Comparative studies on the removal of copper (II) by *Ulva fasciata* activated carbon and commercially activated carbon

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In this work, the efficiency of *Ulva fasciata* sp. activated carbons (CCUC, SCUC and SSUC) and commercially activated carbon (CAC) were studied for the removal of Cu (II) ions from synthetic wastewater. Batch adsorption experiments were carried out as a function of pH, contact time, initial copper concentration and adsorbent dose. The percentage adsorption of copper by CCUC, SSUC, SCUC and CAC are 88.47%, 97.53%, 95.78% and 77.42% respectively. Adsorption data were fitted with the Langmuir, Freundlich and Temkin models. Two kinetic models pseudo first order and the pseudo second order were selected to interpret the adsorption data.

INTRODUCTION

Water pollution is one of the most debatable as almost all inorganic or organic wastes are discharged through the aquatic route either in water soluble or insoluble forms[1]. Among the wastes, mobile and soluble heavy metal species are not biodegradable and tend to accumulate in living organisms, causing various diseases and disorders. Heavy metal contamination exists in aqueous waste streams of many industries such as metal plating facilities, mining operations, and tanneries[2]. Copper, which is one of the most important heavy metals used in electroplating industries and it causes serious toxicological effects at high doses, after uptake it is known to deposit in brain, skin, liver, pancreas and myocardium[3]. For these reasons EPA (U.S.A) has regulated drinking water concentrations not to exceed 1.3 ppm for copper[4].

The removal and recovery of heavy metals from wastewater is important for environmental protection and human health. Several methods have been used to remove heavy metals in high concentrations from aqueous solutions, including precipitation, ion exchange, evaporation, electroplating, and membrane processes. These methods are, however, either inefficient or expensive when heavy metals are present at low concentrations[5]. It is therefore, necessary to find new technologies or materials for removing heavy metal ions from wastewater. Adsorption of heavy metals is one of the possible alternative technologies involved in the removal of toxic metals from industrial waste streams and natural waters using low-cost adsorbents. It is a potential and interesting alternative to conventional processes for the removal of metals, such as ion exchange processes[6,7]. It is a rapid, reversible, economical and ecofriendly technology in contrast to conventional chemical methods of removing metal ions from the industrial effluents. Adsorption of metal ions from the aquatic system using microbial biomass, including algae, fungi and bacteria has gained importance in recent years[8,9]. Among the biological materials marine algae otherwise known as seaweeds have been reported to have high metal binding capacities due to the presence of polysaccharides, proteins or lipid on the cell wall surface containing functional groups such as amino, hydroxyl, carboxyl and sulphate, which can act as binding sites for metals[10–12].

Activated carbon has undoubtedly been the most popular and widely used as adsorbent in wastewater treatment applications throughout the world. However, activated carbon remains an expensive material since the higher the quality of activated carbon, the greater its cost[13]. Therefore, searching for a low cost activated carbon and other adsorbent materials are of great importance for the wastewater treatment[14–16]. *Ulva fasciata* sp. algal cell walls are porous and allow the free passage of molecules and ions in aqueous solutions. The constituents of the cell wall provide an array of ligands with different functional groups capable of binding various heavy metals[17].

Hence, the present investigation aimed to remove copper from its aqueous solution using activated carbons prepared from a marine green algae *Ulva fasciata* sp. and commercially activated carbon as adsorbent materials for various parameters like pH of the solution, contact time, initial Cu (II) concentration and adsorbent concentration. The adsorption capacity of this adsorption process was estimated using Langmuir, Freundlich and Temkin isotherms. The kinetics of the adsorption process was investigated using Lagergren equations.

MATERIALS AND METHODS

Preparation of Activated Carbon Adsorbent

The green marine algae *Ulva fasciata* sp. in the present study were collected from the coastal area of Kanyakumari district, Tamil Nadu, India. The collected algae were washed with tap water and further by deionized water several times to remove impurities. The washing process was continued till the removal of all dirt. The washed algae were then completely dried in the sun light for seven days. Then the dried algae Ulva fasciata were pretreated with Calcium Chloride, Sodium Sulphate and Sodium Cabonate salts respectively. It is further carbonized as three types, known as Calcium Chloride treated Ulva fasciata Carbon (CCUC), Sodium Sulphate Treated Ulva fasciata Carbon (SSUC) and Sodium Carbonate treated Ulva fasciata Carbon (SCUC).

