Preparation and Characterization of Activated Carbon from Bagasse and Jute Fibre for Heavy Metal Adsorption

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Abstract: Over the past few years, activated carbon (AC) has attained significant attention as an efficient adsorbent for heavy metal (lead, cadmium, chromium etc.) removal. In Bangladesh, bagasse and jute fibre are the two most potential raw materials for producing activated carbon due to their high availability and low cost. The activated carbon was produced by thermal treatment method. The produced AC were characterized using FTIR, XRD, SEM etc. Batch experiments under agitation was also carried out for adsorption of heavy metals and then characterized using AAS (Atomic Adsorption Spectroscopy). Adsorption with commercially available activated carbon was also done to use as standard. Among all ACs produced in this study, the highest percentage removal of heavy metals which were Cr^{3+} and Cd^{2+} was at 57.06% and 43.01% respectively for J-400 (AC produced from jute fibre at 400°C). This obtained value was 16.6% and 12.9% higher in comparison to Commercially available Activated carbon for Cr^{3+} and Cd^{2+} respectively

Keywords: Adsorption, Activated carbon, dyes, isotherm

1 INTRODUCTION

Activated Carbon(AC) is an excellent adsorbent with high porosity, internal surface area and pore volume(Girgis). It may be visualized as foam solid that has a large surface area with rigid particle structure of relatively small volume (Bansal, Aggarwal et al. 2002, Asadullah, Asaduzzaman et al. 2010). The large surface area results in a high capacity for absorbing chemical and contaminants from gases and liquids(Dula, Siraj et al. 2014). The adsorptive property stems from the extensive internal pore structure that develops during the activation process(Cuhadar 2005). There are two main methods of producing AC; thermal activation and chemical activation(Asadullah, Rahman et al. 2007, M.S. Shamsuddin 2016). In thermal activation process any carbonaceous material undergo decomposition in absence of air causes evolution of tarry and gaseous products at relatively low temperature and a solid carbon produced as a final product(Foo). However, in chemical activation process, the carbonaceous material is mixed with activating agents. This activating agent restricts the formation of tar and creates more internal pores through dehydration reaction occur at significantly lower temperature (Yagsi 2004). To produce activated carbon different carbonaceous materials of organic origin which are rich in carbon are usually used. However, choice of raw materials is an important factor to produce low cost activated carbon. For instance, in context of Bangladesh, agricultural biomass e.g.; bagasse, jute fibre, kenaf are suitable raw materials to produce low cost activated carbon. Asadullah *et al.* (Asadullah, Rahman et al. 2007) has produced activated carbon by thermal activation method from jute fibre and used the produced activated carbon to remove dye from aqueous solution(Asadullah, Asaduzzaman et al. 2010). Another study has also reported by Asadullah *et al.* to produce activated carbon from jute stick and used to remove arsenic from water (Asadullah, Jahan et al. 2014). Ramesh et al. (Ramesh, Rajalakshmi et al. 2017) also used jute fibre to activated carbon to use as hydrogen storage. Foo et al. used bagasse as raw material for production of activated carbon using microwave heating treatment for the adsorptive

treatment of semi-aerobic landfill leachate (Foo). Another study was reported by Girgis et al. using sugarcane bagasse as raw material in producing activated carbon (Girgis). Shamsuddin et al. prepared AC by chemical activation method from kenaf core fibre (M.S. Shamsuddin 2016). In Bangladesh, industrial pollution is a growing concern of the present days. Untreated Effluents mostly from tanneries contain heavy metals, dyes, oils etc are directly discharged into rivers and streams (McKee, Unal et al. 2005). This study aims to produce low cost activated carbon from jute fibre by thermal activation method which could be used as a potential adsorbent to treat industrial polluted effluents.

2 MATERIALS AND METHODS

2.1 Raw Materials

Bagasse and jute fibres are collected from local farmers and the local market. Sodium Hydroxide was purchased from Merck KGaA, (Germany). Its index no is 011-002 00 6. Chromium standard solution was bought from SIGMA ALDRICH. Cadmium standard solution was also bought from SIGMA ALDRICH. 2% Nitric acid was prepared from 65% nitric acid which was purchased from SIGMA ALDRICH.

