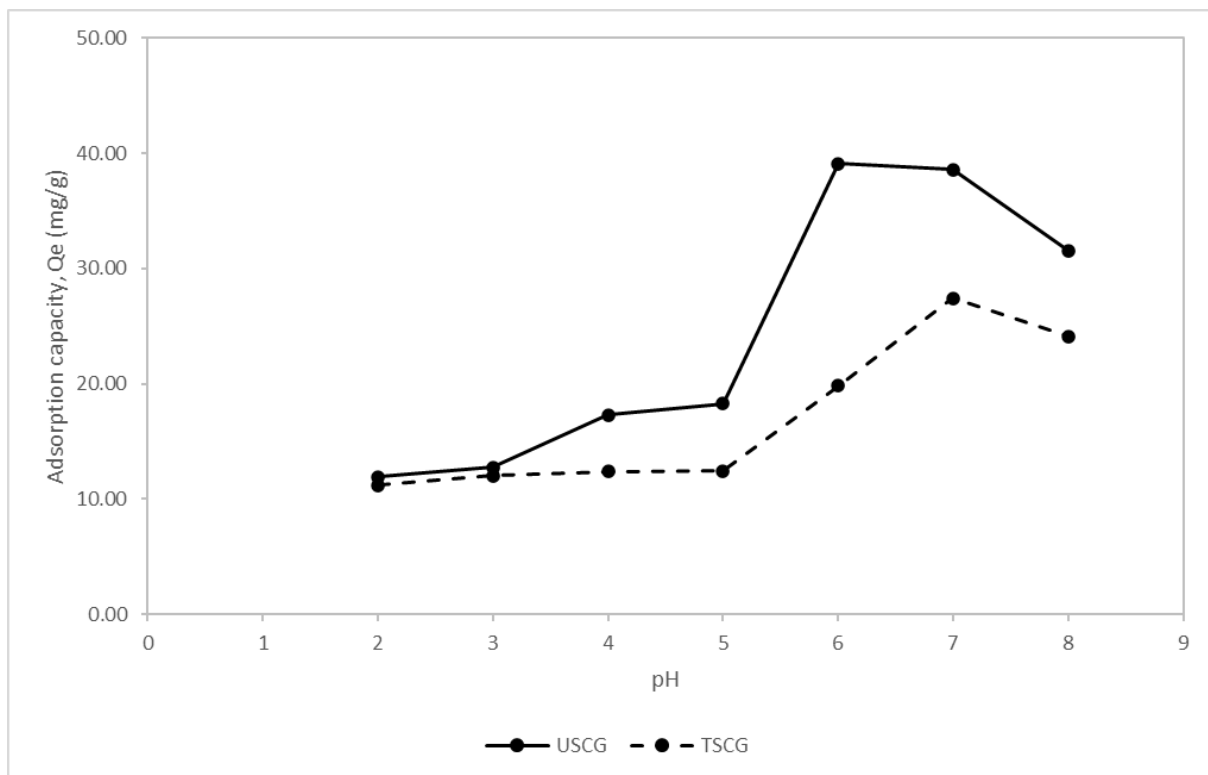


Figure 2. Effect of pH on the adsorption capacity of Cu (II)

The maximum adsorption capacities achieved by USCG and TSCG were 39.1 mg/g and 27.4 mg/g, respectively (Figure 2). The TSCG showed lower removal efficiency and adsorption capacity than USCG, which is in contrast

with a previous study reported by Renu et al. [15]. They reported that the acid treatment of the adsorbent lead to the aggregation particles that were broken to form better structures by disseminating the particles equally for the

adsorption process. From their study, the removal efficiency of Cu (II) obtained was 77% using acid treated-wheat bran as an adsorbent. However, the types of acid, such as HNO₃, HCl, H₂SO₄ and H₂O₂ as well as their concentration used for the adsorbent treatment may influence the adsorption capacity and efficiency, depending on the types of adsorbents [20]. The concentrated HCl acid used in this study might wash away some SCG functional groups such as -OH, -COOH and phenolic that helps in metal binding during the adsorption process [8]. Furthermore, the chloride ions (Cl⁻) elements were found in the pore and surface of TSCG, which resulted from the presence of HCl used in the acid treatment, which possibly blocked the surface pores of TSCG from the adsorption of Cu (II) ions. Thus, the TSCG adsorbed lower Cu (II) ions. This was proven with the detection of Cl⁻ element using the EDX analysis of TSCG as shown in Figure 11(b). A high level of interfering ions concentration may adversely affect the adsorption capacity of the adsorbent [21].

The percentage removal of Cu (II) by USCG and TSCG decreased when pH increased to more than pH 6 and 7 due to the precipitation of ions as hydroxides that hinders the metal adsorption [22]. The adsorption capacity varied depending on the adsorbent and adsorbate treatment of heavy metals by increasing and decreasing the pH due to the positive and negative surface charges [18]. Therefore, to measure other parameters effect on Cu (II) adsorption by SCG in the following experiments, pH 6 and pH 7 were used as the initial pH of Cu (II) aqueous solutions for USCG and TSCG, respectively.

3.2. Effect of Contact Time on Cu (II) Removal

Figures 3 and 4 clearly showed that after 30 mins, no significant results were observed. The removal efficiency and adsorption capacity achieved plateau lines after 30 mins of the adsorption process for both USCG and TSCG. During the first 30mins, the removal efficiency increased greatly with 88% and 32% for USCG and TSCG, respectively. The adsorption capacity of USCG and TSCG was recorded at 44 mg/g and 16 mg/g. The highest

removal efficiency for USCG and TSCG was at 91% (45.5 mg/g) at 90 mins and 36% (17.8 mg/g) at 210 mins, respectively.

The instantaneous sorption by the adsorbent showed the characteristic of physical adsorption in the first 30 mins. Furthermore, the abundance of active sites on the adsorbent made the ions more accessible, resulting in a higher absorption rate at the initial stage [23]. The change of removal efficiency and adsorption capacity of Cu (II) by USCG towards time is minimal, in between 82% and 91%. This shows that the adsorbent was reaching a saturated and equilibrium state within 30-90 mins of the contact time. Furthermore, the insignificant variation of removal efficiency after 30 mins may be associated with the exhaustion of binding sites on the adsorbent [24]. Further increase in contact time resulted in the decrease of the availability of these sites, which led to the difficulties in adsorption of the remaining empty external sites and resulted in low Cu (II) adsorption. Therefore, the contact time of 30 mins was selected for further analysis.

3.3. Effect of Initial Concentration on Cu (II) ion Adsorption

The effect of the initial concentration of Cu (II) (5 mg/L to 90 mg/L) on the adsorption onto USCG and TSCG was conducted in this experiment at 30 mins. The highest percentage removal for USCG and TSCG were recorded at 5 mg/L (75%) and 60 mg/L (41%), respectively. Generally, the removal efficiency of Cu (II) by USCG decreased as the initial concentration of Cu (II) increased (Figure 4). The results indicate that there was a reduction in Cu (II) ions adsorption, owing to the lack of available active adsorption sites required for higher Cu (II) concentrations. This is due to the number of adsorption sites decreasing when the adsorbent becomes saturated (Sertouli et al., 2019). In contrast, the removal efficiency of Cu (II) by TSCG showed an increase as the initial Cu (II) concentration increases and reaches a constant when the Cu (II) concentrations are more than 60 mg/L. This may be closely related to the existence of Cl⁻ ions on the adsorbent surface that blocked the adsorption process.

