

Adsorption of Lead(II) and Cadmium(II) ions from aqueous solutions by adsorption on activated carbon prepared from cashew nut shells

S. Tangjuank, N. Insuk, J. Tontrakoon, V. Udeye

Abstract—Cashew nut shells were converted into activated carbon powders using KOH activation plus CO₂ gasification at 1027 K. The increase both of impregnation ratio and activation time, there was swiftly the development of mesoporous structure with increasing of mesopore volume ratio from 20-28% and 27-45% for activated carbon with ratio of KOH per char equal to 1 and 4, respectively. Activated carbon derived from KOH/char ratio equal to 1 and CO₂ gasification time from 20 to 150 minutes were exhibited the BET surface area increasing from 222 to 627 m².g⁻¹. And those were derived from KOH/char ratio of 4 with activation time from 20 to 150 minutes exhibited high BET surface area from 682 to 1026 m².g⁻¹. The adsorption of Lead(II) and Cadmium(II) ion was investigated. This adsorbent exhibited excellent adsorption for Lead(II) and Cadmium(II) ion. Maximum adsorption presented at 99.61% at pH 6.5 and 98.87% at optimum conditions. The experimental data was calculated from Freundlich isotherm and Langmuir isotherm model. The maximum capacity of Pb²⁺ and Cd²⁺ ions was found to be 28.90 m².g⁻¹ and 14.29 m².g⁻¹, respectively.

Keywords—Activated carbon, Cashew nut shell, Heavy metals, Adsorption

1. INTRODUCTION

Water pollution is serious problem of the environment. The increasing in the use of major 20 heavy metals from over the past few decades has inevitably resulted an increasing flux of metallic substances in natural source of water. Resulting from many industries such as tannery, mining, alloying and battering produce significantly major hazardous heavy metal ions such as lead, cadmium and mercury [1]. All lead compounds are considered cumulative poisons. Acute lead poisoning can effect nervous system and gastrointestinal track [2]. The harmful of cadmium include number of acute and chronic disorders such as “itai-itai” disease,

F. A. Author is Assistant Professor at Department of Physics, Uttaradit Rajabhat University, Uttaradit, 53000 Thailand (phone: 66-5541-1096 ext. 1304 ; fax: 66-5541-1096 ext. 1312; e-mail: singhadejt@yahoo.com).

S. B. Author, she is now with the Department of Chemistry, Uttaradit Rajabhat University, Uttaradit, Thailand 53000 (e-mail: siwathida_b@hotmail.com).

T. C. is Associate Professor at Physics Department, Chaing Mai University, Chaing Mai, 50200 Thailand.

Fo. A. Author is with the Chemistry Department, Naresuan University, Pitsanulok, 65000 Thailand, (e-mail: vudeye@hotmail.com).

emphysema and hypertension [3]. Conventional technique for heavy metals removal water and wastewater including electroplating, evaporating, oxidation, reduction, membrane separation, ion exchange and adsorption. Among these methods, adsorption is worthy economical and effective [4]. Various adsorbents such as silica gel, alumina clay, synthetics polymer resins and carbonaceous materials are used in adsorption method [5]. The activated carbon is the major applying for removal heavy metals adsorption [6], [7]. Agriculture wasted is highly uses as raw material for produce the activated carbon because large quantity of unused and low cost on the production [8]. In recently, activated carbons can be commonly produced from coal, wood or agricultural wastes such as coconut and palm shell, corncob, rich husk, etc., activated by physical or chemical process. Because of their special pore structure, they have super adsorption capacity and are generally used in variety industrial and domestic fields, such water treatment, solvent decolourization, catalyst supports of fuel cell and supercapacitors [9]. In recent years, there is growing interest in the production of activated carbons from agricultural by-products and residual wastes. In previous studies, many researchers found that activated carbons from coconut shells [10], and pistachio shells [11] by KOH activation and CO₂ gasification are essentially microporous with a fairly high surface area [12]. Chemical carbonization of baggage with concentrated sulfuric acid at a 4: 3 ratio and subsequent CO₂ activation at 900oC produced activated carbons with high surface areas (403-1433 m².g⁻¹) [13]. The above mentioned studies show that KOH activation and CO₂ gasification enhance high surface area in activated carbon. However, there are few reports on the preparation and characterization of activated carbons derived from cashew nut shells [14] - [16] but the study about how to prepare activated carbon from cashew nut shells with large surface area is scarce in literature. The cashew tree, *Anacardium occidentale* Linn., is a native plant of eastern Brazil and is introduced into other tropical countries such as India, Africa, Indonesia and South East Asia in the 16th century. It is now found widely in other parts of Central America and the Southern of Thailand, cashew nut shells are usually neglected and abundant agricultural waste. The cashew nut shells have found important commercial usage as the phenolic raw material for the manufacture of certain resins and plastics having unusual electric and frictional properties. Therefore, it is interesting to develop the cashew nut shells as activated carbons with large surface area.