Calcium Chloride Treated Ulva fasciata Carbon (CCUC)

The dried algae *Ulva fasciata* to be carbonized is impregnated with the solution of chloride salts such as calcium chloride for 24 hours. Accordingly sufficient quantities were soaked well with 10% chloride solution of 5 liters capacity respectively so that the solution get well adsorbed for a period of 24 hours. At the end of 24 hours the excess solution were decanted off and air dried. Then the materials were placed in muffle furnace carbonized at 400ºC. The dried materials were powdered and activated in a muffle furnace kept at 800ºC for a period of 10 minutes. After activation, the carbon was washed sufficiently with 4N HCl to remove the cations. Then the materials were washed with plenty of water to remove excess acid, dried and powdered.

Sodium Sulphate Treated Ulva fasciata Carbon (SSUC)

In this method the dried algae *Ulva fasciata* to be carbonized were soaked in 10% solutions of sodium sulphate for a period of 24 hours. After impregnation, the liquid portion was decanted off and then dried. The dried mass was subjected to carbonization process at 400ºC powdered well and finally thermally activated at 800ºC for 10 minutes[18].

Sodium Carbonate Treated Ulva fasciata Carbon (SCUC)

In this method the dried algae *Ulva fasciata* to be carbonized were soaked with 10% sodium carbonate solution for a period of 24 hours. After impregnation, the liquid portion was decanted off and the material dried. The dried mass was subjected to carbonization process at 400ºC powdered well and finally thermally activated at 800ºC for a period of 10 minutes.

In the present study the powdered activated carbons (CCUC, SSUC and SCUC) of algae *Ulva fasciata* in the range of 150μm particle size and particle size of commercially activated carbon (CAC) in the range of 300 mesh were used as adsorbents. The Physico-Chemical properties of Ulva fasciata activated carbons and Commercially activated carbon are shown in Table-1

Preparation of metal ion solution

Stock solution of copper concentration 1000 mg/L was prepared by dissolving 3.93g of 100% $CuSO_4.5H_2O$

Table 1. Physico-Chemical properties of *Ulva fasciata* activated carbon adsorbents and commercially activated carbon adsorben

Properties	(CCUC)	(SSUC)	(SCUC)	(CAC)
pH	8.51	9.37	11.13	7.59
Moisture Content %	17.20	3.73	4.92	4.50
Ash Content %	12.71	22.40	17.35	06.77
Volatile Matter %	27.14	18.20	17.40	14.80
Fixed Carbon %	60.15	59.60	65.25	78.43
Matter Soluble in Water, %	2.03	0.98	1.28	3.06
Matter Soluble in Acid, %	4.50	1.65	3.70	5.43
Surface Area (m²/g)	17.11	58.23	41.52	543.45
Pore Volume(cm³/g)	0.15	0.38	0.22	0.51
Pore Size(A⁰)	304.7	558.4	398.5	96.08

(Merck) in 1000 ml of DD water. The solution was prepared using standard flasks. The range of concentration of the prepared metal solutions varied between 10 to 80 mg/L and they were prepared by diluting the copper stock solutions, which were obtained by dissolving in deionized water.

Batch Adsorption Studies

Batch adsorption equilibrium experiments were conducted for the adsorption of copper on activated carbons of green algae Ulva fasciata and commercially activated carbon as a function of initial pH, initial copper concentration, adsorbent dose and contact time by adding 0.2 g of dried carbon to 100 mL of copper solution with different concentrations in 250 mL stoppered reagent bottles at a constant shaking speed (250 rpm). All the experiments were carried out at room temperature (28 ± 2ºC). For studying the influence of pH on the adsorption of Cu (II), the experiments were conducted at various initial metal solution pH values of 1–10. The pH of each solution was adjusted to different values with either NaOH or HCl. The concentrations of copper metal ions in solution before and after adsorption were determined using atomic adsorption spectrophotometer by monitoring the absorbance for the metal ion used. All adsorption experiments were carried out in triplicates to check the reproducibility of the results. The equilibrium and kinetics data were obtained from batch experiments.