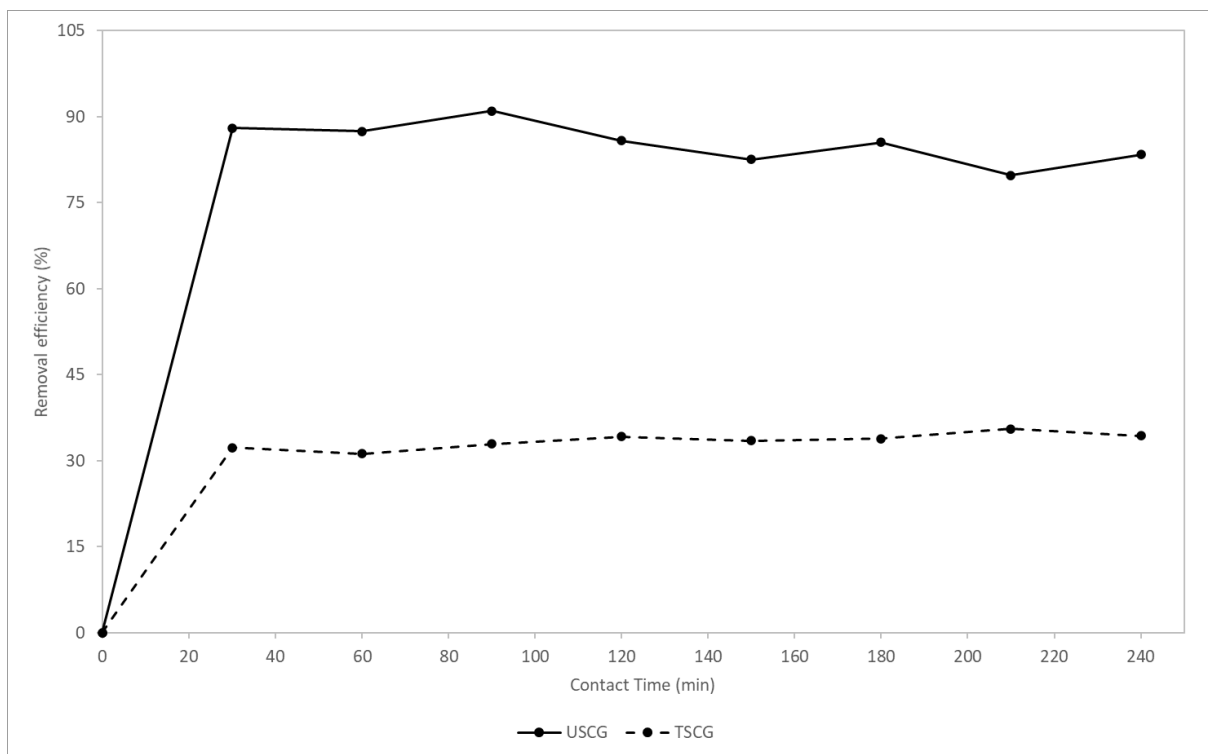


Figure 3. The effect removal efficiency of Cu (II) on adsorbent contact time

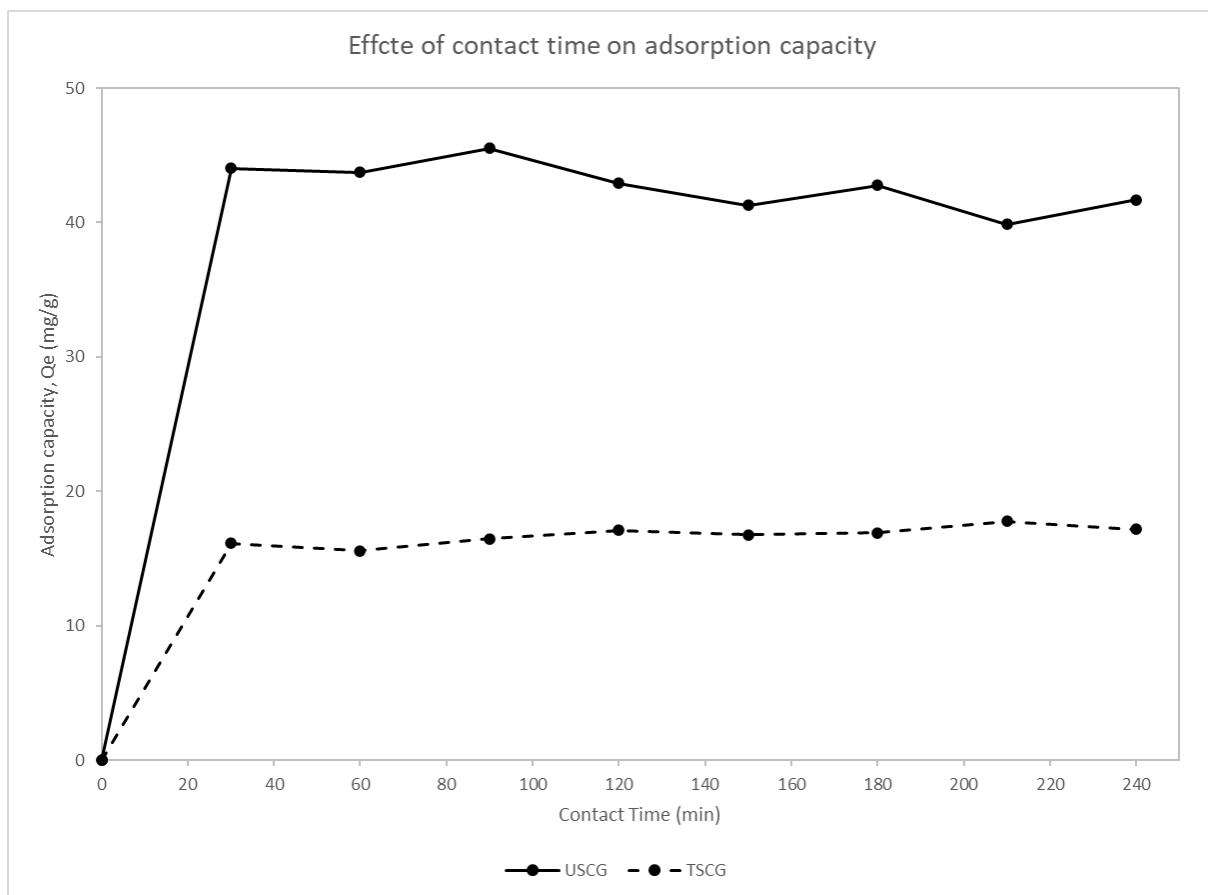


Figure 4. Effect of adsorption capacity of Cu (II) on adsorbent contact time

3.3. Effect of Initial Concentration on Cu (II) ion Adsorption

The effect of the initial concentration of Cu (II) (5 mg/L to 90 mg/L) on the adsorption onto USCG and TSCG was conducted in this experiment at 30 mins. The highest removal efficiency for USCG and TSCG were recorded at 5 mg/L (75%) and 60 mg/L (41%), respectively. Generally, the removal efficiency of Cu (II) by USCG decreased as the initial concentration of Cu (II) increased (Figure 5). The results indicate that there was a reduction