2.2 Preparation of Activated carbon

2.2.1 Pretreatment of Raw materials

Jute fibre was collected from local farmers and bagasse was collected from the local market. Both the raw materials were sorted and washed with water separately to remove sand and dirt. Then the raw materials were dried under sunlight for 48 hrs followed by drying at 110° C for 2 hrs in an oven to remove moisture. Then, the dried samples were cut into small pieces for increasing surface area for proper charring.

2.2.2 Charring of dried raw materials

The dried raw materials were pyrolysed in a furnace at a rate of 8° C per minute from room temperature to a temperature range 400, 450 and 500° C respectively and maintained at this temperature for 10 mins. The produced char was transferred from the furnace after 24 hrs. Then the obtained chars were crushed and sieved.

Table 1: Charring condition of dried raw materials

Raw material	Wt. of the sample (gm)	Pyrolysis Temperature (°C)	Stay in Time (Mins)	Reaction Rate (°C/Min)	Wt. of the char (gm)	Yield (%)	Sample name
Jute Fibre	50	400	10	8	5.6	11.2	J-400
	50	450	10	8	5.2	10.4	J-450
	50	500	10	8	4.4	8.8	J-500

2.2.3 Activation of the char

Activation refers to the change of raw carbon material to the more porous material. The higher the porosity, the better the adsorption capacity. That's why the raw carbon material is activated for increasing its adsorption capacity. The crushed char was activated by sodium hydroxide. The activation was carried out by impregnation of the char with sodium hydroxide for 24 hrs. The preweighted sodium hydroxide and char were mixed with distilled water by a magnetic stirrer. The activation was carried out at room temperature.

2.2.4 *Washing of Activated Carbon*

After the completion of activation, the materials were washed with distilled water several times to remove the activating agent. Finally, the activated carbon was dried at 110°C until it gains a fixed mass. Then the activated carbons were transferred into a desiccator for proper desiccation. AC was kept dry until its application.

2.3 Characterization techniques

2.3.1 *Fourier Transform infrared spectrophotometer (FT-IR)*

FT-IR spectra of the samples were recorded on an FT IR spectrophotometer (SHIMADZU, Model MIRacle 10) in the wavelength range of 4000–450 cm^{-1} , resolution: 4 cm^{-1} , scan 30. Approximately 2–5 mg of samples were ground with mortar and then was spread over the crystal of ATR accessories. The two knobs were tightly rounded to hear a click sound and the spectra were recorded.

2.3.2 *X-ray Diffractometer (XRD)*

XRD patterns of the samples were recorded by an x ray diffractometer (Ultima IV, Rigaku Corporation, Japan) at room temperature. Prior to XRD analysis, the samples were grounded into fine powders using mortar and pestle. $\text{CuK}\alpha$ radiation ($\lambda = 0.154 \text{ nm}$), from a broad focus copper tube operated at 40 KV and 40 mA, was applied to the samples for measurement. The XRD pattern of the samples was measured in the continuous scanning mode with the scan speed of 3°C/min and in the scan range of 0 to 50. Bragg's law was used to compute the basal spacing of the samples.

2.3.3 *Scanning Electron Microscopy (SEM)*

The morphology of the samples was analysed by an analytical scanning electron microscope (JEOL JSM-6490LA, Tokyo, Japan) operated at an accelerating voltage of 20 KV in the back scattered electron mode. In order to get further insight into the morphology, micro structures of the samples were examined in various magnification.

2.4 Application of the produced activated carbon

The produced activated carbons were used to absorb chromium (Cr^{3+}) and cadmium (Cd^{2+}) from a standard solution of chromium and cadmium. For this purpose, the calibration curve was produced by spectrophotometric method. Standard solutions of heavy metals which are Cr and Cd of different concentrations (0.2, 0.4, 0.6, 0.8, 1, 1.5 ppm) were made and their absorbance was determined by Atomic Absorption Spectroscopy (AAS).

