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Efficiency of Plant Based Activated Carbon in the Removal of Boron Ion from Aqueous Media: Kinetics and Equilibrium Studies

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ABSTRACT

The Present work explores the batch adsorption experiments to investigate the suitability of prepared nitric acid activated carbons (Mixed) derived from *Tamarindus Indica* Stem, *Ocimum Sanctum* bio mass carbon in removing Boron metal ion Derived carbon material was investigated using different techniques such as FTIR for functional group analysis, SEM (for determining the nature of carbons surface), EDX (to identifying the chemical composition before & after adsorption process and XRD analysis carried out for identification of crystalline nature. Batch experiments were performed to test effects of adsorbent dosage (0.5 to 10 g/L), contact time (5-80 minutes), initial Boron concentration (2-100 mg/L), adsorbate solution pH (4-12) and particle size (75 microns) on metal adsorption process Pore structure and size evaluated by N_2 adsorption at 77 K, surface area calculated by BET isotherm study. Boron adsorption capacity data were obtained by using Langmuir and Freundlich isotherm models and based on correlation coefficient value (0.99), it was identified that Langmuir isotherm fitted well. The pseudo-first-order, pseudo-second-order and the intraparticle diffusion models were used to describe the kinetic parameters and the rate constants were evaluated. The satisfactory adsorption percentage of Boron ions (82.5%) from 50 mg/L solution obtained at $30 \pm 1°C$ with 5g/L of dose, 40-45 minutes agitation time and in alkaline pH condition.

KEY WORDS: 50% + 50% of mixed Activated carbons, *Tamarindus Indica* wood Carbon, *Ocimum Sanctum* bio mass carbon, Bath adsorption, Boron Removal, Isotherm and Kinetic study

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INTRODUCTION

Activated carbon (AC) is a sort of carbonaceous materials. It normally varies from natural carbon by the oxidation of carbon atoms that are available on the inner and outer surfaces[1]. As of late, these materials have turned into a vital research area because of their excellent properties. This includes their large specific areas, non-toxicity, high porosity, and the capacity of their tunable surface to contain diverse functional groups. As indicated by these properties, AC composes have been broadly utilized as adsorbent materials for an extensive variety of applications[2–4]. The utilization of agricultural by-products for removal of heavy metals from solutions is gaining much attention these days. The toxic nature of heavy metals necessitates the design and synthesis of novel adsorbents for their effective removal from the environment. Selective adsorption has become important in recognition, sensing, and separation of molecules and ions. An adsorbent with a high adsorption capacity and a good selectivity is very critical in adsorptive separation.

The synthesis and characterization of activated carbons (ACs) acquired from lignocellulosic precursors is a subject broadly examined by various researchers around the world. In the most recent decades, an increase has been seen in the quantity of publications identified with the synthesis, modifications, characterization and application of ACs synthesized from lignocellulosic materials. Especially, the applications of these carbons are principally engaged in the adsorption/removal of a few inorganic and natural pollutants from water and wastewaters. The world's activated carbon creation and utilization in the year 2000 was evaluated to be 4 x 108 kg [5]. By 2005, it had multiplied[6] with a creation yield of 40% In the business, activated carbon is set up by methods for oxidative pyrolysis beginning off delicate and hardwoods, peat, lignite, mineral carbon, bones, coconut shell, and agricultural waste materials, byproducts of agricultural materials[5]. There are two sorts of carbon activation procedures: Physical and Chemical activation comprises of impregnating the lignocellulosic or carbonaceous crude materials with chemicals, for example, $ZnCl_2$, H_3PO_4, HNO_3, H_2SO_4, NaOH, or KOH[7].

Boron is an essential element for normal growth of plants and animals, however, excessive amounts of boron are harmful Furthermore there is little difference between boron deficiency and its toxicity levels. High boron concentrations can be found in wastewater from some industries including semiconductor, ceramic, borosilicate glass and detergent manufacturers[8]. Excessive consumption of boron will cause the lethal if it is more than the dosage of 640 mg per kg body weight[9].

Numerous investigations has been done for boron removal from water and wastewater by different methods such as coagulation, co-precipitation, adsorption, ion exchange using cation

exchangers, selective ion exchange resins, solvent extraction, and membrane operations In water treatment different adsorbents were employed, such as activated carbon, fly ash, resins, metal oxides, clay minerals and composite magnetic particles[10].

Equilibrium adsorption studies conducted in laboratory model systems have provided the basis for the understanding of the surface chemistry of minerals. In this study, activated carbons were prepared from *Tamarindus Indica* Stem (wood) (TIC) and *Ocimum Sanctum* bio mass carbon (OSC), activated with nitric acid, suitable for removing heavy metal ion boron from aqueous media. The present study also focused on preparation and characterization of mixed carbons by using advanced techniques including Scanning Electron Microscope (SEM)-Energy dispersive spectroscopy (EDX), Fourier Transform Infrared (FTIR) Spectroscopy and XRD technique Low temperature nitrogen adsorption isotherms were used to estimate the BET surface area and pore size. Equilibrium and kinetic models were used to estimate the sorption potential and the rate of reaction respectively. The overall goal of this research was to characterize TIC+OSC (50%+50%) combined adsorbent sample in order to establish an economical and environmental friendly method for the removal and pre-concentration of Boron from aqueous matrices. The potential benefit of this study is to provide a certain theoretical basis for operational design and applicable practice of the sorption systems of boron metal removal, which has drawn increasing attention in the area of water environmental protection.

EXPERIMENTAL

All chemicals used were of analytical grade and obtained from Merck/SD Fine chemical Ltd India.

Apparatus

Atomic absorption spectrophotometer (AA220 Model, VARIAN Co, USA) and a pH meter (420A Model, ORION Co, USA) were used for measuring the concentration of Boron ions and pH of solutions respectively.