in Cu (II) ions adsorption, owing to the lack of available active adsorption sites required for higher Cu (II) concentrations. This is due to the number of adsorption sites decreasing when the adsorbent becomes saturated [25]. In contrast, the removal efficiency of Cu (II) by TSCG showed an increase as the initial Cu (II) concentration increases and reaches a constant when the Cu (II) concentrations were more than 60 mg/L. This may be closely related to the existence of Cl⁻ ions on the adsorbent surface that blocked the adsorption process.

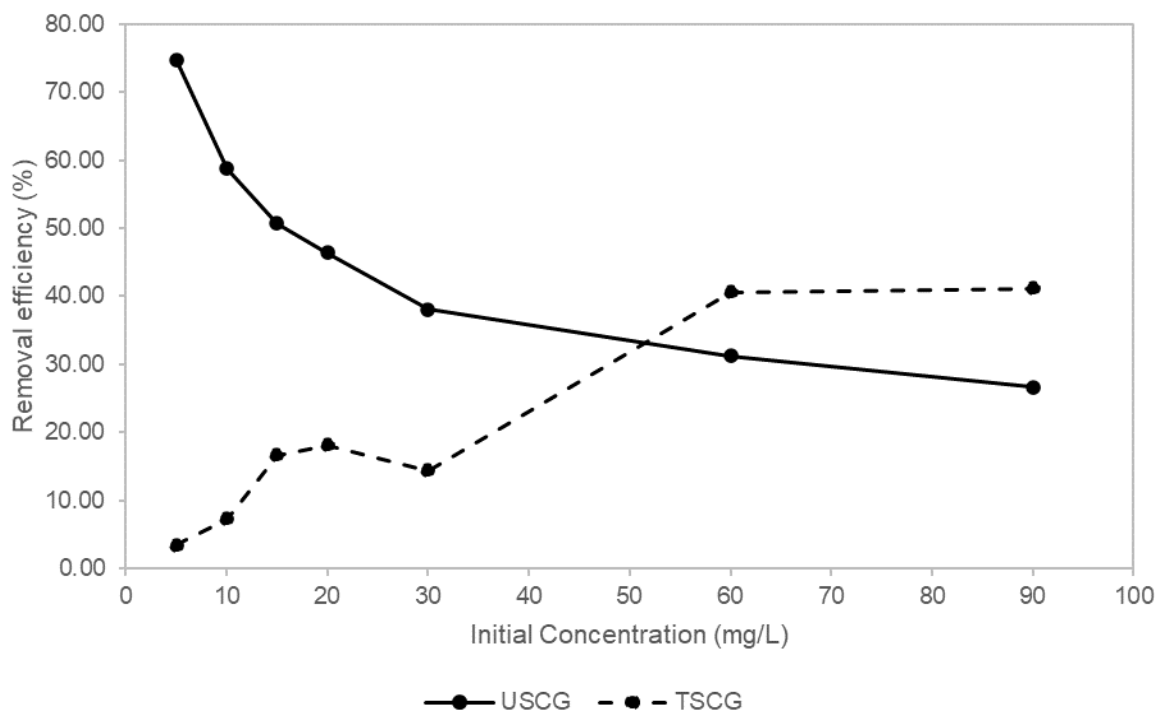


Figure 5. Effect initial concentration on percentage removal of Cu (II) for 30mins contact time

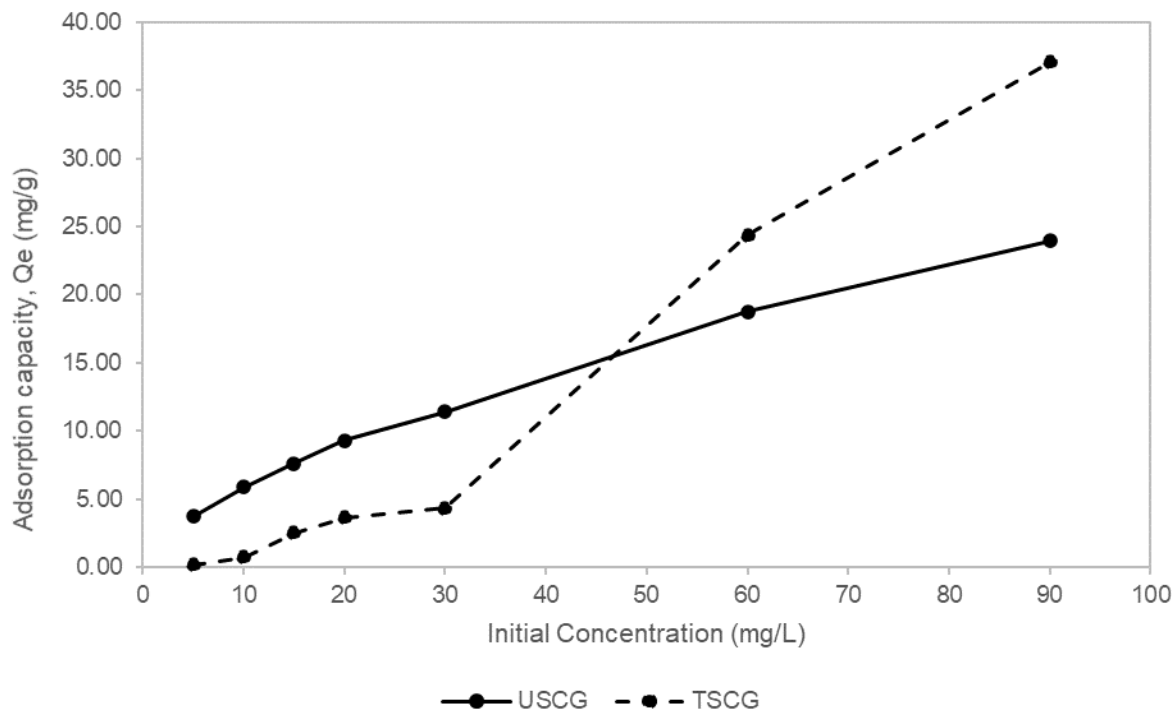


Figure 6. Effect initial concentration on adsorption capacity of Cu (II) for 30 mins contact time

The adsorption capacity for both USCg and TSCg showed an increase with the increment of the initial Cu (II) concentration (Figure 6). This may be due to the increase of the mass transfer driving force to overcome all mass transfer resistance of the pollutant between the aqueous and solid phases, thus, increasing the uptake [26]. The highest adsorption capacity of USCg and TSCg recorded were 37 mg/g and 24 mg/g, respectively. A low concentration of Cu (II) resulted in a low adsorption capacity. This means that part of the dissolved Cu (II) stayed in the solution, thus, the concentration of Cu (II) in the solution needs to be increased to get a higher adsorption capacity [8]. There are also possibilities that the metal (Cu) was not absorbed by the adsorbent due to insufficient affinity of the metal ions and adsorption sites, which lead them to stay in the aqueous solution [8]. Table 2 shows the adsorption capacities and removal efficiency (%) of heavy metals using SCG with different treatment methods reported from previous studies. It was shown that the removal efficiency adsorption capacity of Cu (II) by USCg is comparable with the values reported in previous studies.