2.4.1 *Atomic Absorption Spectroscopy:*

Concentration of the heavy metals before and after adsorption was determined using AAS (Analytik jena 350). The technique makes use of the atomic absorption spectrum of a sample in order to assess the concentration of a specific analyte within it. It requires standard with known analyte concentration (0.2, 0.4, 0.6, 0.8, 1, 1.5 ppm) to establish the relation between the measured absorbance and the analyte concentration and therefore relies on the Beer-Lambert law.

The parameters changed for determining the optimum condition during the adsorption process are given below.

2.4.2 *Types of adsorbent*

To find out the best suitable adsorbent, 25 ml of 1 ppm Cr^{3+} and Cd^{2+} solution was taken for each batch of adsorbent. Same amount of adsorbents (400 mg) was added at room temperature. pH of the solution was same. The solution was shaken for 5 hrs at 150 rpm in each case.

2.4.3 *pH of the solution*

To study the influence of pH on the adsorption by the best suitable adsorbent, 25 ml of 1 ppm solution of Cr^{3+} and Cd^{2+} was taken in each of the ten reagent bottles. pH of the solutions was adjusted from 2 to 10 using 2M

NaOH solution. 400 mg of same adsorbent were added in each of the reagents bottles. Then all the reagents bottles were placed in an orbital shaker for shaking about 5 hours at 150 rpm.

2.4.4 Adsorption dosage

The effect of different adsorbent dose in the range 200 – 600 mg was experimented. Initial concentration in case of both metals was 1 ppm (actual concentration 1.16 ppm for Cr^{3+} and 1.12 ppm for Cd^{2+} solution). Since pH 6 showed best percentage removal for Cr^{3+} and pH 8 showed best percentage removal for Cd^{2+} in earlier experiment, here pH of the Cr^{3+} solution and Cd^{2+} solution was maintained at 6 and 8 respectively. 25 ml solution was taken in each of the 10 reagent bottles and all the reagent bottles were placed in an orbital shaker for 5 hrs at 150 rpm.

2.4.5 Contact Time

We studied the effect of contact time on the adsorption for a time varying from 1 to 6 hours. 25 ml solution of Cr^{3+} was taken in each of five reagents bottles and 25 ml solution of Cd^{2+} in each of the another five reagent bottles. pH of the Cr^{3+} solution was maintained at 6 and for Cd^{2+} solution; it was 8 as the best suitable condition. 400 mg adsorbent (J-400) was added in each of the bottles. Then all the bottles were placed in an orbital shaker for different time period at 150 rpm.

During the change of every parameter, the removal yield of chromium and cadmium were calculated by the following relationship:

$$\text{Removal yield\%} = (C_0 - C_e)100 / C_0$$

where C_0 and C_e are the initial and final (equilibrium) concentrations (ppm) of the metal of interest respectively. The adsorption capacity, q_e at any time was calculated by:

$$q_e = (C_0 - C_e) V / W$$

where C_0 and C_e are the initial and concentrations (ppm) at any time of the metal, V is the volume of the test solution and W is the mass of the adsorbent used in adsorption.

2.5 Adsorption isotherm

Adsorption isotherm is one of the most important characteristics to describe the adsorption behavior. It also describes relationship between the amount of adsorbate adsorbed on the adsorbent and the concentration of the dissolved adsorbate in the liquid at equilibrium (Kamal 2014). Among many isotherm models, the Langmuir isotherm and the Freundlich isotherm were employed in this study to observe the adsorption behavior. Adsorption isotherm of Cr^{3+} was carried out at room temperature using optimum experimental conditions (pH 6, 5 hours contact time) with initial concentration of 1 ppm Cr^{3+} solution.

2.5.1 Langmuir Isotherm

Langmuir isotherm model is well known isotherm model for monolayer adsorption. It assumes that the adsorption takes place at specific homogeneous sites within the adsorbent. The linear form of Langmuir isotherm can be represented with the following equation:

$$\frac{C_e}{q_e} = \frac{C_e}{q_{\max}} + \frac{1}{q_{\max} K_L}$$

Where,

q_e = equilibrium adsorbate concentration on the adsorbent (mg/g);

C_e = equilibrium concentration of the adsorbate on the solution (ppm);

$q_{\max}$ = maximum adsorption capacity of the adsorbent (mg/g);

K_L = Langmuir adsorption constant related to the free energy of adsorption (L/g).