The objectives of this work are to prepare activated carbons from cashew nut shells using KOH activation under N₂ and CO₂ atmosphere. The prepared activated carbon which characterized their properties from typical technique was use for removal of lead(II) and

copper(II) ions in aqueous solutions by batch method. The parameters such as effect of initial pH of heavy metal solution, contact time, dosage of activated carbon, and initial concentration of heavy metals were studied.

2. EXPERIMENTAL

2.1. Preparation of activated carbon

Chars were prepared from cashew nut shells by carbonization in the absence of air. These chars were well mixed with water and KOH in a glass beaker with the weight ratios of KOH per char equal to 1 and 4. The mixed chars were dried in oven at 120°C for 24 h to obtain the dried mixtures consisting of chars and KOH. The dried mixtures were heated in oven from room temperature to 850°C (1027 K) with a rate of 15 °C.min⁻¹, and temperatures for 20 to 150 minutes. When the time was up, the nitrogen gas was switch off and CO₂ immediately flowed into the oven. The activated carbons obtained were thoroughly washed with distilled water several times, dried at 110°C, cooled at room temperature and stored in desiccators for activated carbon characterization.

2.2. Characterization of the produced activated carbon

FT-IR spectrometer (Spectrum GH, Perkin Elmer) was employed to determine the presence of surface functional groups in samples and samples were analyzed as KBr pellets. The change of crystal structures was characterized by X-ray diffractionmeter (XRD) with CuK- α radiation (Siemens, D-500). The microstructure of activated carbon was investigated with Scanning electron microscope (LEO, Model 1455VP). The BET surface area of the activated carbon was obtained from the N₂ adsorption isotherm at 77K with adsorption meter (Micromeritics, Porous Materials, BET-2020). The yield was calculated by the following formula as in (1);

$$\% \text{yield} = (\text{weight of the final products}) / (\text{weight of the initial samples}) \times 100. \quad (1)$$

2.3. Adsorption experiments

The activated carbon which has highest BET surface area (1127 m².g⁻¹) were chosen as adsorbent for adsorption of heavy metals solution. The adsorption of Pb(II) and Cd(II) ions from aqueous solution was investigated by batch method. The effect of initial pH, contact time and activated carbon dosage and initial heavy metals concentration were studied. The aqueous which aliquots of 50 mL of Pb(II) and Cd(II) solution of 40 mg.L⁻¹ were poured into Erlenmeyer flask(100 mL) containing accurately weight amount of activated carbon which used as adsorbents. The required initial pH of solution were adjusted by adding 0.1 M HCl or NaOH. Then, the flasks were shaken continuously at 200 rpm by auto-shaker for prescribed length of time attain to equilibrium. After filtration through Whatman filter paper, Pb(II) and Cd(II) ions remaining in the solution were determined by atomic adsorption spectrometer(Varian SpectraAA 220).

The amount of metals ion adsorbed[17] was calculated in percentage(%) and metal uptake(q_e) as in (2) and (3);

$$\% \text{ Adsorption} = (C_i - C_e) / C_e \times 100 \quad (2)$$

$$q_e = (C_i - C_e) V / 1000 w \quad (3)$$

where C_i is the initial concentration (mg.L⁻¹)
C_e is metal concentrations at various time interval (mg.L⁻¹)
V is the volume of the heavy metal solution (mL)
w is the mass of adsorbent(g)

The Freundlich equation [18]-[21] is in the linearise form as in (5);

$$\log q_e = 1/n (\log C_e) + \log k \quad (5)$$

where q_e is the metal ions adsorbed(mg.g⁻¹) at equilibrium
C_e are the equilibrium concentration(mg.L⁻¹)
k is Freundlich constant with multilayer adsorption
n is adsorption intensity

The Langmuir equation [22] is in the form as in (6);

$$C_e / q_e = 1/q_{max} K_L + C_e / q_{max} \quad (6)$$

where q_e is the metal ions adsorbed(mg.g⁻¹)
C_e are the equilibrium concentration(mg.L⁻¹)
q_{max} is monolayer adsorption capacity(mg.g⁻¹)
K_L is Langmuir adsorption constant

Langmuir and Freundlich isotherms were obtain from the experiments.