Adsorbent Preparation

The adsorbent for the removal of iron from ground water samples was prepared from the wood of *Tamarindus Indica* Stem wood. The wood (60cmx 25cm) was collected and dried naturally. It was then cut into small pieces and strongly heated in open air, cooled and then pulverized using a ball mill and sieved using a standard sieves to obtain the adsorbent of 75□□particle size (Figure 1). This carbons sample is indicated as (TIC) in further discussion In the same way 500g of dried bio mass (except root part) of *Ocimum Sanctum* collected from agricultural field carbonized as in *Tamarindus* Carbon preparation (Figure 1). This carbons sample is indicated as (OSC) in further discussion 5g of

each carbon (separately) was stirred with 0.5 M HNO_3 solution for 30 min at 200 rpm at $100^{o}C$ on magnetic stirrer for 2 hours (Remi Made). The acid treated carbon was filtered, washed with 1% $NaHCO_3$ and washed with hot double distilled water for several times. Later, the suspension was decanted, washed with distilled water until filtrate get 7 pH and then kept in an oven at $110°C$ up to 6 h for complete drying Obtained carbon samples are mixed in equal weights (50:50) used as adsorbent material in the Present adsorption study for the removal of Boron ion from aqueous media.

*TamarindusIndica*Stem Carbon (TIC)   +   *Ocimum Sanctum* bio mass carbon (OSC)

Figure 1:Pictorial representation of the process involved in the derivation of activated carbon

ADSORBENT CHARACTERIZATION

Determination of surface area by BET method

BET-N_2 adsorption experiments were carried out manometrically using an Autosorb (Quantachrome Crop). All samples were degassed overnight at $200^{o}C$, prior to the adsorption experiments. The BET-N_2 surface area, pore volume (micro/meso) and pore size (micro/meso) before and after adsorption of boron was obtained by applying the BET equation to the adsorption data and results were given in table 1.

FTIR analysis

The adsorbents are examined using Fourier Transform Infrared spectroscopy (FTIR). The sample discs were prepared by mixing of 1 mg of powdered carbon with 500 mg of KBr (Merck; for spectroscopy) in an agate mortar, then pressing the resulting mixture successively under a pressure of 5 tones/cm^2 for about 5 minutes, and at 10 tones/cm^2 for 5 min, under vacuum The spectra were measured from 4000 to 400 cm^{-1} on a JASCO-FTIR-5300 model.

Scanning electron microscopy (SEM)& EDX analysis

The scanning electron microscope (SEM) is one of the most versatile instruments available for the examination and analysis of the microstructure morphology and chemical composition characterizations. The microphotograph and EDX analysis of AC sample before and after adsorption was recorded using SEM JEOL model, JSM-5600 equipped with EDX Analyzer, an accelerating voltage of 5 kV, at high vacuum mode. The maximum magnification possible in the equipment is 3,00,000 times with a resolution of 3 nm, typically setting at various magnifications for all the samples of study.

Adsorbate Solution

The boric acid solutions used in this study were obtained synthetically in the lab using deionized water and boric acid (AR Quality 998%, Merck) Standard boron stock solution in concentration of 1000 mg/l was prepared by dissolving 5.716 g of boric acid in 800 ml deionised water and diluting the sample to 1000 ml. Then, samples of 100 ml in 250 ml beaker were prepared by diluting the stock solution to various concentrations of boric acid solutions in order to be used for the experiments.

Batch adsorption Process for the removal of Boron ion

50 ml of standard Boron ion solution (50 mg/L) was pipette out into a 500 ml beaker. To it, mixed amount of 100mg(50mg of TIC + 50mg of OSC) of the prepared active carbon was added and stirred at 200 rpm mechanically for 30minutes. Then, solution was filtered through Whatman No- 42 filter paper The Boron ion concentration in the sample after adsorption was determined using AAS The same procedure has been adopted for the experiments carried out by varying parameters viz (i) initial pH of the standard Boron ion solution (ranging from pH 4 to pH 12)   (ii) agitation time (ranging from 5-80 min), and (iii) initial concentration of the standard Boron solution (ranging from 2to 100 mg/L).

The percentage removal of Boron ionand amount adsorbed (in mg/g) were calculated using the following relationships:

$$\text{Percentage removal } (\%R) = \frac{C_i - C_e}{C_i} \times 100 \qquad \text{Eq1}$$

$$\text{Amount adsorbed } (q_e) = \frac{(C_i - C_e)}{m} \qquad \text{Eq2}$$

Where C_i and C_e are the initial and final concentrations (in mg/L) of Boron ion respectively and m is the mass of carbon (in mg/L). The average values of duplicate runs were obtained and

analyzed Error in data was found to be: ±0.5– 1 % for percentage removal, ± 0.002–0.02 mg/g for amount adsorbed.

RESULTS AND DISCUSSION

According to the BET method, the specific surface area and total pore volume was obtained as 796.62 $m^2 \cdot g^{-1}$ and 0.42 $cm^3 \cdot g^{-1}$ After adsorption process surface area and pore volume were slightly decreases to 672.01 $m^2 \cdot g^{-1}$ and 0.40 $cm^3 \cdot g^{-1}$This trend clearly explaining that, after adsorption process carbon material lost their available surface area and expecting Boron ions occupied on the surface of the AC and it was very good evidence to know the adsorption process is happened or not The results show that adsorption process may reduce the pore volume of the AC also This is because incorporation of the foreign material in the pores of various carbons atoms.