2.5.2 Freundlich Isotherm

The Freundlich isotherm is a popular model used to describe heterogeneous adsorption process, i.e. adsorption that takes place on a heterogeneous surface through a multilayer adsorption mechanism. Freundlich isotherm is expressed by the equation:

$$q_e = K_f C_e^{1/n}$$

3 RESULTS AND DISCUSSION

3.1 FT-IR spectra of prepared activated carbon

Figure 1: FTIR spectra of ACs produced from jute fibre at different temperature

Table 2: FTIR band position and their corresponding assignment.

Observed Band position (cm ⁻¹)	Corresponding assignments
3360-3398	Stretch vibration of –OH group(Zhang, Wang et al. 2018)
3350-3400	Stretch vibration of –NH group in amines and amides(Auta and Hameed 2011)
2326-2363	Stretch vibration of C≡C bond of Alkyne(Auta and Hameed 2011)
1570-1592	Stretch vibration of C=C in alkene(Auta and Hameed 2011), bending of C=C in aromatics
1365-1371	Bending vibration of C-H in alkane(Zhang, Wang et al. 2018), N-O symmetric stretch in nitro group
1180-1203	Stretching of C-O in alcohol, carboxylic acid group
670-684	Stretching of C-H group in alkane, alkene and aromatics

Figure 1 shows the FTIR spectra of produced activated carbons (J-400, J-450 and J-500) and the corresponding peaks are presented in Figure 1: *FTIR spectra of ACs produced from jute fibre at different temperature*

Table 2. From Figure 1 the peaks associated with O-H, C-H, C-C, C=C, C-O and C≡C vibrations are identified (Table 2). The presence of these functional groups on the produced ACs agree with the findings of Auta and Hameed (Auta and Hameed 2011). Auta and Hameed produced activated carbon from waste tea and identified the presence of hydroxyl, alkyl and carbonyl functional groups. They explained that these functional groups can be dissociate and become negatively charged to produce electrostatic attraction between the adsorbent and positively charged metal ions (Auta and Hameed 2011). They concluded that the presence of numerous and varieties of functional groups in the activated carbon can contribute to higher adsorption activities.

Figure 2: Comparison of FTIR spectra of J-400 before and after adsorption

Figure 2 shows the comparison of the FTIR spectra of J-400 before and after adsorption of heavy metals (Cr and Cd). No major difference in FTIR spectra were observed before and after adsorption of heavy metals. This observation indicates that there is no chemical bonding/ change occurred during adsorption.

3.2 X-ray diffraction spectroscopy:

Figure 3 represents the XRD pattern of the produced AC (J 400). Two broad diffraction peaks at 26.6° and 43.5° were observed which could be attributed to the presence of carbon and graphite (Bouchelta, Medjram et al. 2008). Moreover, the broad diffraction indicates the amorphous nature and low graphitization (Fan, Yang et al. 2014, Chen, Peng et al. 2015, Zhang, Wang et al. 2018).

Figure 3: Comparison of ACs produced from jute fibre with commercial AC

3.3 SEM images of the produced activated carbon

Figure 4 represents the SEM images of the AC (J-400) before and after adsorption.

Figure 4: SEM images of AC (J-400) before (a, b) and after (c, d) adsorption

SEM image before adsorption (Figure 4a) showed the porosity with small openings on the surface of the AC which enhance the diffusion of heavy metals during adsorption. Whereas, Figure 4b shows that the porosity had decreased after adsorption indicated that most of the pores were filled with the heavy metals.

3.4 Atomic Absorption Spectroscopy:

3.4.1 Calibration Curve

The calibration curve was produced by spectrophotometric method. For this purpose, standard solutions of heavy metals which were Cr^{3+} and for Cd^{2+} of different concentrations were made and their absorbance were determined by Atomic Absorption Spectroscopy (AAS).