3. RESULTS AND DISCUSSION

3.1. Effects of KOH/char and activation time

Fig. 1 shows the effects of the activation time on the yield of activated carbons. It can be seen that, an increase of activation time decreases the yield of activated carbons. For the activated carbons of group with KOH/char ratio equal to 4, the yield decreased from 82-64% with the increase of the activation time from 20–150 minutes. For the activated carbons of group with KOH/char ratio equal to 1, the yield decreased from 77-60% with the increase of the activation time from 20–150 minutes. The results indicate that with increase of the activation time the yield of group with KOH/char ratio equal to 1 are lower than that of group with KOH/char ratio equal to 4. This is due to the occurrence of the activation reaction between CO₂ and carbons, so the longer activation time favors the progress of activation reaction, which increases in the degree of burning of the produced carbon. However, a large amount of KOH enveloped the carbon, thus lowered the reaction between CO₂ and carbon, resulting of decrease in the degree of burning of the produced carbon.

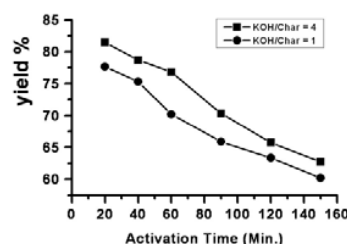


Fig. 1. Effect of activation time on yield(%) of the activated carbons.

3.2. Surface chemistry

The adsorptive capacity of the activated carbon is influenced by its surface chemical structure. The functional groups suggested most

often in activated carbon are carboxyl groups, phenolic hydroxyl groups, carbonyl groups and lactone groups [24]. The FTIR spectra of activated carbon are shown in Fig. 2. The spectra were recorded from 4000 cm^{-1} to 400 cm^{-1} . The FTIR spectrum of the raw cashew nut shell (Fig. 2a) was quite similar to that of rockrose [25], which is also a type of lignocellulosic materials. The band at about 3436 cm^{-1} was attributed to $\nu(\text{O-H})$ vibrations in hydroxyl groups or surface-bonded water. The location of hydrogen-bonded OH groups is usually in the range of 3200-3650 cm^{-1} for alcohols and phenols. The band located around 2923 and 2852 cm^{-1} corresponded to $\nu(\text{C-H})$ vibrations in methyl and methylene groups [26], [27]. The $\nu(\text{C=C})$ vibrations can also be inferred from peak in the region of 1631 cm^{-1} . The band around 1457 cm^{-1} corresponded to carboxylate groups (-COOH). The band shows around 1113 cm^{-1} referred to the vibration of the C-O group in lactones [28]. The band at 1384 cm^{-1} could be attributed to $\nu(\text{C-O})$ vibrations in carboxylate groups. The appearance of bands between 1300 and 900 cm^{-1} could be assigned to C-O stretching vibrations. Absorption due to $\gamma(\text{C-H})$ bending occurred at 776 cm^{-1} whilst $\gamma(\text{O-H})$ bending attributed to the absorptions at 579 cm^{-1} . For activated carbons with KOH/char ratio equal to 1 with activation time 20 min (Fig. 2b) and 60 min (Fig. 2c), appearance of bands located at 2335 and 1740 cm^{-1} which could be assigned to the C=O stretching vibrations in ketones or carbonyl groups [29] while the bands at 2923 and 2852 cm^{-1} disappeared. The decreasing of the intensity of the peaks between 3436 cm^{-1} indicated a decomposition of the cellulose-based cashew nut shell structure and the loss of surface-bonded moisture. Besides these peaks, the other bands in all activated carbons were quite similar even though the magnitude of the bands decreased with increasing activation time, which suggested that they have similar structures. These trends were also consistent with the activated carbons with KOH/char ratio equal to 4 (Fig. 2d-2e). These results agree with the surface chemistries of other agricultural by-products, such as peach stones [30] and pistachio-nut shell [31].