3.4. Adsorption Isotherm on Cu (II) ion Adsorption

Adsorption isotherms are important to define the equilibrium distribution of Cu (II) between adsorbent and solution. Langmuir and Freundlich models were used to

describe the adsorption process in this study. Langmuir isotherm is a model that proposed a fixed surface and adsorbate uptake that occurs by monolayer sorption without interacting among the adsorbate, whereas, Freundlich is described as the equilibrium of adsorption system with a heterogenous surface [27].

Table 3 shows a summary of the adsorption isotherm model parameters for USCg and TSCg obtained from this study. The equilibrium data were fitted to the isotherm models, Langmuir (Equation 3) and Freundlich (Equation 4) were expressed as a linear equation as follows [28];

$$\frac{1}{q_e} = \frac{1}{Q^\circ} + \frac{1}{bQ^\circ C_e} \tag{3}$$

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \tag{4}$$

where, q_e (mg/g) is the adsorbate adsorbed per unit weight of adsorbent at equilibrium, Q° (mg/g) is monolayer adsorption capacity, C_e (mg/L) is the equilibrium concentration of the adsorbate in solution, b is a constant related to the free energy or net enthalpy of adsorption. K_F (mg/g) represents the adsorption capacity constant of the adsorbent. Meanwhile, $1/n$ is the adsorption intensity or measure of the nature and strength of the sorption process and distribution of active sites. The value of $1/n$ that is less than the unity represents exceptional adsorption at low concentration and n values that lie between 0 and 10 show beneficial adsorption [29].

Table 2. Summary of performance of SCG as adsorbent from previous studies

Treatment description of SCG as adsorbent	Operating Condition	Heavy Metals	Q _e	Removal (%)	References
Dried at 25 °C (5hrs)	pH 5, 140 rpm, 25 °C, 24 h and 50mg/L, 1 g/L adsorbent	Copper	44mg/g	70	[11]
		Chromium (VI)	35 mg/g	60	
Dried at 105 °C and treated with 2% formaldehyde		Copper	54 mg/g	76	
		Chromium (VI)	40 mg/g	62	
Dried at 100 °C (particle size <200 µm)	120-130rpm, 1h, 0.5mg/L, 1 g/L adsorbent	Copper	-	97	[32]
		Lead	-	96	
Treated with 0.1M NaOH at 40 °C for 3 h and dried at 70 °C for 24 h	pH 4.5, 12 h, 25 °C, 400rpm and 1mM	Copper	0.21 mmol/g	-	[33]
		Cadmium	0.12 mmol/g	-	
		Lead	0.32mmol/g	-	
Calcium Alginate/Spent Coffee Grounds Composite Beads	pH 6, 30 °C, 250rpm and 10ppm, 24h	Cadmium	~2 mg/g	98.8	[8]
		Nickel	~3 mg/g	80.2	
Dried at 100 °C	pH 6, 140 rpm, 25 °C, 30-90 mins and 50mg/L of Cu (II)	Copper	44.0 – 45.5 mg/g	88-91	Present study
Treated with HCl	pH 7, 140 rpm, 25 °C, 30mins and 90mg/L of Cu (II)		37.06 mg/g	44.18	

Table 3. Summary of Adsorption Isotherm Model of Langmuir and Freundlich for USCG and TSCG

Model	Adsorbent	Parameters		
		Adsorption maxima, Q ^o (mg/g)	Binding energy, constant b (mg/L) ⁻¹	R ²
Langmuir	USCG	14.05	0.2678	0.8931
	TSCG	0.8117	0.0396	0.9052
Freundlich		Adsorption capacity, K _F (mg/g)	Adsorption intensity, 1/n	R ²
	USCG	3.0952	0.4735	0.9912
	TSCG	173.78	2.2378	0.9622

Figures 7 and 9 showed the Langmuir isotherm model for USCG and TSCG, respectively, with R² coefficient values of 0.9912 (USCG) and 0.9622 (TSCG). The Freundlich isotherms for USCG and TSCG are presented in Figures 8 and 10, respectively. The values of R² coefficient for the Langmuir model are 0.8931 (USCG) and 0.9052 (TSCG). The USCG and TSCG adsorbents

follow both isotherm models, however, the Freundlich model is the best fit in this study. A good correlation, R² > 0.9, possesses high sorption capacity and high affinity for the metal ions [30]. Both SCG adsorbents indicate favourable adsorption, as the *n* values of USCG and TSCG were 0.5 and 2, which lies between 0 and 10, showing beneficial adsorption [29].