During the adsorption, a rapid equilibrium was established between the adsorbed metal ions on the active cites of adsorbent (q_e) and unadsorbed metal ion in the solution. The amount of adsorption at equilibrium (q_e) (mg/g) and the percentage adsorption (%) were computed as follows:

$$q_e = \frac{(C_0 - C_e)V}{X} \tag{1}$$

$$\text{Percentage adsorption (\%)} = \frac{(C_0 - C_e)}{C_0} \times 100 \tag{2}$$

Where C_0 and C_e are represented the initial and equilibrium concentrations (mg/l), V is the volume of solution and X the weight of adsorbent (g).

RESULTS AND DISCUSSION

Effect of pH

The pH of the aqueous solution is an important controlling parameter in the heavy metal adsorption process[19]. Therefore, the effect of hydrogen ion concentration was examined from solutions at different pH levels covering a range of 1.0–10.0 with 100 mL of Cu (II) concentration 20 mg/L containing 0.2g activated carbon. Fig. 1, shows that adsorption of Cu(II) increased at a steady rate as pH increased up to about 5, attaining a maximum value of around 85.81%, 95.78% and 93.16%, for activated carbons prepared from *Ulva fasciata* CCUC, SSUC, and SCUC respectively. The minimum adsorption observed at low pH may be due to the fact that the higher concentration and higher mobility of H⁺ ions present favoured the preferential adsorption of hydrogen ions compared to Cu (II) ions[20]. But the pH values from 6 to 10 lower adsorption percentage were observed for copper in activated carbons made from *Ulva fasciata*
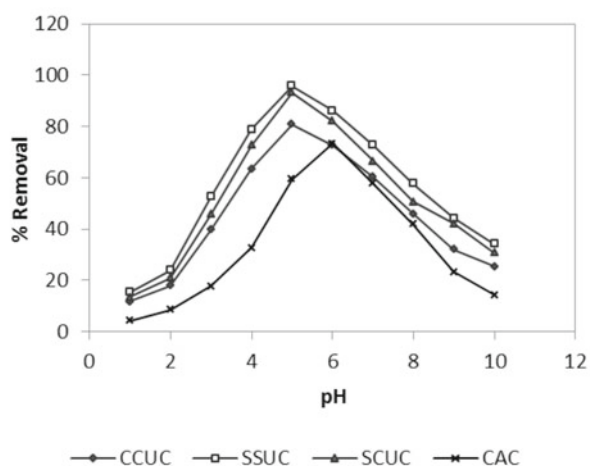
Figure 1. Effect of pH on the Cu (II) removal (initial Cu (II) concentration-20mg/L, adsorbent dose-0.2g/100 mL, contact time-2h)

(CCUC, SSUC, and SCUC), this could be due to the precipitation and lower polarity of copper (II) ions at higher pH values. At low pH values, the surface of the adsorbent would be surrounded by hydronium ions, which decreases the copper ion interaction with binding sites of CCUC, SSUC, and SCUC by greater repulsive forces. As the pH increased the overall surface on the *Ulva fasciata* activated carbons became negative and adsorption increased. In this study, copper (II) ions around pH 5 might be interacted more strongly with the negatively charged binding sites in *Ulva fasciata* activated carbons (CCUC, SSUC, and SCUC). It could be also observed from Fig.1, in the case of commercially activated carbon (CAC), the removal efficiency increased steadily with pH range up to 6 and attaining maximum value of 70.31%, after pH 6 adsorption was decreased. After pH > 6.0, Cu^{2+} ions were precipitated, due to hydroxide anions forming a Cu $(OH)_2$ [19].