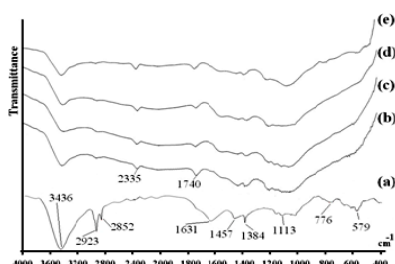


Fig.2. FTIR spectra of the cashew nut shell and activated carbons; (a) the cashew nut shell, (b) KOH/Char = 1 with activation time 20 min, (c) KOH/Char = 1 with activation time 60 min, (d) KOH/Char = 4 with activation time 20 min, (e) KOH/Char = 4 with activation time 60 min.

3.3. X-ray analysis

Fig. 3 shows the X-ray diffraction profile of the raw cashew nut shell and the prepared activated carbons at different times and KOH/Char ratios. The raw material (Fig.3a) had a less organized structure with no indication of any specific crystalline structure probably due to the various organic impurities and volatile matters present within the structure. For char (Fig. 3b), there appeared to have a peak at around $2\theta = 26^\circ$. Whilst at a furnace temperature of 850 $^\circ\text{C}$, much of the volatiles and other impurities would have been released and therefore there was formation of any crystalline structures for activated carbons (Fig. 3c-3f). The results indicated that the diffraction profiles of all activated carbons exhibited broad

peaks and the absence of a sharp peak revealed a predominantly amorphous structure, and two broad peaks seemed to appear at around $2\theta = 26^\circ$ and 43° which were similar to the peaks of crystalline carbonaceous structure such as graphite (JCPDS). In addition, increasing activation time (Fig. 3c-3f) resulted in slightly sharper peak at around 43° , signified an increasing regularity of crystal structure and resulted in better layer alignment. However, the XRD peaks of group of KOH/char ratio equal to 1 (Fig. 3c and 3d) and 4 (Fig. 3e and 3f) were very similar. This indicated that the KOH effect was not significant for development structure.

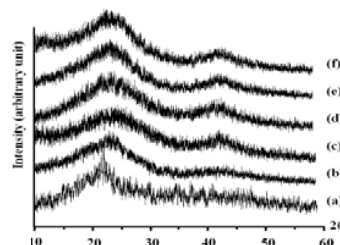


Fig.3. XRD patterns of the cashew nut shell, char and activated carbons; (a) Cashew nut shell, (b) Char, (c) KOH/Char = 1 with activation time 20 min, (d) KOH/Char = 1 with activation time 60 min, (e) KOH/Char = 4 with activation time 20 min, (f) KOH/Char = 4 with activation time 60 min.

3.4. Microstructure

Typical SEM microstructures of various conditions of activated carbon from cashew nut shell are shown in Fig. 4a-4g. The char surface (Fig. 4a) shows the irregular structure with prolonged slit pores of the order of 10 μm . Activation of the sample for KOH/Char equal to 1 produced the irregular structure with rough texture and a large number of shallow cavities on the surface (Fig. 4b-4d). With the increase of activation time from 20 to 120 minutes, the random arrays of pore structures had more appeared due to the progress of activation reaction between CO_2 and carbon and the release of the volatile. On the other hand, the increasing both of impregnation ratio and activation time, more pores appear in the interporous areas. With increasing of ratio of KOH/char from 1 to 4 resulted in significantly different of surface and pore structures as observed in Fig. 4e - 4g. For the ratio of KOH/Char equal to 4 with activated time 20 min (Fig. 4e), the surface was enveloped with an amount of KOH and interspersed with generally large pores due to some of the volatiles being evolved. When the activation time was increased from 20 to 120 minutes, decreased the amount of KOH on the surface (analogous to release of volatiles), and there are many uniformly pore structures and becoming honeycomb shape as shown in Fig. 4f-4g. This is because at prolonged activation time favors the progress of activation reaction between CO_2 and carbon, the surface was destroyed by violent activation and large pore numbers were created with increased activation time (analogous to release of volatiles) [32]. Meantime, there were the development of porosity due to reaction between KOH and carbon. This is attributed to the fact that the most of KOH seeped deeply into the interior of char; while at higher KOH/Char ratio, the more severe etch of the wall takes place to create a great quantity of micropores, resulting in an increase in the pore volume [33]. This difference in the development of pore structure can also exhibit the apparently larger BET surface area of the resulting activated carbons produces with higher impregnation ratio of KOH. Furthermore, the SEM result shows that the activated carbon appears to have well developed macropores of the order of 10-30 μm .