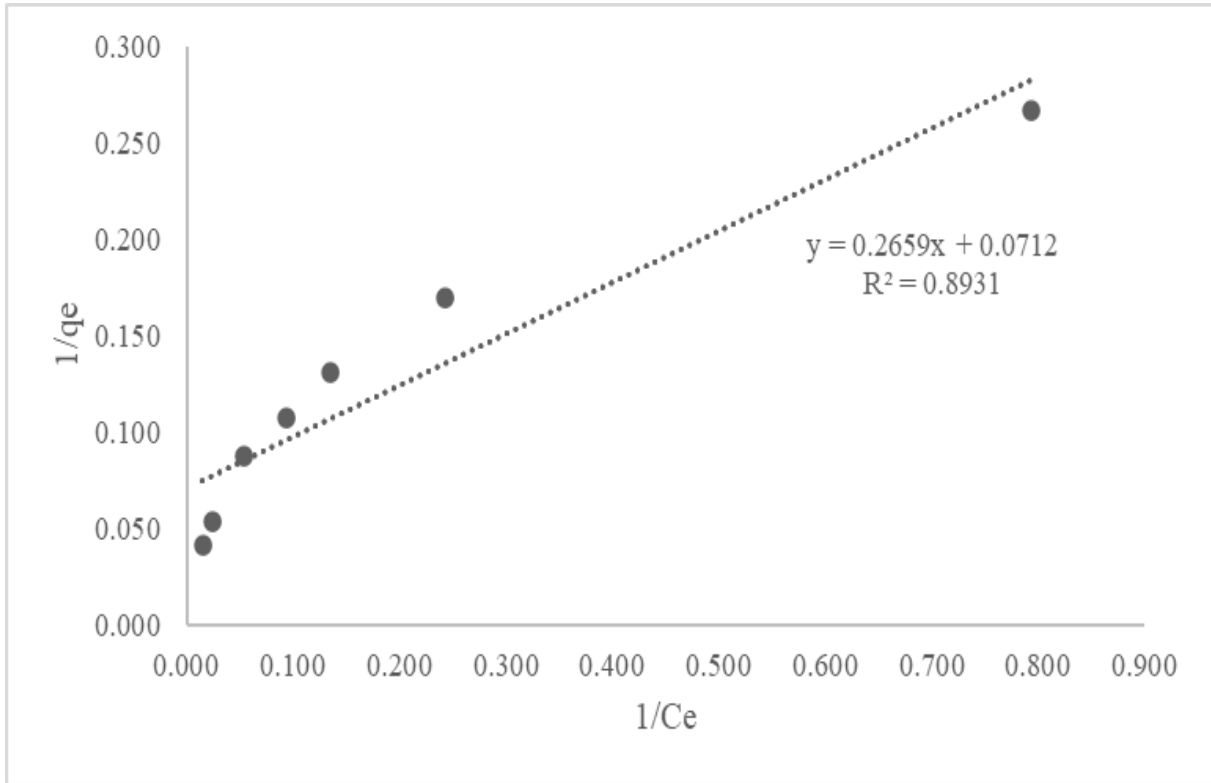


Figure 7. Langmuir isotherm model for USCG

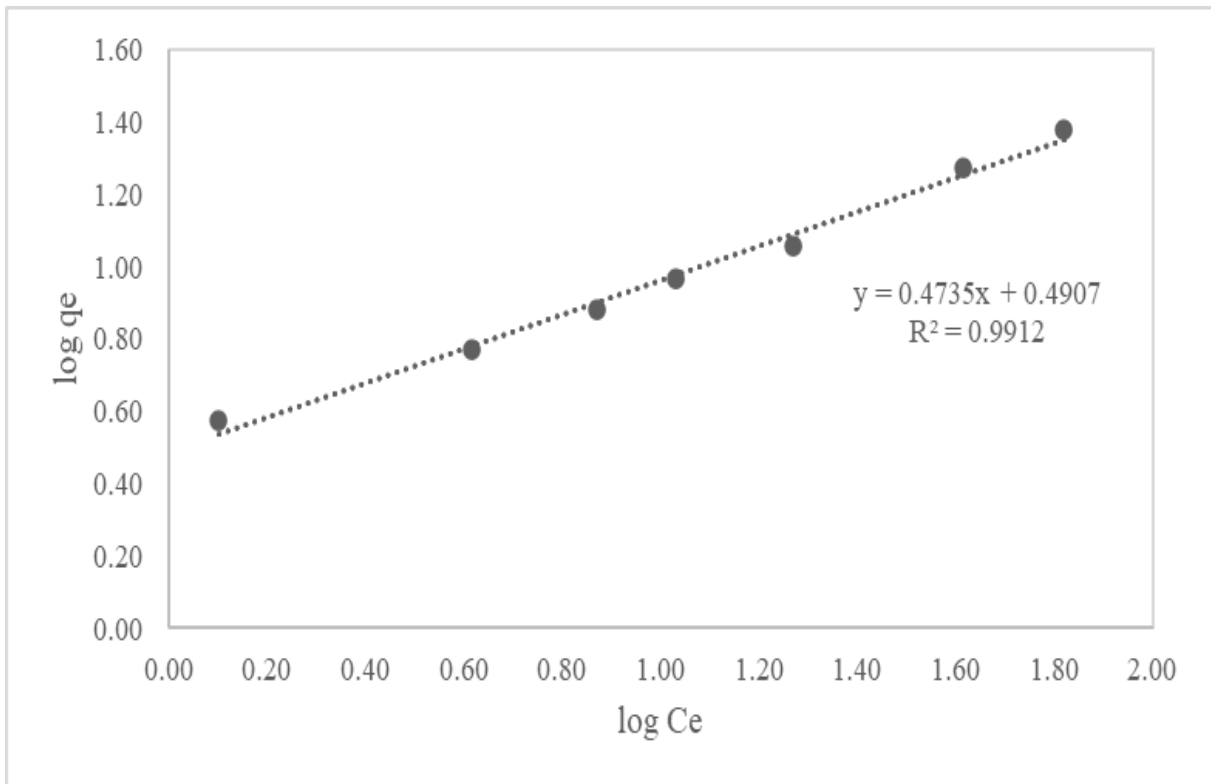


Figure 8. Freundlich isotherm model obtained for USCG