Table 1: The specific surface area and pore structure parameters of TIC+OSC sample

TIC+OSC Sample	S_{BET} (m^2/g)	S_{mic} (m^2/g)	S_{meso} (m^2/g)	V_{tot}(cm^3 /g)	V_{mic}(cm^3 /g)	V_{meso} (cm^3 /g)
Before adsoprtion	796.62	122.13	674.49	0.42	0.3	0.12
(After Adsorption)	672.01	120.35	564.024	0.40	0.032	0.0604

*S_{BET} : BET specific surface area; , S_{Micro} : micropore specific surface; , S_{Meso}mesopore specific surface; V_t: total pore volume; V_{micro}: micropore volume; and , V_{meso} : mesopore volume

FT IR Spectral analysis

The FT IR spectra of TIC+OSC sample before and after are depicted in Figure 2. The bands obtained between 3350-3200 cm^{-1} representing stretching vibration of O-H in hydroxyl groups of polymeric compounds, such as alcohols, phenols and carboxylic acids, as in pectin, cellulose groups on the adsorbent surface. The oxygen functional groups on the surface of AC greatly enhance its hydrophilic properties and also act as binding sites for the organic pollutant molecules[11]. The characteristic band around 2900 cm^{-1} assigned to C-H stretching indicate the methyl and methylene groups and the peak observed at 1640 cm^{-1} is due to C=C stretching that can be attributed to the aromatic C–C bond, C–N and C–O– (1118 cm^{-1}). In addition, bands at 1422cm^{-1} is indicative of aromatic compounds (C-C) stretching in the aromatic ring. Bands at 1332 cm^{-1} and 1331 cm^{-1} attributed to N-O and C-O stretching vibration respectively. Other important absorption bands at 1021cm^{-1} represent C-O stretching and 1120 cm^{-1} associated to the C-O stretching of the aryl group in lignin. It can be suggested from the spectrum that the main oxygen groups present in the raw AC are carbonyl, ethers and alcohols group which are normally present in plant cellulose [12]. Hao et al [13] had reported that the changes in some peaks of silkworm were seemed to be fact that –OH participate

in the adsorption process. Adsorption of the metal ion was considered to take place mainly by dispersion forces between electrons in the metal ions and electrons in the adsorbent carbon surface The adsorption of boron metal ion on prepared AC may be mainly due to dispersion forces and polarization of pi electrons (electron-rich portion of the adsorbate).
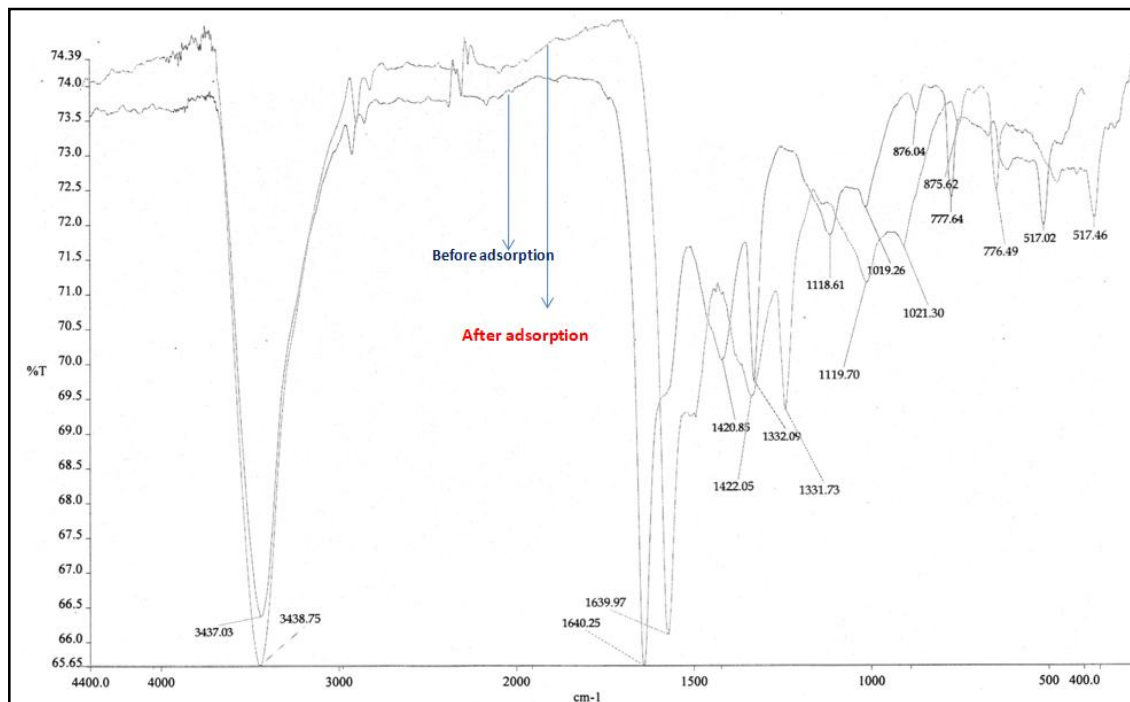

Figure 2: FT IR Spectra of carbon adsorbent sample before and after adsorption process

The slight reduction of stretching vibration bands clearly indicates the adsorption of metal ion on the adsorbent by physical forces[14]. From the above discussions, it assumed that the presence of functional groups such as -OH, carbonyl groups, nitro groups on the carbon surface could be the potential adsorption sites for interaction with the Boron ions[15.]

SEM-EDX analysis

The SEM image has been studied for information about the surface features such as pore characteristics, shape and size of the particles making up the surface of carbons, the elements that the activated carbon is composed of and the relative amounts of these and how the atoms are arranged in the activated carbon sample. The SEM micrograph of TIC+OSC is shown in Figure 8 along with EDX graphs. The SEM image of carbon adsorbent before adsorption illustrates the irregular size and shape of individual grains and heterogeneous surface morphology The porous structure is appearing with different widths.