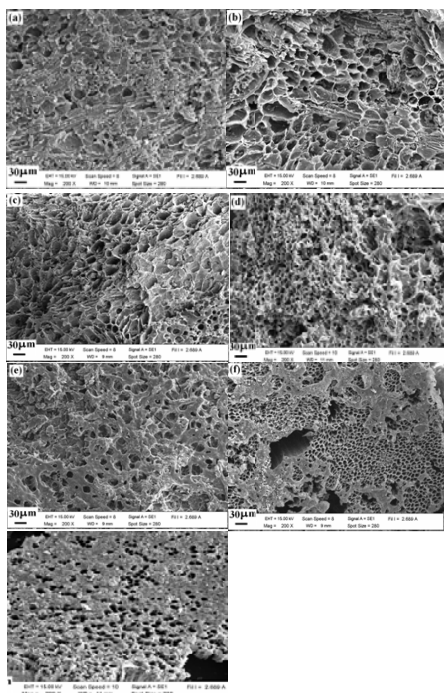


Fig.4. SEM micrographs of the char and activated carbons; (a) Char, (b) KOH/Char = 1 with activation time 20 min, (c) KOH/Char = 1 with activation time 60 min, (d) KOH/Char = 1 with activation time 120 min, (e) KOH/Char = 4 with activation time 20 min, (f) KOH/Char = 4 with activation time 60 min, (g) KOH/Char = 4 with activation time 120 min.

3.5. Surface area

The effect of KOH/Char has shown in table. 1. It can be seen that the activated carbon with KOH/char ratio equal to 4 and CO₂ gasification time from 20 to 150 min exhibited higher BET from 682 to 1120 m².g⁻¹ and pore volume from 0.3675 to 0.5789 cm³.g⁻¹. This is due to at a longer CO₂ activation time, there is an sufficient amount of CO₂ reacting with the carbon to produce pores, while at higher KOH/Char ratio, the more severe etch of the wall takes place to create a great quantity of micropores, resulting in an increase in the pore volume and the high BET is obtained. In the classification by the International Union of Pure and Applied Chemistry (IUPAC), pores are classified as micropores (< 2 nm diameter), mesopores (2-50 nm diameter) and macropores (>50 nm diameter). It can be seen from table.1 that all activated carbons prepared at different ratio of KOH/Char are composed mainly of mesopore with a pore size about 2.1–2.3 nm; with increasing of KOH/Char, the ratio of mesopore volume and the pore volume increase. For the activated carbon with KOH/char ratio of 4 with activation time of 20-150 minutes, there was swiftly the development of mesoporous carbon with increase of mesopore volume ratio from 28-46%, with the average pore size being 2 nm, while mesopore volume ratio of KOH/char ratio of 1 increases slowly from 21-28%. With increasing activation time, probably due to the violent attack of carbon by chemical materials, the opening of pores is clearly damaged and partly burnt, resulting in the widening of pore diameters, i.e. the increasing of mesopore volumes and decreasing of micropore volumes. These results indicate that the increase in activation time and the KOH/Char weight ratio produces an increase in pore and mesopore volumes. Therefore, in this work cashew nut shells activated carbon had predominantly

mesopores, which make them more suitable for liquid-phase adsorption for example wastewater treatment or drinking water purification. It was found that the KOH activation could provide the activated carbon with relatively high levels of BET surface area when compared to other activation methods. Based on this observation, it can suggest that cashew nut shell is a good material for the preparation of a high quality activated carbon.

Table 1 Physical properties of activated carbons derived from cashew nut shells under different.

Sample	Gasification time (min.)	BET (m ² .g ⁻¹)	Pore volume (cm ³ .g ⁻¹)	Average pore size (nm)
1	20	222	0.1127	20.35
	40	263	0.1321	20.11
	60	272	0.1389	20.48
	90	285	0.1450	20.36
	120	553	0.2802	20.26
	150	627	0.3142	21.46
4	20	682	0.3675	21.57
	40	699	0.3682	21.07
	60	819	0.4258	20.80
	90	828	0.4431	21.42
	150	995	0.5677	21.63
		1120	0.5789	22.57