Effect of contact time

The effect of the contact time on the adsorption efficiency of Cu (II) on activated carbons of *Ulva fasciata* and CAC is shown in Fig. 2. The experiments were carried out using 100 mL of Cu (II) concentration 20 mg/L containing
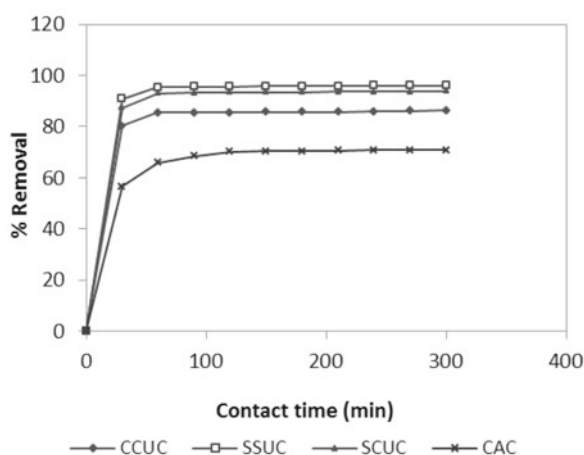
0.2g activated carbon at pH 5 for activated carbons of *Ulva fasciata* (CCUC, SCUC and SSUC) and pH 6 for CAC. A set of solutions containing these carbons were equilibrated for varying periods ranging from 30 to 300 minutes at an agitation speed 250 rpm. From the Fig. 2, it is shown that increase in contact time increased the removal efficiency until equilibrium adsorption was established. As shown in Fig. 2 the uptake of Cu (II) ions increased quickly, after 30 min the change became slow. The adsorption process of Cu (II) on activated carbons of green algae *Ulva fasciata* and CAC was speedy and in 60 min, the process of adsorption quickly reached equilibrium. After this equilibrium period, the amount of adsorbed Cu (II) ions not significantly changed with time. From the results, it has been observed that 1 hour time was sufficient for attaining the equilibrium for activated carbons of *Ulva fasciata*, the removal of 85.33% copper by CCUC, 95.40% copper by SSUC and 93.03% copper by SCUC. However 70.14% of copper was removed by CAC in a period of 2 hours.

Effect of Cu (II) initial concentration

The effect of the initial Cu (II) ion concentration on the adsorption efficiency of   Cu (II) at activated carbons of *Ulva fasciata* and CAC has been shown in Fig. 3. The experiments were carried out using 100 mL of Cu (II) concentrations ranging from 10 to 80 mg/L at pH 5 for CCUC, SSUC, SCUC and pH 6 for CAC. An amount of 0.2 g of adsorbent was used for each adsorption experiment. Fig. 3 shows that the removal of Cu (II) was depending on the initial concentration of metal ions which decrease with the increase of initial metal ions concentration. Though an increase in metal uptake was observed, the decrease in percentage adsorption may be attributed to the lack of sufficient surface area to accommodate much more metal available in the solution. The percentage adsorption at higher concentration levels shows a decreasing trend whereas the equilibrium uptake of copper displays an opposite trend. At lower concentrations, all the copper ions present in the solution could interact with the binding sites and thus the percentage adsorption was higher than those at higher copper ion concentrations. At higher concentrations, a lower adsorption yield is due to the saturation
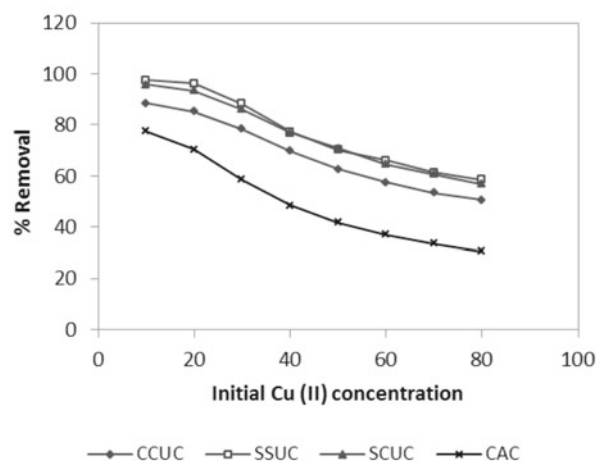

Figure 2. Effect of contact time on the Cu (II) removal (pH-5 for CCUC, SSUC, SCUC and 6-for CAC, initial Cu (II) concentration-20mg/L, adsorbent dose-0.2g/100 mL)

Figure 3. Effect of initial Cu(II) concentration on the Cu (II) removal (pH-5 for CCUC, SSUC, SCUC and pH-6 for CAC, adsorbent dose-0.2g/100 mL, contact time -2h)

of adsorption sites. The maximum removal of Cu (II) was achieved at 10 mg/L of copper solution on CCUC, SSUC, SCUC and CAC were 88.47%, 97.53%, 95.78% and 77.42% respectively.