Figure 5: Calibration curve for Cr^{3+} and Cd^{2+} solution

The R^2 value of the Cr^{3+} calibration curve obtained from Figure 5 and of the Cd^{2+} calibration curve obtained from figure 4.10 is .9997 and .9985 respectively.

3.4.2 Adsorption capacity of produced AC:

AC's (J 400, J 450, J 500) were used to adsorb heavy metals from the pure solution of heavy metals (Cr^{3+} and Cd^{2+}) to get the best adsorption result. A commercially available activated carbon (CAC) was used as standard for comparison.

The percentage removal of heavy metal ions using produced AC's and the CAC are presenting in Figure 6. All ACs showed better adsorption for Cr in comparison to Cd. For instance, J-400 showed 14.05% higher adsorption

for Cr in comparison to Cd which is predicted to be due to the greater atomic radius of Cd^{2+} ($0.97 \text{ \AA}$) than Cr^{3+} ($0.52 \text{ \AA}$) (Faur-Brasquet, Reddad et al. 2002).

Figure 6: Removal yield of heavy metals using different batches of activated carbons produced.

All ACs produced in this study showed better adsorption for both Cr^{3+} and for Cd^{2+} in comparison to CAC. However, J-400 showed the best removal yield among all adsorbents. In comparison to CAC, J-400 showed statistically significantly higher removal at 16.63% ($P < 0.001$) for Cr^{3+} (57.06%) and 12.9% ($P < 0.001$) for Cd^{2+} (43.01%) (see Table 3). This could be potentially due to the fact that for produced ACs, the amount of micropores which is mainly responsible for adsorption, decreases with increasing charring temperature. So the best removal yields was obtained by the adsorbent J 400 and was used for further experiments as the best suitable adsorbent. Variables (pH, adsorbent doses and time) that affect the adsorption process were further studied for J-400.

Table 3: Comparison for percentage removal of heavy metal using J-400 and CAC

Adsorbent	J-400	CAC	% difference	P value	Statistically significant
% removal of Cr	57.06	40.43	16.63	<0.001	yes
% removal of Cd	43.01	30.02	12.9	<0.001	yes

3.4.3 Effect of pH on adsorption of J-400

pH is one of the most important parameters to control the adsorption of heavy metals from the solution. Figure 7 revealed that the percentage removal of Cr^{3+} and Cd^{2+} increases as pH increases up to a certain value. The highest percentage removal (89%) of Cr^{3+} was obtained at pH 6 and for Cd^{2+} 88% removal was found around pH 8.

However, for both metal ions a decrease in percentage removal was observed at higher pH, for Cr^{3+} the value decreased to 40% at pH 10 and for Cd^{2+} the value decreased to 65% at pH 10.

Figure 7: Effect of pH on the percentage removal of metal ions by J-400.

For instance, by using 400 mg of J-400 for 25 ml solution, we found almost 90% adsorption for Cr^{3+} and 88% adsorption for Cd^{2+} .

Adsorption of metal ions at different pH depends on the amount of metal ion distribution in prepared solution and also on the nature of the adsorbent surface. For instance, at lower pH (~2 to 4), the predominant cations of Cr(III) are Cr^{3+} , CrOH^{2+} , CrOH_2^+ . Moreover, in lower pH the surface of the adsorbent becomes protonated and hence there is a decrease in the electrostatic attraction between the Cr^{3+} ion and the adsorbent surface which causes a decrease in percentage removal of Cr^{3+} ion^(Wu, Zhang et al. 2008, Wang, Wang et al. 2010). So, better adsorption is expected at higher pH (< 6), since at that condition, the adsorbent surface would be less protonated and would have strong attraction for cationic species. However, when pH exceeds the value 6, the value decrease which might be due to the decrease in adsorption by Cr^{3+} ion, however, ions still remove at that pH is that Cr ions get precipitated from the solution in that pH range in the prepared solution which ultimately again resulted in a decrease in adsorption. So an optimum pH of 6 is suggested for better adsorption of Cr with adsorbent J-400.