3.6. Adsorption Efficiency

The pH of the aqueous solution is an important controlling parameter in the adsorption process. The effect of initial pH on the adsorption is exhibited in Fig. 4. The result of Pb(II) and Cd(II) ions from Fig. 5 exhibited in the high range 97.50 to 99.13 %. The maximum adsorption efficiency for both of Pb(II) and Cd(II) ion was obtained at pH 6.0-6.5 respectively. The pH of the solution at the equilibrium increased initial pH from 6.0-6.5 to 7.0-7.75. The pH of the initial solution are affected variables in the adsorption process that treated surface charge of the adsorbent and degree of specification and ionization of activated carbon. Between pH 6.0-6.5, the surface is negative charge on the surface of the adsorbent increase there for Pb²⁺ and Cd²⁺ could be enhanced the physical sorption on active site. Thus, the optimum condition value were chosen at 6.0 for Cd(II) and 6.5 for Pb(II) adsorption for further experiments.

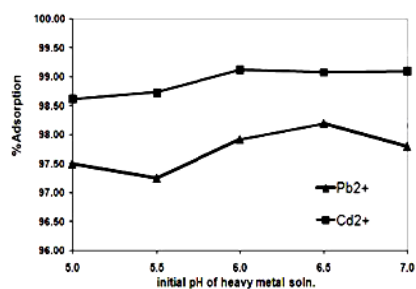


Fig. 5. Effect of initial pH on adsorption of Pb(II) and Cd(II) solutions(initial concentration 40 mg.L⁻¹, contact time 30 min. , 0.6 g Activated carbon/solution 50 mL and temp. 303 K).

The effect of the contact time on adsorption of Cd(II) and Pb(II) ions is presented in Fig. 6. For Cd(II), the adsorption equilibrium are obtained at 30 to 120 minutes which showed high range of adsorption of 99.68-99.83%, respectively. The percentage removal of Cd(II) ions increase rapidly from 5 to 30 minutes and then

close to constant value of adsorption efficiency although further increasing contact time till 120 minutes. Thus, the equilibrium contact time of 30 minutes for Cd^{2+} adsorption could be required because of the adsorbate diffused around adsorbent particle and penetrated into internal pore. Though, the equilibrium of the contact time on adsorption of Pb(II) ion was attained after shaking 5 to 30 minutes, then desorption are received. However, it could be re-adsorbed at high efficiency are shown at 90 to 120 minutes. However, from the results, the agitation time required for uptake of Pb(II) ions and Cd(II) ion were fixed at 30 minutes for another next parameter to make sure that the equilibrium was accomplished. As seen from Fig. 5, Pb^{2+} ions exhibited greater attributed than Cd^{2+} ions.

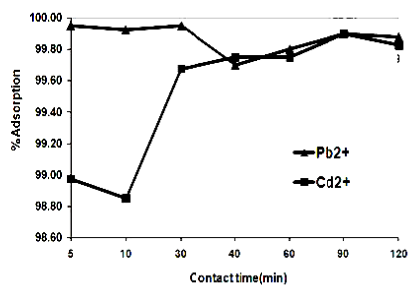


Fig. 6. Effect of contact time on adsorption of Pb(II) and Cd(II) ions (initial concentration 40 mg.L^{-1} , initial pH of heavy solution of Pb(II) 6.5 and Cd(II) 6.0, 0.6 g Activated carbon/ solution 50 mL and temp. 303 K).

The effect of activated carbon dosage on adsorption of Cd(II) and Pb(II) ions is shown in Fig. 7. For both of heavy metal ion adsorption, the optimum of adsorbent were chosen as 0.6 g per 50 mL of solution. However, the increasing of removal adsorption percentage while increasing adsorbent dosage up to certain quantity and then seem to be almost constant. Thus, sufficiency site are mainly essential for adsorption of heavy metal solution. The high BET surface of activated carbon prepared from cashew nut shell which total external and internal active pore site could be indicated predominary the adsorption efficiency. Because of very tiny of adsorbent with short contact time are the important point for economical wastewater treatment application [20]. Therefore, the high percentages of adsorption could be indicated that activated carbon from cashew nuts that play as excellent adsorbent.