Effect of adsorbent dose

The dependence of copper adsorption on the amount of algae was studied by varying the adsorbent amount from 0.05g to 0.4 g at pH 5.0 for CCUC, SCUC, SSUC and pH 6.0 for CAC. The experiments were carried out using 100 mL of Cu (II) concentration 20 mg/L, contact time (2h) and agitation speed (250rpm). The results are graphically shown in Fig 4. It is apparent that the percentage removal of copper increases with an increase in the dose of carbon due to the greater availability of the adsorbent. Generally it can be concluded that higher dosage of adsorbent increases the % adsorption. This is because more surfaces and binding sites for ions are available at a higher dose of adsorbents. It is known that a minimum carbon dosage of 0.15 g/100 mL was sufficient for the maximum removal of 85.23% copper
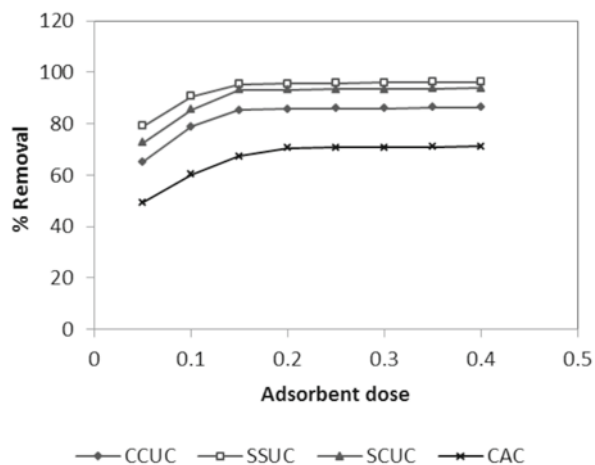

Figure 4. Effect of adsorbent dose on the Cu (II) removal (pH-5 for CCUC, SSUC, SCUC and pH-6 for CAC, contact time-2h, initial Cu (II) concentration-20mg/L)

by CCUC, 95.28% copper by SSUC and 93.13% copper by SCUC. But 0.20 g/100 mL of CAC required for maximum removal of 70.59% copper. The results show that SSUC was found to be a superior adsorbent than other activated carbons.

Adsorption Isotherms

The capacity of an adsorbent can be described by equilibrium adsorption isotherm. The isotherm represents the equilibrium relationship between the metal uptake by the adsorbent and the final metal concentration in the aqueous phase. Several isotherm equations are available, three important isotherms are chosen in this study, which are namely the Langmuir, Freundlich and Temkin isotherms.

Langmuir Isotherm

The Langmuir adsorption isotherm describes the surface as homogeneous assuming that all the adsorption sites have equal adsorbate affinity and that adsorption at one site does not affect adsorption at an adjacent site[21,22]. The Langmuir equation may be written as
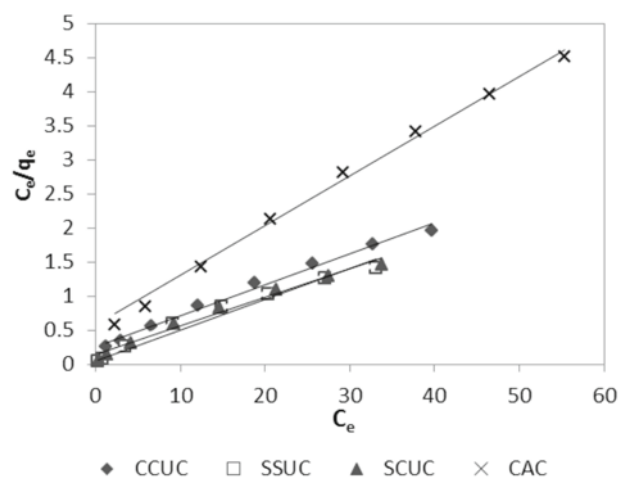

Figure 5. Langmuir isotherm for Cu (II) onto activated carbons (CCUC, SSUC and SCUC) from *Ulva fasciata* and CAC

$$q_e = \frac{Q_0 b C_e}{1 + b C_e} \quad \text{(nonlinear form)} \quad (3)$$

$$\frac{C_e}{q_e} = \frac{1}{Q_0 b} + \frac{C_e}{Q_0} \quad \text{(linear form)} \quad (4)$$

Where q_e is the amount of solute adsorbed per unit weight of adsorbent (mg/g), C_e the equilibrium concentration of solute in the bulk solution (mg/L), Q_0 the monolayer adsorption capacity (mg/g) and b is the constant related to the free adsorption energy.