The SEM images (Figure 3) of the adsorbent and the Boron ion loaded adsorbent indicated the presence of coverage of Boron ions (confirmed by EDX analysis) over the adsorbent material The

examination of the SEM micrographs of the magnification micro pores was clearly identifiable EDX data was presented Figure 3. On comparing the spectrum of samples taken and after adsorption process, a small peak pertains to Boron could be noted with the sample after adsorption process. The EDX elemental analysis highlighted the presence of carbon and oxygen ions in untreated and Boron ion treated samples. The intensity of the Boron signals was higher in samples treated with Boron and was below the limit of detection on the untreated samples.
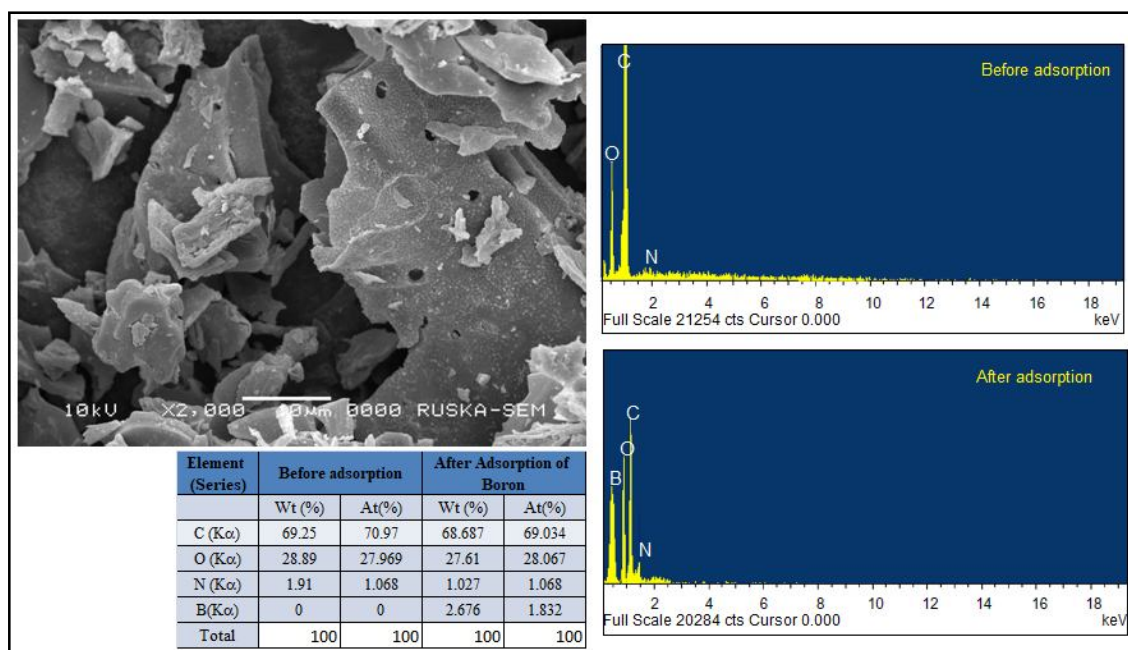

Element (Series)	Before adsorption		After Adsorption of Boron	
	Wt (%)	At(%)	Wt (%)	At(%)
C (Kα)	69.25	70.97	68.687	69.034
O (Kα)	28.89	27.969	27.61	28.067
N (Kα)	1.91	1.068	1.027	1.068
B(Kα)	0	0	2.676	1.832
Total	100	100	100	100

Figure 3: The SEM-EDX spectra of before and after adsorption onto AC (TIC+OSC) sample

XRD analysis

The intense main peak shows the presence of highly organized crystalline structure of raw activated carbon [14]. The XRD pattern of the prepared adsorbent sample showed (Figure 4) that defined and considerably sharp peaks at 22.6^o, 28.4^o and 29.6^o were attributed to the presence of carbon and graphite.[16] After the adsorption of metal ion, the intensity of the highly organized peaks is slightly diminished This has attributed to the adsorption of metal ion on the upper layer of the crystalline structure of the carbon surface by means of physisorption (Figure not shown here) .
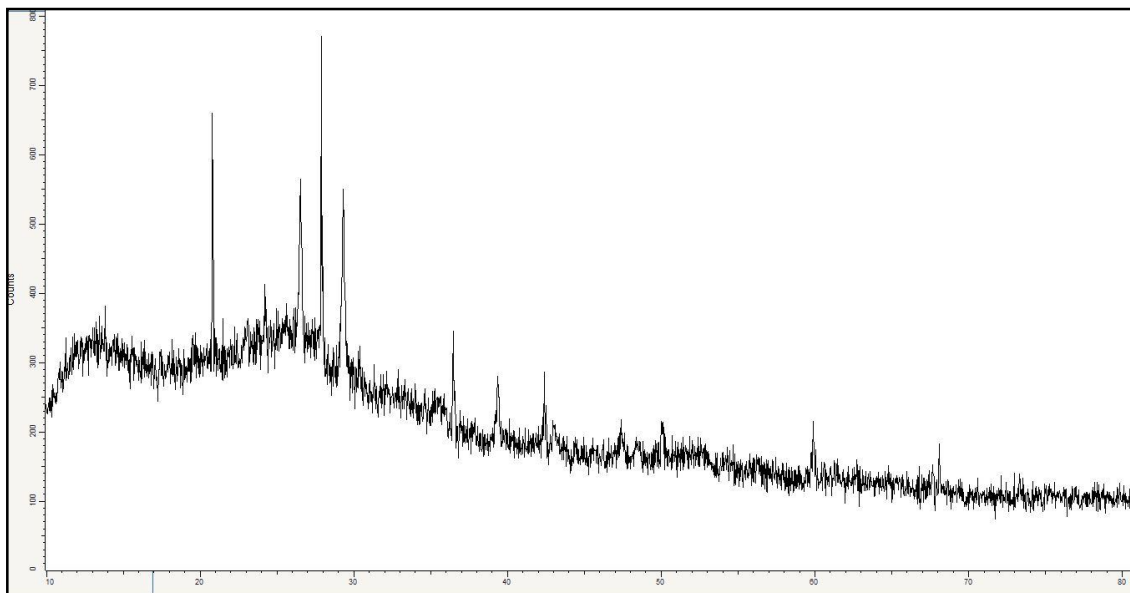
Figure 4: XRD spectra of AC (TIC+OSC) sample (Before adsorption)