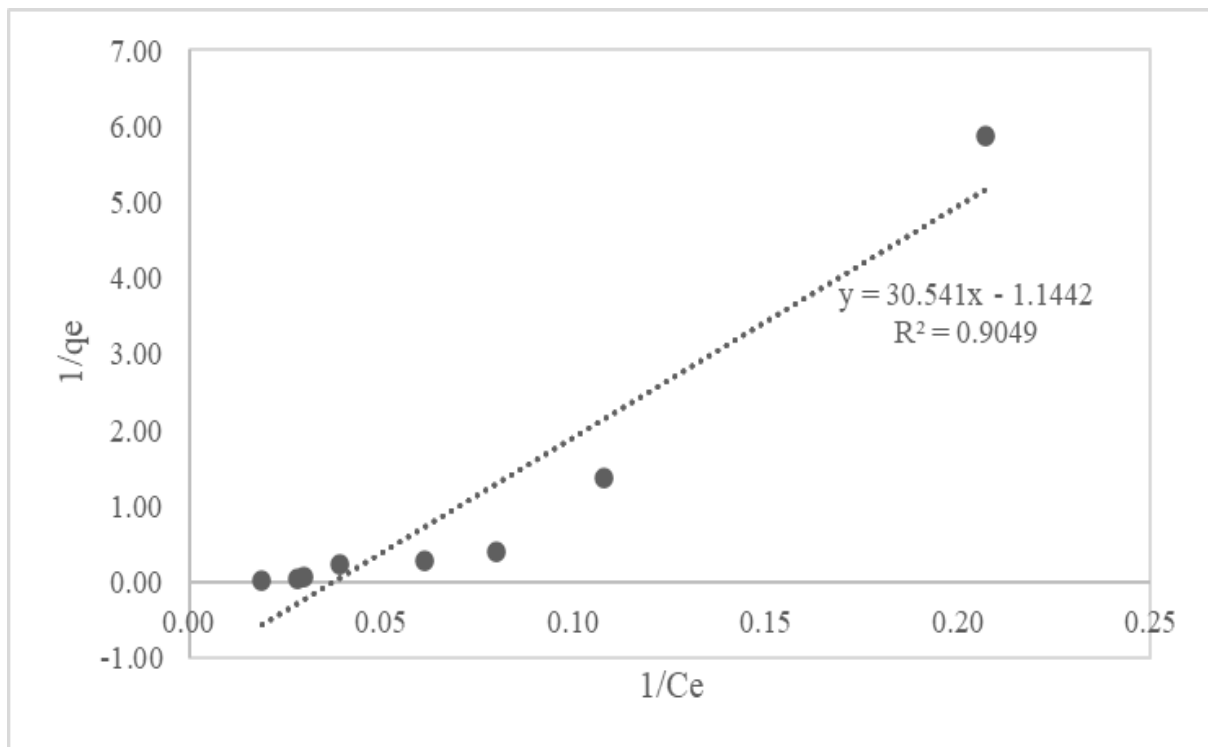


Figure 9. Langmuir isotherm model for TSCG

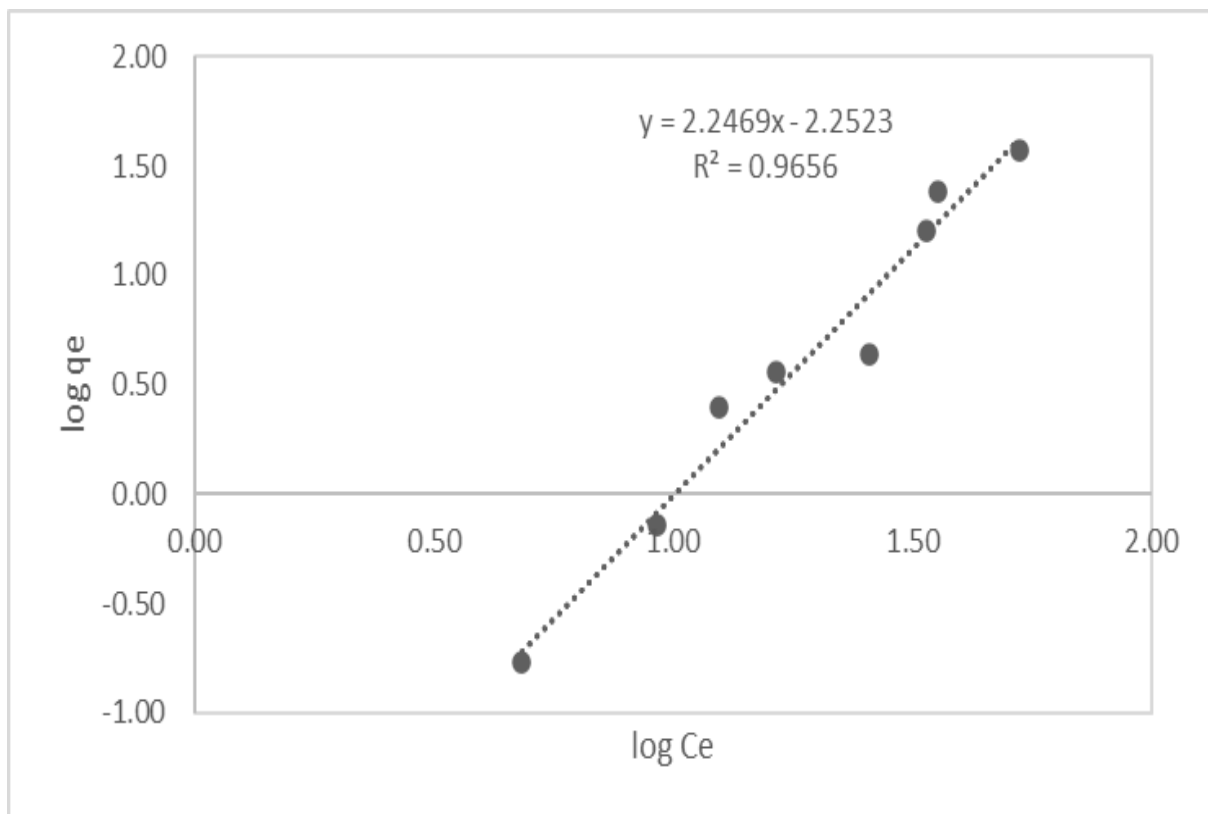