Similarly for cadmium adsorption, Cd species are found to be present in deionized water in the forms of Cd^{2+} , Cd(OH)^+ , Cd(OH)_2 , $\text{Cd(OH)}_2(\text{s})$, at pH 8, the percentage removal of Cd^{2+} was highest at 88%. However, at pH > 8, percentage removal of Cd^{2+} ion decreased to ~65%. This might be due to the fact that at pH > 8, the adsorption of AC capacity decreased and of Cd^{2+} ion also started to precipitate from the solution in the form of Cd(OH)_2 (Mohammad, Akram et al. 2017). Wang et al. used adsorb bamboo charcoal to precipitate Cd ion and also reported highest percentage removal of Cd ion by bamboo charcoal dominantly controlled by adsorption at pH values

Figure 8:Effect of pH on adsorption capacity of J-400.

3.5 Effect of adsorbent dosage on adsorption

Figure 9:Effect of adsorbent dose on the % removal of metal ions by J-400.

Figure 9 shows the effect of different adsorbent dose in the range 200 – 600 mg. The % removal of Cr^{3+} and Cd^{2+} increased by 45.25% and 27.18% respectively with an increase in the adsorbent dosage from 200 to 500 mg, however, became constant for further increase of adsorbent dosage. The increase in % removal of metal ions with an increase in adsorbent dosage is due to the availability of larger surface area and more adsorption sites (Naiya, Bhattacharya et al. 2009). At adsorbent dosage >500 mg, the adsorbent surface gets saturated with the metal ions and an equilibrium establishes between the concentration of the metal ions in the surface of the adsorbent and in the solution. Naiya et al. (Naiya, Bhattacharya et al. 2009) also reported an increase in percentage removal of Cd^{2+} ion with an increase in ion removal increased up to 8 g/L adsorbent, however, this value remains constant on increasing the value up to 32 g/L.

Thus, after a certain dosage, increased adsorbent dosage did not enhance the removal percentage of metal ions.

Figure 10: Effect of adsorption dosage on adsorption capacity of J-400.

Figure 10 shows a decrease in adsorption capacity by 34.7% and 52.27% for Cr and Cd respectively with an increase in the adsorption dose from 200 to 600 mg. The decrease in adsorption capacity with increase in the adsorbent dose is mainly to be due to the unsaturation of adsorption sites during the adsorption process (Wang, Wang et al. 2010). Another explanation could be the particle interactions, for example aggregation results from high adsorbent concentration which would eventually causes a decrease in the total surface area of the adsorbent and in turn the adsorption capacity (Rao, Rao et al. 2008).

From the above discussion, it can be said that although the percentage removal of Cr^{3+} and Cd^{2+} increases (Figure 9) with increased amount of adsorbent, however the adsorption capacity decreases (

Figure 10) for 25 ml solution. So, it can be suggested that, using a high amount of adsorbent will not be economical.

For instance, From the Figure 9 and

Figure 10 it can be observed that for Cr^{3+} ion, using 300 mg adsorbent, the highest adsorption capacity of J-400 was 0.07 mg/g and the percentage removal of Cr^{3+} ion was 73%. On the other hand, using 400 mg J-400, the adsorption capacity was found to be 0.064 mg/g and the percentage removal of Cr^{3+} ion was 88%. So it can be said that on using 400 mg adsorbent, although adsorption capacity decreased by 8.5% sorbent, however removal efficiency increased by 15.69%. So using 400 mg adsorbent can be suggested to be the best economic approach.

Similarly for Cd^{2+} ion, using 200 mg adsorbent, the highest adsorption capacity of J-400 was .088 mg/g and the percentage removal for Cd^{2+} ion was 63.24%. On the other hand, using 300 mg adsorbent although adsorption capacity decreased to 0.075 mg/g, however percentage removal increased to 80.63%. So, for Cd^{2+} ion, it can be

suggested that using 300 mg adsorbent will be the best economical approach since 17% higher removal yield was found in comparison to using 200 mg adsorbent.