The effect of solution initial pH on adsorption percentage

The solution initial pH is the major parameter controlling sorption processes. Boron uptake as a function of hydrogen ion concentration (pH) was determined for pH values from 4 to 12 pH effects at equilibrium are presented in figure 5As seen in figure 5, Boron sorption on to AC sample is increased from pH=4 to9 and later decreases from 9 to 12.The satisfactory Boron sorption occurred at higher pH values (pH8to9). In general, results indicated that the adsorption is highly pH dependant. Similar results have been reported in literature[11].
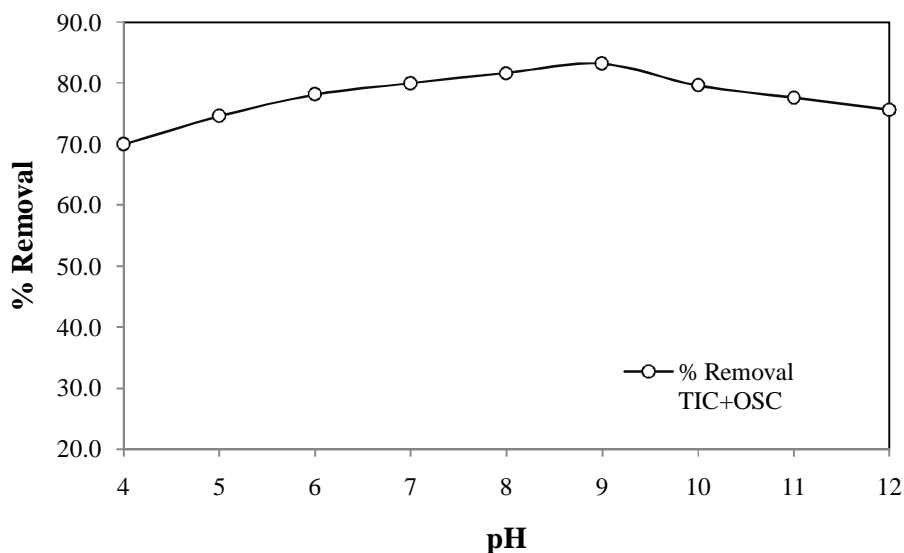

Figure 5: Effect of Boron ion solution pH onto AC (TIC+OSC) sample

(Initial concentration, 50mg/L; adsorbent dosage, 5 g/L; contact time, 40 min and temperature =30±1°C)

pH values affect species of heavy metals in aqueous solutions and heavy metals removal increases as pH value rises, reaching a maximum around 8 to 9 Solution pH also makes effects on the adsorbent and the surface charge of the AC samples changes. This means that the removal of Boron ions from the solution also contributes to the pH modification Therefore, all experiments were conducted at pH range of 8.0–8.5By increasing the pH from 9 to 12 (>pHzpc of ACs) the gradual decrease in boron adsorption capacity could be assigned to the electrostatic repulsion between negative surface charge of AC and negative charge of $B(OH)_4^-$ formed in high pH values. Simultaneously, the observation was attributed to a strong electrostatic repulsion force presents between borate anions with the surface of adsorbent, leading to a sharp reduction of adsorptive uptake.

Effect of Initial Concentration

The metal ion adsorption capacities of AC sample was presented as a function of equilibrium concentration in aqueous solution in figure 6.All other Parameters such as contact time (40 min) and quantity of sorbents (5g/L) and pH 8 were kept constant. The metal uptake mechanism is particularly dependent on the initial Boron concentration (Ci). At low concentrations metals are absorbed by specific sites, while with increasing metal concentrations the specific sites are saturated and the exchange sites are filled Sorbent exhibited very high metal loading capacities for this metal ion 42.99 mg/g for Boron adsorption at optimum conditions. This is due to the increment in the driving force produced from the concentration gradient [12].
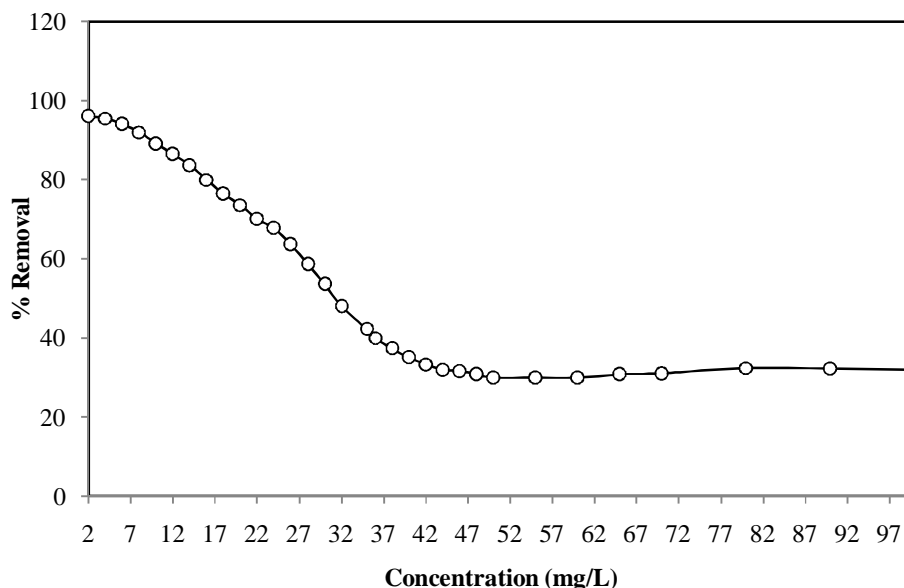

Figure6: The effect of initial concentration of Boron ion on its adsorption percentage removal, pH8; contact time, 40 min; adsorbent dosage, 50 g/L and temperature =30±1°C

ADSORPTION ISOTHERMS STUDIES

This study was carried out to establish the relationship between the concentration of Boron ions and its degree of adsorption onto the surface of the AC adsorbent sample at a fixed room temperature. The adsorption isotherm constants obtained from the plots of the linearized Langmuir and Freundlich models from Figure 7 & Figure 8. The Freundlich and Langmuir expressions for the removal of Boron ions by TIC+OSC carbons sample are shown in Eq 3 and Eq 4, respectively.