Freundlich Isotherm

Freundlich isotherm was used to describe the adsorption pattern[23] describes the equilibrium on heterogeneous surfaces and does not assume monolayer capacity. The Freundlich equation is

$$\frac{X}{m} = K_F C_e^{\frac{1}{n}} \quad \text{(nonlinear form)} \quad (5)$$

$$\log \frac{X}{m} = \log K_F + \frac{1}{n} \log C_e \quad \text{(linear form)} \quad (6)$$

Where X is the amount of the solute adsorbed (mg), m is the mass of the adsorbent (g), C_e the equilibrium concentration of solute in the bulk solution (mg/L), K_F a constant indicative of the relative adsorption capacity
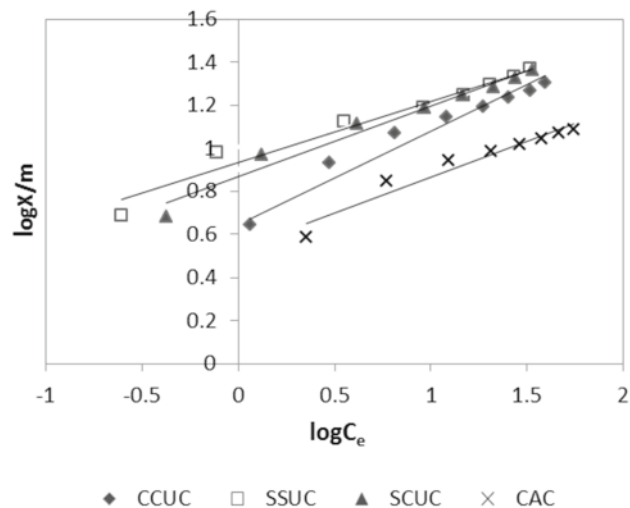

Figure 6. Freundlich isotherm of Cu (II) onto activated carbons (CCUC, SSUC and SCUC) from *Ulva fasciata* and CAC

Table 2. Langmuir, Freundlich and Temkin isotherms and their constants

Isotherms & constants		Adsorbents			
		CCUC	SSUC	SCUC	CAC
Langmuir	Q_0	22.221	23.640	23.860	13.774
	b	0.173	0.367	0.299	0.125
	R^2	0.989	0.978	0.988	0.994
Freundlich	K_F	1.905	1.328	2.379	1.704
	$\frac{1}{n}$	0.429	0.224	0.328	0.332
	R^2	0.953	0.960	0.971	0.944
Temkin	K_T	1.460	3.332	2.370	1.461
	B	4.250	3.434	3.922	2.495
	R^2	0.994	0.964	0.981	0.991

of the adsorbent (mg/g) and the constant $1/n$ indicates the intensity of the adsorption.

Temkin Isotherm

Temkin isotherm is given as

$$q_e = B \ln (K_T C_e) \quad \text{(nonlinear form)} \quad (7)$$

It can be expressed in the linear form as

$$q_e = B \ln K_T + B \ln C_e \quad \text{(linear form)} \quad (8)$$

Where $B = \dfrac{RT}{b}$, a plot of q_e versus hC_e enables the determination of the Isotherm constants B and K_T from the slope and the intercept, respectively. K_T is the equilibrium binding constant corresponding to the maximum binding energy and constant B is related to the heat of adsorption[24]. The sorption capacity for copper the metal increased with an increase in the metal concentration in solution. The experimental data were modeled according to Langmuir, Freundlich and Temkin isotherm, and the evaluated constants are given in Table 2.
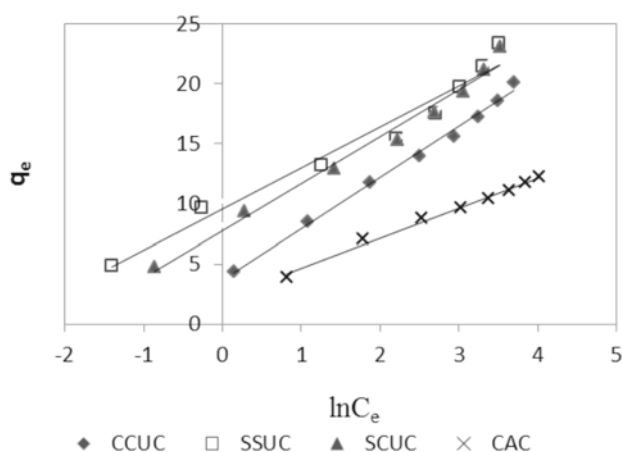

Figure 7. Temkin isotherm of Cu (II) onto activated carbons (CCUC, SSUC and SCUC) from *Ulva fasciata* and CAC

Kinetic Studies

In order to understand the adsorption kinetics of Copper (II) ions, two kinetic models, which are pseudo first order and pseudo second order, have been applied for the experimental data.