3.5.1 Effect of contact time on adsorption

Contact time is another important factor that influences the adsorption since it provides information on the adsorption and desorption efficiency. It is the time which corresponds to the adsorption equilibrium. The effect of contact time on the adsorption for a time varying from 1 to 6 hours is presented in Figure 11.

Figure 11: Effect of contact time on adsorption by J-400.

From Figure 11 it can be observed that, in the first hour the percentage removal of Cr and Cd was around 30%. This value increased gradually up to 4 hours and reached at 91.5% for Cr and 87.23% for Cd at hour 4. The percentage removal of metal ion remain constant over next 2 hours. The rapid increase in the percentage removal at the initial stage to be due to the high availability of the sorption sites and then reached a constant value due to the saturation of the active site, which did not allow more adsorption to take place (Mohammad, Akram et al. 2017).

3.6 Adsorption isotherm

Adsorption isotherm is one of the most important characteristics to describe the adsorption behavior. It also describes equilibrium relationship between the amount of adsorbate adsorbed and the concentration of the adsorbate dissolved in the liquid. Among many isotherm models, the Langmuir isotherm and the Freundlich isotherm were employed in this study to observe the adsorption behavior.

3.6.1 Langmuir Isotherm

For a given adsorption process, when the values of (C_e/q_e) are plotted against the corresponding value of C_e , the following curve is obtained.

The equilibrium data were analyzed using, Langmuir model (Eqs. (6), (8) and (9)) to get the isotherm. The isotherm were shown graphically in Fig. 6 and the isotherm parameters were listed in Table 2. All the plots showed a straight line, indicating that the adsorption of Cd (II) ions follows the isotherms well. Langmuir adsorption isotherm model is presented by Figure 12. The maximum adsorption capacity, $q_{\max}$ and the Langmuir constant, K_L

are calculated from the slope and the intercept respectively. Values obtained for the adsorption of Cr are listed in table 3

The basic assumption of Langmuir adsorption isotherm is based on monolayer coverage of the adsorbate on the surface of adsorbent [26,27], which is an indication of the fact that the adsorption of Cd (II) ions onto bamboo

Figure 12: Langmuir adsorption isotherm

3.6.2 Freundlich isotherm

The Freundlich isotherm is a popular model used to describe heterogeneous adsorption process, i.e. adsorption that takes place on a heterogeneous surface through a multilayer adsorption mechanism. A graph of $-\log q_e$ vs $-\log C_e$ is given in the next page.

A graph of $-\log q_e$ vs $-\log C_e$ is shown below. Figure 4.18 shows the Freundlich adsorption isotherm model. The value of the K_F and $1/n$ can be calculated from the intercepts and slopes of the plot of $-\log q_e$ vs $-\log C_e$. Values obtained are given in table 4.3.

Figure 13: Freundlich adsorption isotherm

Figure 13 shows the Freundlich adsorption isotherm model. The value of the K_F and $1/n$ can be calculated from the intercepts and slopes of the plot of $-\log q_e$ vs $-\log C_e$. Values obtained are given in table 4. When the $1/n$ value is between 0.1 and 0.5, the adsorption process is wonderful. If the value is between 0.5 and 1, the adsorption process is easy and if the value is greater than 1, it is difficult to adsorb (Dhananasekaran, Palanivel et al. 2016). In our study the value of $1/n$ was found 0.117 at room temperature. Therefore, we can conclude that the Freundlich adsorption isotherm is applicable for the adsorption of chromium.

Table 4: Isotherm parameter for the adsorption of Cr^{3+}

Langmuir Isotherm	q_{max} (mg/g)	R_L	R^2
	0.0512	.006	.993
Freundlich Isotherm	K_F (L/g)	$1/n$	R^2
	14.45	0.117	.870

The essential characteristics of Langmuir can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter, R_L which is defined by:

$$R_L = \frac{1}{1 + K_L C_0}$$

Where C_0 is the highest initial concentration (ppm). The value of R_L indicates the nature of the adsorption process as given below:

$R_L > 1$, Unfavorable;

$0 < R_L < 1$, Favorable;

$R_L = 0$, Irreversible.

From Table 4 & Error! Reference source not found., it is seen that the value of R_L is less than 1, which indicated that adsorption is favorable.