Linear form of Freundlich isotherm equation:

$$Log\ (q_e) = \log K_f + \left(\frac{1}{n}\right) \log C_e \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3)$$

Linear form of the Langmuir isotherm:

$$Ce/qe = Ce/q_m + 1/Kaq_m \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

From Figure 8 it can be seen that coefficients of determination (R^2) for AC sample from the Langmuir isotherm model was found to be 0.9801. This indicates that Langmuir isotherm model satisfactorily described the adsorption of Boron onto AC Sample. This indicates the monolayer coverage of Boronions on the homogenous surface of TIC+OSC carbons sample.The Langmuir equilibrium parameter R_L value 0.344 (table 2) for AC was found to be within the range for favorable adsorption $(0 < R_L < 1)$[17].The maximum uptake capacity for AC sample was found to be 42.9 mg/g This is better than some of the adsorption capacities for agricultural by-products reported in the literature[14] It can be seen that the Freundlich R^2 value from AC sample was found to be 0.964, (Figure 7). This indicates that the adsorption data was not adequately described by Freundlich isotherm model. The adsorption intensity 1/n value for Boron ions adsorption was found to be 0.478. This indicates a favorable adsorption process with increasing adsorption capacity and the appearance of new adsorption sites[18].The R^2 value for the Langmuir isotherm was 0.9801, which is higher than the values obtained from the Freundlich isotherm model. The experimental data fit very well to this isotherm model, and indicates that boron adsorption occurs on heterogeneous surfaces.
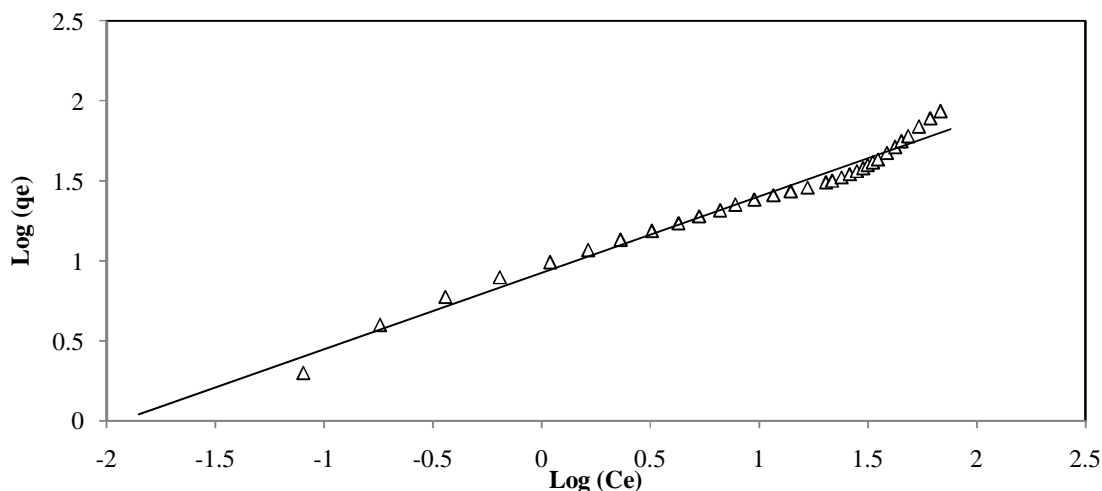
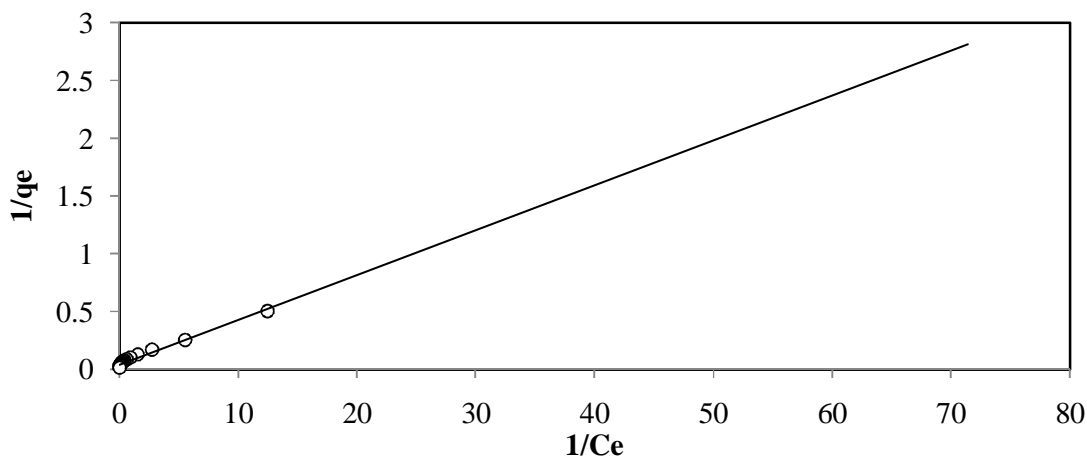**Figure 7: Freundlich Isotherm for Boron ions removal**

Figure 8: Langmuir isotherm for Boron ions removal

Table 2: Isotherm (Freundlich and Langmuir) characteristic constants for Boron ion sorption

Adsorbent	Langmuir isotherm				Freundlich parameters		
	a (mg/g)	b (L/g)	R^2	R_L	K_f (mg/g)	1/n	R^2
TIC+OSC	0.033	0.038	0.9801	0.344	0.926	0.478	0.964

Effect of Stirring Time

In the adsorption system contact time place a vital role, irrespective of the other experimental parameters that affect the adsorption kinetics. In order to study the kinetics and dynamics of adsorption of boron by various adsorbents, the adsorption experiments are conducted and the extent of removal of boron is conducted by varying the contact time (range: 5-80 min) at optimum conditions. The effect of contact time on Boron ion adsorption is shown in Figure 7.