The pseudo-first order equation

Kinetic analysis is required to get an insight of the rate of adsorption and the rate limiting step of the transport mechanism, which are primarily used in the modeling, and design of the process. The pseudo-first order equation of Lagergren[25] is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (9)$$

Where, q_e and q_t are the sorption capacities at equilibrium and at time t, respectively (mg/g) and k_1 is the rate constant of pseudo-first order sorption, (1/min). After integration and applying boundary conditions, $q_t = 0$ to $q_t = q_t$ at $t = 0$ to $t = t$ the integrated form of equation (9) becomes:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \quad (10)$$

The pseudo first order rate constant k_1 can be obtained from the slope of plot between $\log(q_e - q_t)$ versus time (t). Fig. 8 shows the Lagergren pseudo-first order kinetic plot for the adsorption of copper onto activated carbons of green algae *Ulva fasciata* and CAC. The calculated k_1 values and their corresponding linear regression correlation coefficient values are shown in Table-3.

The pseudo second order equation

A pseudo-second-order model proposed by Ho and McKay[26] was then used to explain the sorption kinetics. The pseudo-second order chemisorption kinetic rate equation is expressed as:

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (11)$$

Table 3. Pseudo first order and pseudo second order constants and their correlation coefficients

Kinetics & constants		Adsorbents			
		CCUC	SSUC	SCUC	CAC
Pseudo first order	K_1	0.0092	0.0142	0.0140	0.0191
	q_e	1.612	1.700	1.794	1.119
	R^2	0.731	0.843	0.832	0.963
Pseudo second order	K_2	0.0658	0.0382	0.0772	0.0232
	q_e	8.665	9.775	9.416	7.246
	R^2	1.000	0.999	1.000	0.999

Figure 8. Pseudo first order kinetics of Cu (II) onto activated carbons (CCUC, SSUC, SCUC) from *Ulva fasciata* and CAC
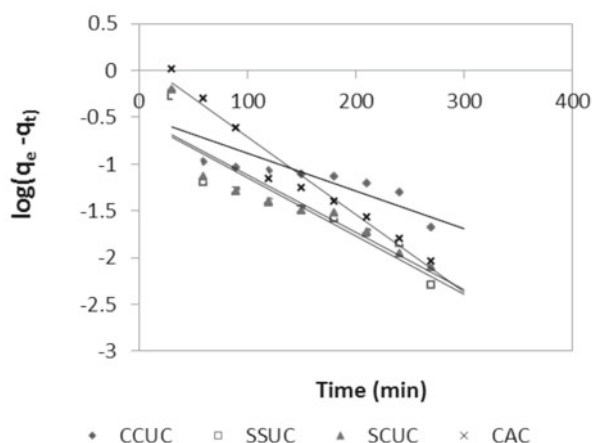

Figure 9. Pseudo second order kinetics of Cu (II) onto activated (CCUC, SSUC and SCUC) carbons from *Ulva fasciata* and CAC

Where q_e and q_t are the sorption capacity at equilibrium and at time t, respectively (mg/g) and k_2 is the rate constant of pseudo-second order sorption, (g/mg min) for the boundary conditions $q_t = 0$ to $q_t = q_t$ at $t = 0$ to $t = t$; the integrated form of equation (11) becomes:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \qquad (12)$$

Where t, is the contact time (min), q_e (mg/g) and q_t (mg/g) are the amount of the solute adsorbed at equilibrium and at any time, t. If the pseudo-second order kinetics is applicable, the plot of t/q_t against t of equation (12) should give a linear relationship, from which q_t and k_2 can be determined from the slope and intercept of the plot (Figure-9).

The pseudo-second order rate constant k_2, the calculated q_e value and the corresponding linear regression correlation coefficient value R^2 are given in Table.3. At all initial copper concentrations, the linear regression correlation coefficient R^2 values confirm that the adsorption data are well represented by the pseudo-second order kinetics and supports the assumption behind the model that the adsorption is due to chemisorptions.

Kinetics only deals with the motion of the solute and dynamics deals with the reason why they move, this is the main difference between kinetics and dynamics study. An adsorption kinetics describes the solute adsorption rate, which also provides valuable information about the mechanism of adsorption and subsequently investigation of the controlling mechanism of the adsorption process. While dynamics focuses on the force and their effects, an adsorption isotherm is a graphical representation showing the relationship between the amounts adsorbed by a unit weight of adsorbent and the amount of adsorbate remaining in a test medium at equilibrium.