Table 5: Comparison of adsorption capacity of the prepared activated carbon compared to other adsorbents to adsorb Chromium (1ppm initial concentration, 400mg adsorbent, 25ml volume)

Adsorbents	Adsorption capacity (mg/g)	Reference
Soya cake	0.0001	(Daneshvar, Salari et al. 2002)
Coconut shell powder	0.0004	(Pino, de Mesquita et al. 2006)
Rice bran	0.0005	(Singh, Rastogi et al. 2005)
Coffee husk	.002	(Oliveira, Franca et al. 2008)
Almond shell	0.003	(Dakiky, Khamis et al. 2002)
Eucalyptus bark	0.014	(Sarin and Pant 2006)
Rubber wood sawdust	0.014	(Karthikeyan, Rajgopal et al. 2005)

Wood activated carbon	0.028	(Selomulya, Meeyoo et al. 1999)
Coconut shell activated carbon	0.038	(Hamadi, Chen et al. 2001)
Jute fibre activated carbon (J-400)	0.065	In this study

Prepared activated carbon shows greater adsorption capability than most other adsorbents.

Table 6: Comparison of adsorption capacity of the prepared activated carbon compared to other adsorbents to adsorb Cadmium (1ppm initial concentration, 400mg adsorbent, 25ml volume)

Adsorbents	Adsorption capacity (mg/g)	Reference
Bamboo charcoal	0.025	(Ofomaja and Ho 2007)
Rice husk	0.018	(Kumar and Bandyopadhyay 2006)
Corn cob	0.018	(Reddad, Gerente et al. 2002)
Spent grain	0.036	(Low, Lee et al. 2000)
Sugar beet pulp	0.035	(Reddad, Gerente et al. 2002)
Bagasse fly ash	0.013	(Srivastava, Mall et al. 2008)
Mungbean husk	0.073	(Saeed, Iqbal et al. 2009)
Cassava waste	0.037	(Abia, Horsfall Jr et al. 2003)
Jute fibre activated carbon (J-400)	0.062	In this experiment

In case of Cadmium adsorption, prepared activated carbon also shows greater adsorption capability than most other adsorbents.

4 Conclusion

In this work, six different batches of Activated carbon was prepared from two different raw materials, bagasse and jute fibre at three different temperature (400, 450 & 500 °C) which were successfully used as adsorbents for the adsorption of two heavy metals, Cr and Cd from their pure solution. All ACs showed better adsorption for Cr in comparison to Cd which is predicted to be due to the greater atomic radius of Cd^{2+} (0.97 Å) than Cr^{3+} (0.52 Å). Among all the adsorbents, J-400 showed best adsorption efficiency for both metals. Adsorption process was carried out by changing different parameters such as pH, adsorbent dose and contact time. The percentage removal of both metal ions increased with the increase of pH of the solution up to a certain value. For Cr^{3+} solution, best result was obtained at pH 6 and for Cd^{2+} solution at pH 8. If the pH of the solution was further increased, the metal ions got precipitated which ultimately again resulted a decrease in adsorption. So an optimum pH of 6 is suggested for better adsorption of Cr and pH 8 is suggested for better adsorption of Cd with adsorbent J-400.

It has also been observed that percentage removal of Cr and Cd ions increased with increasing contact time. However, as the contact time increased, the percentage removal became constant. For example, upon using 400 mg of J-400 adsorbent for 25 ml solution, as contact time increased from 4 to 5 hours, a small and insignificant increase

in removal yields was observed for both metal ions (1.5% for Cr^{3+} and by 2.2% for Cd^{2+}). So for 25 ml solution of both metal ions, 4 hours contact time would be preferable.

In Bangladesh, the effluents from tannery industry and other industries are highly concentrated with chromium, cadmium and other heavy metals which are deliberately disposed to the river without any pretreatment. This is a very alarming situation to our health as well as to the aquatic life and for environment. In this regard, the activated carbon produced from this study could be an effective and potential adsorbent to remove heavy metals from industrial effluent and thereby to save our environment.

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