Figure 10. Freundlich isotherm model for TSCG

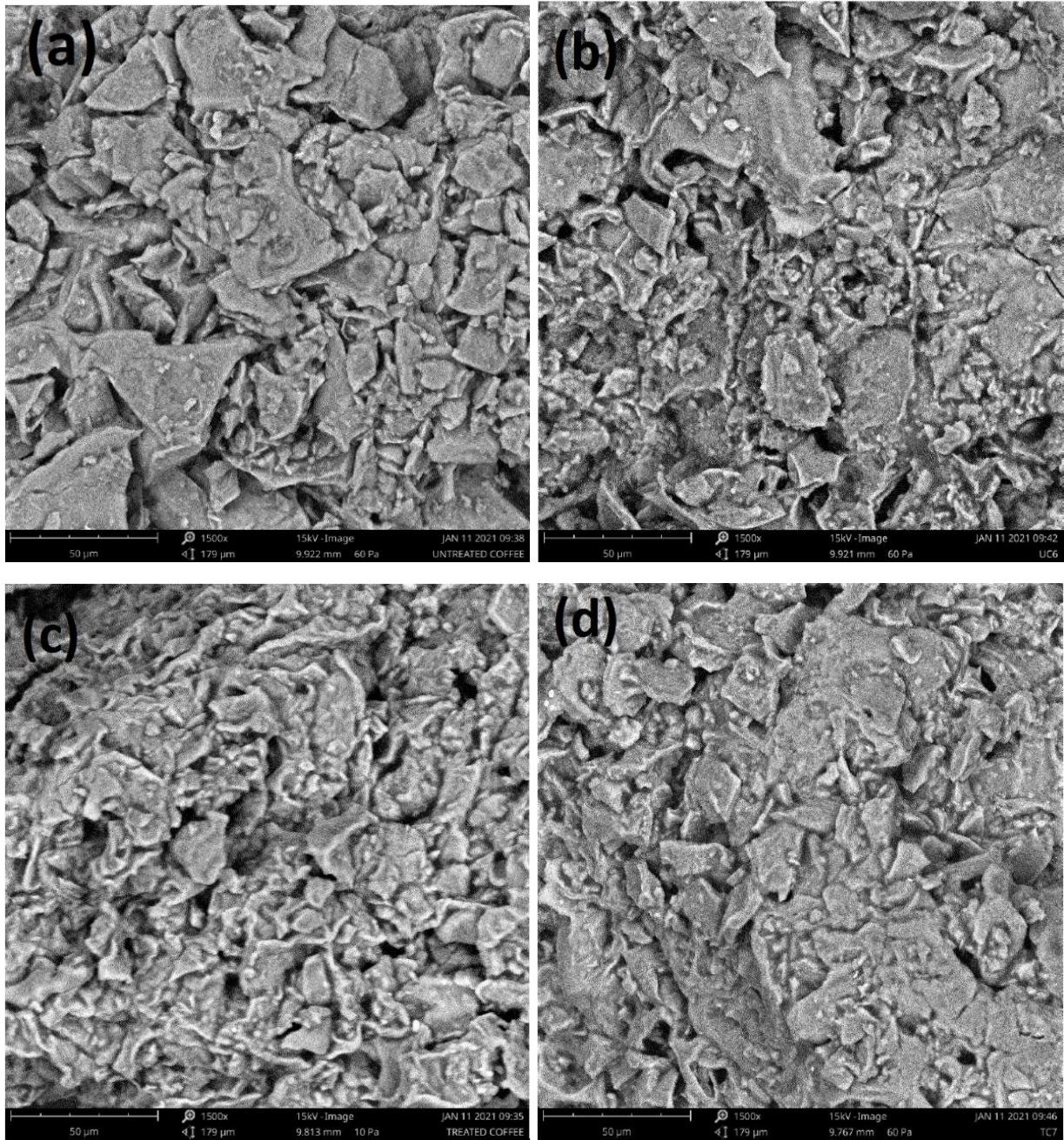
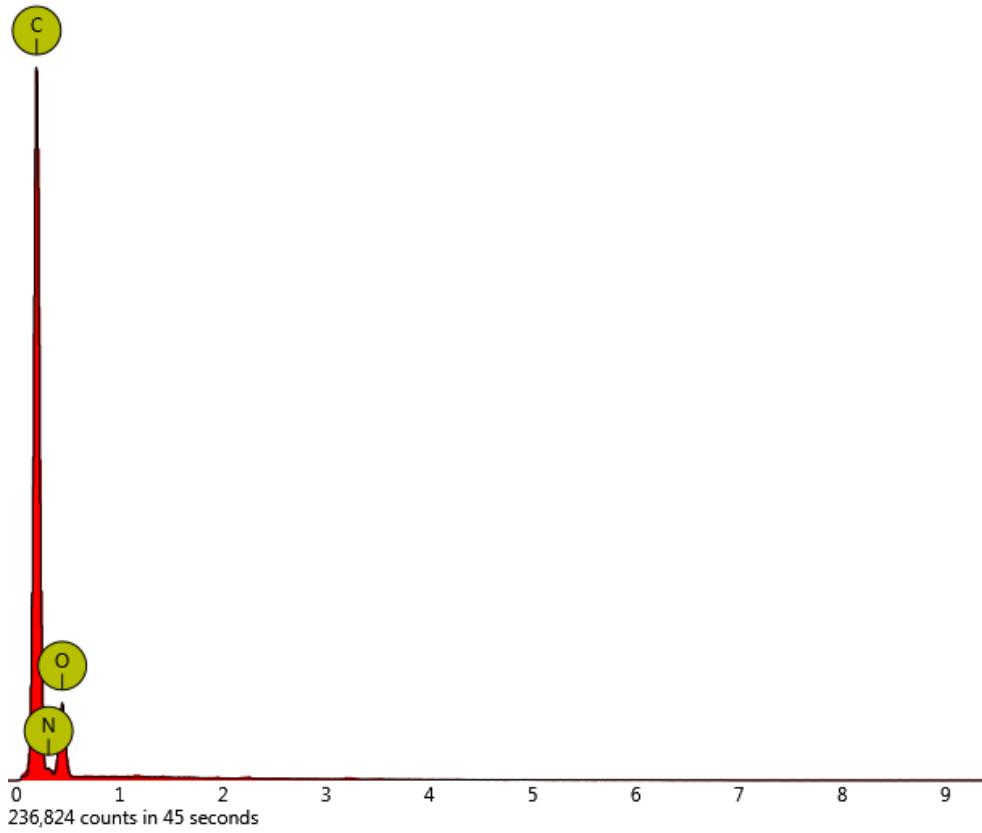
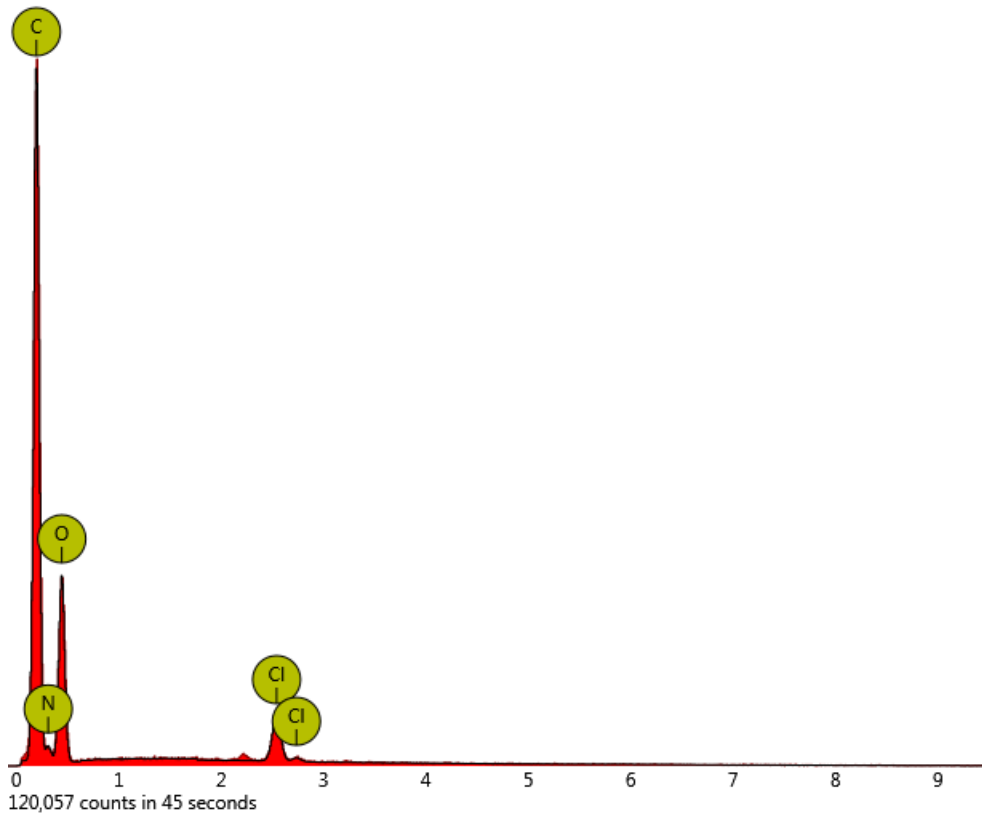