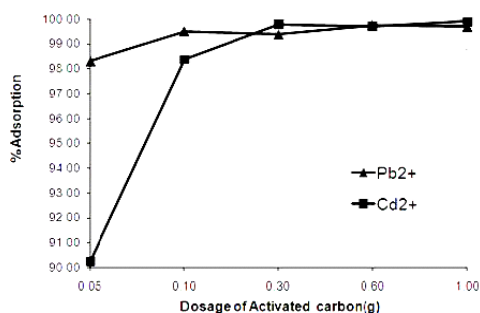


Fig. 7. Effect of activated carbon dosage on adsorption of Pb(II) and Cd(II) ions (initial concentration 40 mg.L^{-1} , initial pH of heavy solution of Pb(II) 6.5 and Cd(II) 6.0, contact time 30 min. and temp. 303 K).

The effect of initial concentration on the percentage removal of Pb(II) and Cd(II) ions by activated carbon prepared from cashew nut shell is shown in Fig. 8. where it is seen that the adsorption of Pb(II) ions decrease from 99.9% to 99.28% and Cd(II) ions is decrease from 99.6% to 91.45%, respectively. For this case, the increase of solution concentration leads to a significantly decrease of the adsorption. Cadmium ions has significantly decrease of adsorption capacity more than Pb(II) ions. This was due to high initial concentrations the number of mole of heavy Pb(II) and Cd(II) ions available to the surface are very high, so functional adsorption become dependent on initial concentration. This characteristic indicated that surface saturation was dependent on initial metal ions concentration.

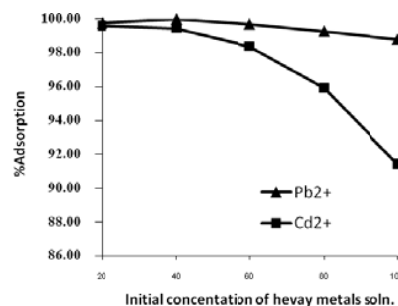


Fig. 8. Effect of initial concentration of heavy metals solution on adsorption of Pb(II) and Cd(II) ions (initial pH of heavy solution of Pb(II) 6.5 and Cd(II) 6.0, contact time 30 min., 0.6 g Activated carbon/solution 50 mL and temp. 303 K).

Freundlich and Langmuir constant and regression coefficient calculated from the adsorption data are given in Table 2. The values of regression coefficient (R^2) of both model close to linear are suitable for describing the adsorption of lead [34]. Hence, the adsorption both of heavy metals activated carbon prepared from cashew nut shell seem to be favorable. But cadmium adsorption fitted the Freundlich more than Langmuir model. The adsorption capacity of activated carbon prepared from cashew nut shells for uptake of Pb(II) and Cd(II) ions is 28.90 and 14.29 mg.g^{-1} , respectively.

Table 2 Values of Freundlich and Langmuir constants for adsorption of Pb(II) and Cd(II) ions.

Heavy metals	Freundlich constant				Langmuir constants		
	q_{max}	K	$1/n$	R^2	Adsorption capacity $q_{max} (\text{mg/g})$	K (L/mg)	R^2
Lead(II)	1.320	0.859	0.168	0.945	28.90	0.0029	0.922
Cadmium(II)	1.390	0.289	0.161	0.933	14.29	0.1280	0.845

The comparison of adsorption capacity of various adsorbents for lead and cadmium ions taken from literatures are showed in Table 3. From these results could be assess the quantitatively the binding capacities of prepared activated carbon from cashew nut are competitive when compare other adsorbent. However, prepared activated carbon exhibited preferred Pb(II) ions adsorption more than Cd(II) ions adsorption.

Table 3 Comparison of adsorption capacity of various sorbent for Pb(II) and Cd(II).

Sorbent	Adsorption capacity(mg/g)		pH	C ₀ (mg/L)	Reference
	Pb(II)	Cd(II)			
Coconut shell carbon	26.50	-	4.5	50	[35]
Eichhornia activation	16.58	9.30	3.0	50	[1]
Hazelnut husk A.C.	13.05	-	5.7	40	[17]
Ceiba Pentandra hulls	-	19.50	5.7	80	[20]
Cashew nut shells A.C.	28.90	14.29	6.0-6.5	40	This study