While comparing the percentage removal and adsorption capacity of activated carbons made from Ulva fasciata (CCUC, SCUC and SSUC) with commercially activated carbon (CAC), the activated carbons of Ulva fasciata are superior adsorbents than the commercially activated carbon. This is due to the negatively charged binding sites in Ulva fasciata activated carbons, which are found more than that of the activated carbon.This could be seen from table-4.
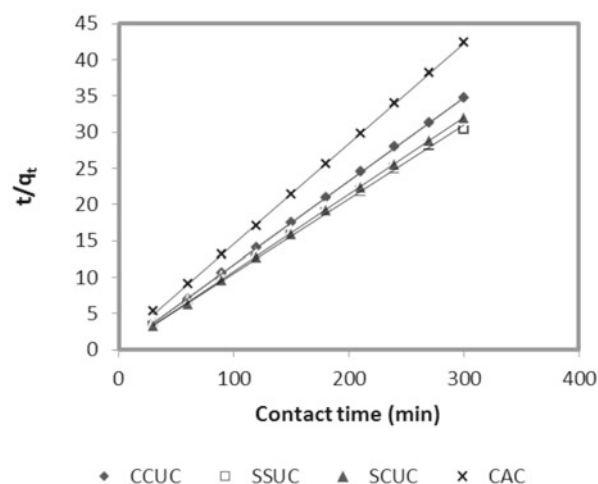
Table 4. Comparison between activated carbon made from *Ulva fasciata* with the commercially activated carbon on adsorption of copper (II) ions

Parameters	CCUC	SSUC	SCUC	CAC
Maximum % removal	88.47	97.53	95.78	77.42
Optimum pH	5	5	5	6
Optimum time	1h	1h	1h	2h
Adsorbent dose	0.15g	0.15g	0.15g	0.2g
Adsorption capacity	22.22	23.64	23.86	13.77

CONCLUSIONS

In the present study, the activated carbons (CCUC, SSUC and SCUC) prepared from marine green algae Ulva fasciata and commercially activated carbon (CAC) were used as adsorbents for removing Cu(II) ions from aqueous solution. The batch study parameters, pH of solution, contact time, initial Cu (II) concentration and adsorbent dose were found to be effective on the adsorption efficiency of Cu(II). The kinetic studies revealed that the adsorption of copper shows that the pseudo-second order model provides better correlation of adsorption data than the pseudo-first-order model. The Langmuir and Temkin isotherm models were fitted well than Freundlich isotherm.

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Table 5. Comparison between the adsorption of Cu (II) for present study and other adsorbents found in the literature

Adsorbent	Operation conditions			q_{max} (mg/g)	Ref
	pH	C_0 (mg/L)	X (g/L)		
Chlorella vulgaris	4.5	100	1	40	[27]
Scenedesmus obliquus	4.5	100	1	20	[27]
Synechocystis sp.	4.5	100	1	23.4	[27]
Chlorella fusca	6	6.3	n.a	3.2	[28]
Chlorella vulgaris	5	5	1	1.8	[29]
Scenedosmus quadricauda	4	5	1	2.8	[29]
Saccharomyces cerevisiae	5	100	0.1	1.25	[30]
O. Limnetica	4-5	1000	1	23.96	[31]
A. Spiroides	4-5	1000	1	0.2	[31]
E. Elegans	4-5	1000	1	1.08	[31]
C. Vulgaris	4.5	1000	1	9.47	[31]
Manihot esculenta Cranz	5	500	2.5	71.3	[32]
Thuja orientalis	7.7	50	4	19.23	[33]
Ecklonia radiate ($CaCl_2$-pretreated)	5	n.a	2	1.11	[34]
Durvillaea potatorum ($CaCl_2$-pretreated)	5	n.a	2	1.30	[34]
Ulva facsiata activated carbon ($CaCl_2$-pretreated)	5	100	0.2	22.22	This study
Ulva facsiata activated carbon ($NaSO_4$-pretreated)	5	100	0.2	22.17	This study
Ulva facsiata activated carbon ($NaCO_3$-pretreated)	5	100	0.2	23.17	This study
Commercially activated carbon	6	100	0.2	13.77	This study

n.a : not available

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