The percentage Boron ion removal at different time was worked out using equation 1 and a plot was prepared between the percentage boron removal and contact time Figure 9. It can be noted that the percentage boron removal is increasing with time and attained almost an equilibrium condition (at which the rate of adsorption of solute is equal to the rate of desorption). In about 35-40 minutes the decreasing removal rate, particularly towards the end indicates a possible monolayer of Boron ion on the outer interface of the carbon and pore (Intra particle) diffusion onto the inner surface of the adsorbent particles through the film due to continuous agitation maintained during the experiments. The data also indicate the removal of Boron ion by these adsorbent samples is rapid at the initial period but becomes slow and almost stagnates with the increase in the contact time. The relative increase in the extent of removal of Boron ion is substantially low after 40 min of contact time and it is negligible after 45 min by the adsorbent sample, which is fixed as the optimum contact time. This indicates that the rate of removal of Boron ion is higher in the initial stage due to the availability of adequate surface area of the adsorbent. With increase in contact time and due to the decrease in the availability of active sites the adsorption process decreases.
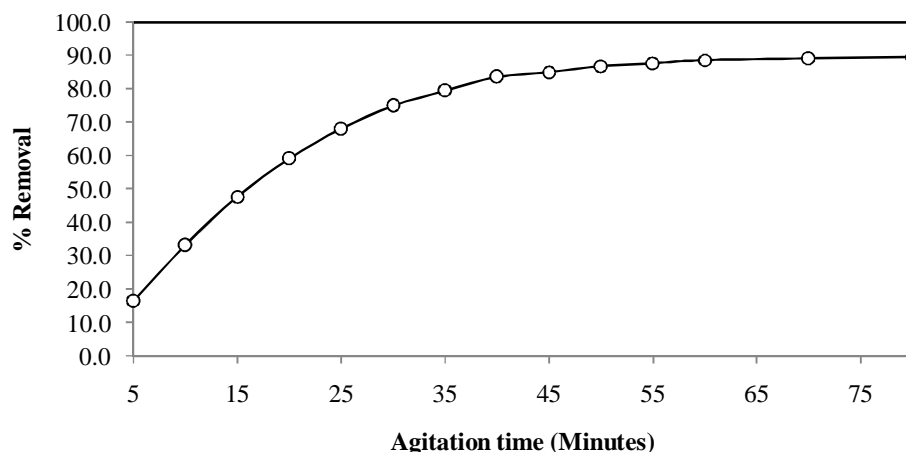

Fig 9: The effect of Stirring time of Boron ion on its adsorption percentage removal

KINETICS STUDY

The kinetics of sorption describes the solute uptake rate, which in turn governs the residence time of sorption reaction It is one of the important characteristics in defining the efficiency of sorption. In the present study, the kinetics of boron ion removal was carried out to understand the behavior of prepared low cost carbon adsorbent sample.

Lagergren model

The Lagergren first order rate expression (equation 6) that follows the valid for the present adsorption system and the same has been used for the determination of a specific rate constant as shown in Figure 10 and Table 3.

$$\text{Log } (q_e - q) = \log q_e - (k_{ad} \, t) \, / \, 2.303 \qquad \text{……………………Eq 6}$$

Where q_e and q_t (both in mg/g) are the amount of solute adsorbed solute adsorbed at any time, t(min) and at equilibrium time respectively Table 3 shows comparison of calculations for first order reaction rate constants for the removal of boron.
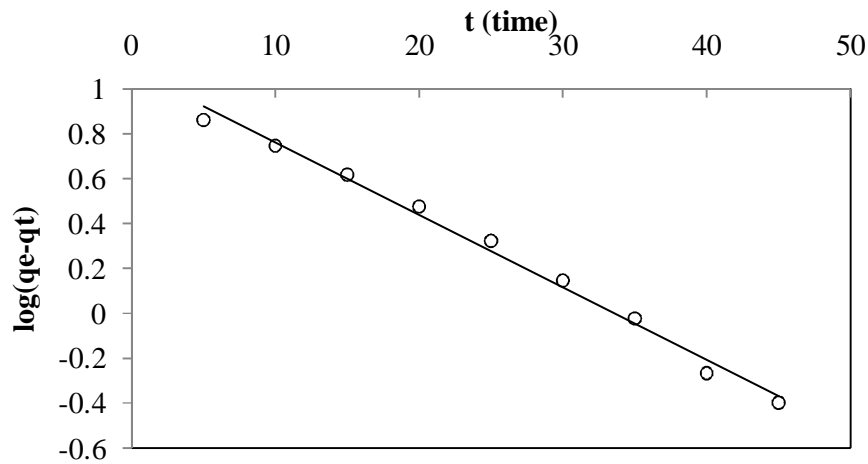

Figure 10: Lagenrgren model for the adsorption of Boron onto AC sample

Pseudo second order

The pseudo second-order adsorption kinetic rate equation is expressed as[19]

$$\frac{t}{qt} = \frac{1}{K_2 q^2{}_e} + \frac{1}{qe}(t)\text{…………………………………Eq 7}$$

The plot of (*t/qt*) and *t* of Eq 7 should give a linear relationship from which *qe*and *k₂*can be determined from the slope and intercept of the plot, respectively. Available studies have shown that the pseudo-second order rate equation is a reasonably good fit of data over the entire fractional approach to equilibrium and therefore has been employed extensively in the study of adsorption kinetics.However, it is not uncommon to observe multi linearity on *t/qe*Vs*t* plot (Figure11). The trend is usually such that the rate constant decreases with time or more specifically decreases with increasing solid phase concentration.
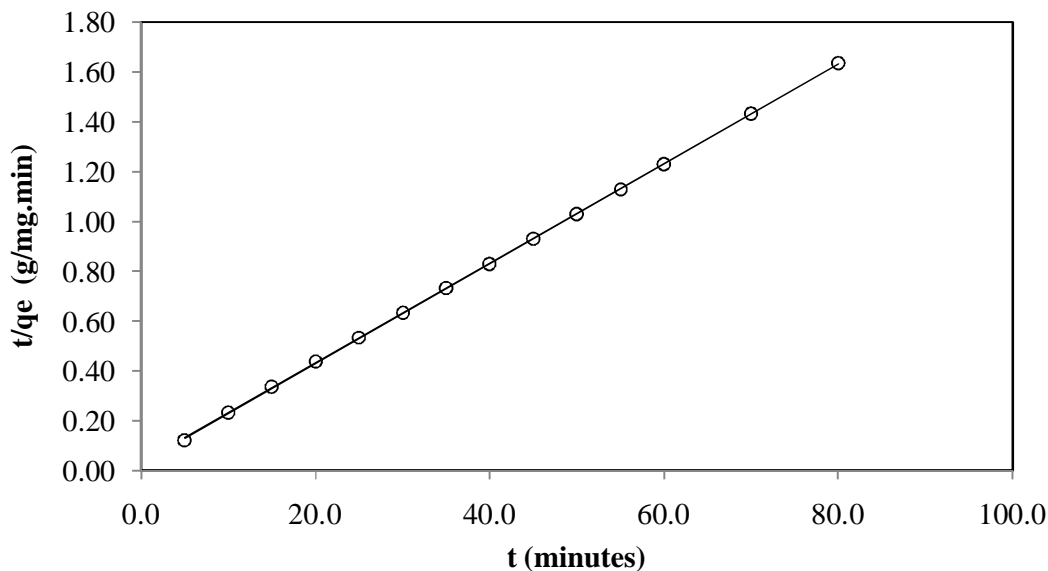
Figure 11: Pseudo-second-order kinetics for the adsorption of Boron onto AC sample