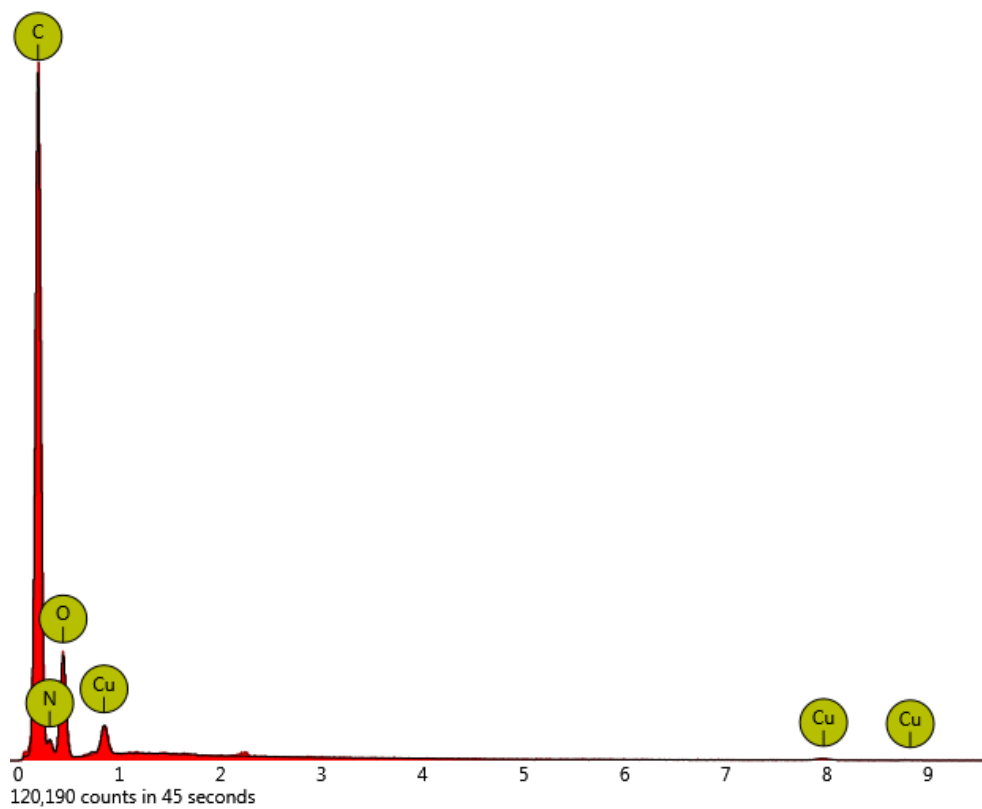
Figure 11. SEM images of a) USCG and b) TSCG before adsorption. The images of c) USCG and d) TSCG are after adsorption process



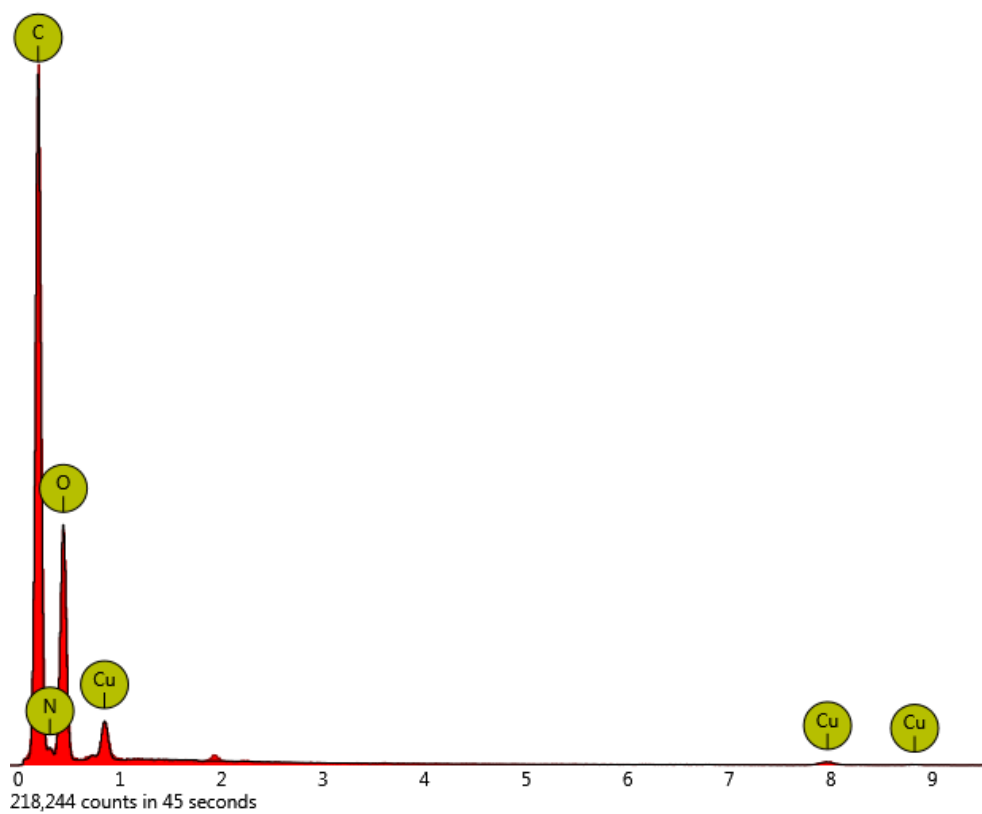
(a)



(b)



(c)



(d)

Figure 12. EDX Spectra line analysis of SCG adsorbent (a) raw USCG, (b) raw TSCG, (c) USCG after adsorption process and (d) TSCG after adsorption process

3.5. The Microstructure of Spent Coffee Ground before and after the Adsorption

SEM images in Figure 11 showed the surface morphology of USCG and TSCG before and after the adsorption process. The TSCG (Figure 11c) shows a more coarse, rougher and uneven surface compared to USCG (Figure 11a). The higher the surface roughness leads to higher surface area for better adsorption [25]. Both of the samples have a porous structure that allows Cu (II) adsorption onto the surface.

After the adsorption process, the pores were filled, suggesting the adsorption of Cu (II) onto the USCG (Figure 11b) and TSCG (Figure 11d) surfaces [31]. The adsorption of Cu (II) ions onto both adsorbent samples were identified by the elemental analysis EDX (Figures 12c and 12d). The main elements of the SCG are carbon, oxygen and nitrogen (Figure 12a). Cl⁻ element was detected on the raw TSCG (Figure 12b), which may be due to the incomplete washing after the acid treatment of SCG using hydrochloric acid. However, the chlorine was not detected after the adsorption process, which could either be dissolved in the aqueous solution during the adsorption process or remained in the pores (Figure 12d).

4. Conclusions

The performance of the two types of SCG, USCG and TSCG on Cu (II) removal have been investigated in this study as potential low adsorbent materials. The USCG showed better performance as an adsorbent than TSCG. The highest removal efficiency of Cu (II) for USCG was achieved at pH 6 at 90 min of contact time with removal efficiency and adsorption capacity of 91.03% and 45.52 mg/g, respectively. The removal efficiency for TSCG is lower than USCG. This might be closely related to the flushed off of the SCG functional groups that used metal binding in adsorption during the acid treatment and the interference of Cl⁻ ion on the adsorbent surface. The equilibrium data fitted best using Freundlich model with R² coefficients equal to 0.9912 and 0.9622 for USCG and TSCG, respectively. The ability of USCG to remove the Cu (II) ions from an aqueous solution showed that it is feasible to be commercialised as a natural adsorbent and an alternative to activated carbon for wastewater treatment.

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