Table 3: Comparison of various kinetic models for the adsorption of Boron ion

Lagergren equation	R^2 Value	Lagergren constant (K)	
	0.991	0.02	
Pseudo-second-order kinetic model	q_e (mg/g)	k_2(g/mg/min)	R^2 Value
	49.62	0.0137	0.999
Intraparticle diffusion model equation	(K_p)	R^2 Value	
	0.975	0.830	

In the present kinetic study we compare the R^2 values of Langmuir and Freundlich models for the prepared adsorbent sample having 0.999& 0.991 But R^2 value of Langmuir model is very close to unity (0.999), hence pseudo-second order kinetic equation is fit for the AC adsorption study.

Intraparticle Diffusion Method

Intraparticle diffusion model assumes that the film diffusion is negligible and intraparticle diffusion is the only rate controlling step, which is usually true for well-mixed solutions. The

intraparticle diffusion model is a single-resistance model in nature and can be derived from Fick's second law under two assumptions.

The mathematical expression thus obtained for the intraparticle diffusion model is

$$q_e \approx k_p t^{05} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Eq 8}$$

Where k_p (mg/g min^{-05}) is defined as the intraparticle diffusion rate constant and is related to the intraparticle diffusivity in the following way,

$$k_p = \frac{6q_e}{R}\sqrt{\frac{D}{\pi}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Eq 9}$$

Where R (cm) is the particle radius and qe (mg/g) is the solid phase concentration at equilibrium. The plot of the average particle loading, q_e(mg/g), versus the square root of time, t^{05} (Figure 12), would yield a straight line passing through the origin if the adsorption process obeyed the intraparticle diffusion model. The slope of the straight line equals to k_p, the Intraparticle diffusion rate constant. This has resulted in linear relationship as evidenced by the r-values (0.830) for the current study which indicate the existence of intraparticle diffusion process.
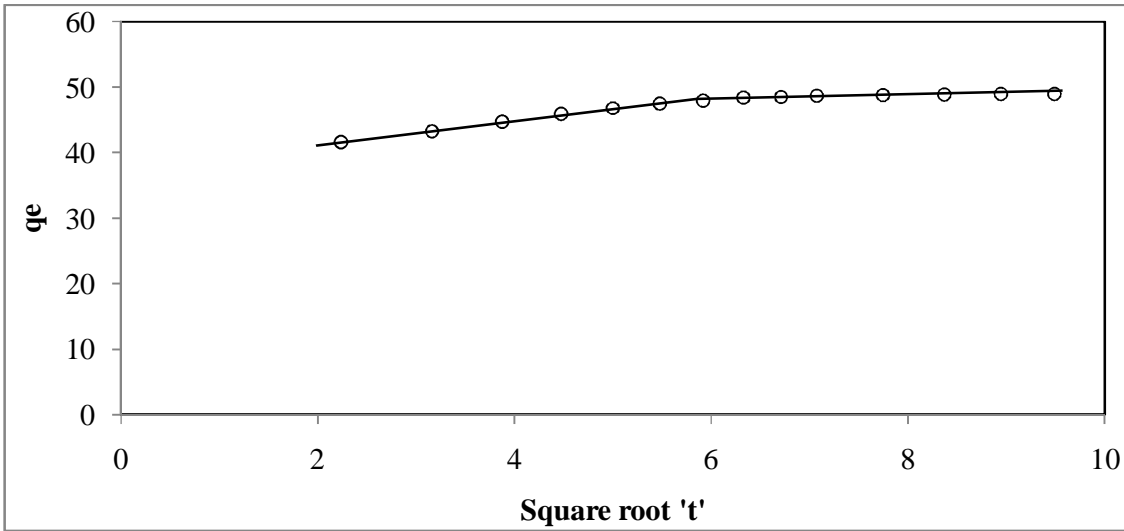

Figure 12: Intra particle diffusion plot for the removal of Boronion by the AC sample

When intra particle diffusion plot was observed from figure 12 for the prepared AC sample, the process was occurred in two stages. In the current adsorption system stage I one is observed in the square root 't' value 20 to 65 In this stage R^2 value was observed and confirm that for the current system close to unity but in the second stage ie above 65 ($\sqrt{t}$) were found to be 0.863 for AC sample So the current adsorption system strongly following the intraparticle diffusion process at initial stages compare to the final stage.

CONCLUSIONS

The present study has shown that activated carbons mixed sample produced from *TamarindusIndica* Stem Carbon, *Ocimum Sanctum* bio mass carbon, can be engaged as an environment friendly and low cost adsorbent for the removal of Boron (I) ions from synthetic aqueous solution. The study on the effect of pH revealed that the competition between -OH and metal ions at low pH values is the main leading factors that affect the adsorption characteristics of AC sample Optimum removal efficiency was achieved at higher pH values. The number of adsorption sites increased due to an increase in AC dosage and optimum removal efficiency of 825% was achieved at AC sample dosage of 5g/L.

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