4. CONCLUSIONS

A high BET surface area activated carbons could be prepared from cashew nut shells by KOH activation plus CO₂ gasification. FTIR spectrum of activated carbons exhibited the presence of different oxygen groups, and aromatic carbon structures. The X-ray diffraction profiles showed a predominantly amorphous structure, and two broad peaks seemed to appear at around $2\theta = 26^\circ$ and 43° which were similar to the peaks of crystalline carbonaceous structure such as graphite. SEM photographs showed that the structure of activated carbons composed of a great porous with honeycomb shaped and increased with increase of KOH/char ratio and gasification time. Increasing activation time from 20 to 150 min resulted in higher values of BET surface area, pore volume and ratio of mesopore volume. The activated carbons prepared at an activation time of 150 minutes with KOH/char ratio to 4 yielded the highest BET surface area (1120 m².g⁻¹). The optimum conditions of lead and lead showed highly 99.90% and 98.87%, respectively. The adsorption capacity of both of heavy metals exhibited high values that use as beneficial adsorbent. The study indicated that activated carbon prepared from cashew nut shells could be use as an effective adsorbent for the treatment of lead and cadmium aqueous wastewater.

Acknowledgment

The authors are very grateful to the Thailand Research Fund (TRF), Commission on Higher Education and Thailand Toray Science Foundation(TTSF) for the financial support.

REFERENCES

- [1] K. Kadirvelu, J. Goe, I. Rajagopal, Sorption of lead, mercury and cadmium ions in multi- component system using carbon aerogel as adsorbent, *J. Hazard. Mater.*, vol. 153 pp. 502-507, 2008.
- [2] K.Zhang, W.H. Cheung, M. Valix, Roles of physical and chemical properties of activated carbon in the adsorption of lead ions, *Chemosphere.*, vol. 60, pp. 1129-1140, 2005.
- [3] S. Cay, A. Uyanik, A. Ozasik, Single and binary component adsorption of copper(II) and cadmium(II) from aqueous solutions using tea-industry waste, *Sep. Purif. Technol.*, vol. 38, pp. 273-280, 2004.
- [4] G.P. Park, W.K. Tae, Y.C. Myeoung, K.Y. Ik, Activated carbon-containing alginate adsorbent for the simultaneous removal of heavy metals and toxic organics, *Process. Biochem.*, vol. 42 (2007) 1371-1377.
- [5] A.K. Gupta, K. Ganeshan, K. Sekhar, Adsorptive removal of water poisons from contaminated water by adsorbents, *J. Haz. Mat. B.*, vol. 137, pp. 396-400, 2006.
- [6] Dabrowski, Adsorption-from theory to practice, *Adv. Coll. Interf. Sci.*, vol. 93, pp. 135-224, 2001.
- [7] J.W. Kim, M.H. Sohn, D.S. Kim, S.M. Sohn, Y.S. Kwon, Production of granular activated carbon from waste walnut shell and its adsorption characteristics for Cu²⁺ ion, *J. Haz. Mat.*, vol. 85, pp. 301-315.
- [8] A. Kuniawan, G.Y. Chan, W. Lo, S. Babel, Comparisons of low-cost adsorbents for treating wastewaters laden with heavy metals, *Sci. Total. Environ.*, vol. 366, pp. 409-429, 2006.
- [9] D. Yang, U. X, Studies of the activated carbons used in double-layer supercapacitors, *J. Power. Source.*, vol. 109, pp. 403-411, 2002.
- [10] H.Z. Guo, H. Srinivasan, M.P. Yaming, A simple method for developing mesoporosity in activated carbon. *Sep. Purif. Technol.*, vol. 31, pp. 47-52, 2003.
- [11] R.L.Tseng, S.K. Tseng, F.C. Wu, Preparation of high surface area carbons from corncob with KOH etching plus CO₂ gasification for the adsorption of dyes and phenols from water, *Coll. Surface A.*, vol. 279, pp. 69-78, 2006.
- [12] Y. Guo, K. Yu, Z. Wang, H. Xu, Effects of activation conditions on preparation of porous carbon from rice husk, *Carbon.*, vol.41, pp. 1645-1648, 2003.
- [13] M. Valix, W.H. Cheung, G. McKay, Preparation of activated carbon using low temperature carbonisation and physical activation of high ash raw bagasse for acid dye adsorption, *Chemosphere.*, vol.56, pp. 493-501, 2004.
- [14] N. Kannan, A. Rajakumar, Kannan, N., Rajakumar, A., 2003. Suitability of various indigenously prepared activated carbons for the adsorption of mercury(II) ions. *Toxicol. Envi. Chem.*, vol.84, pp. 7-19, 2003.
- [15] V. Srihari, B.S. Madhan, A. Das, Kinetics of phenol-sorption by raw agro-wastes, *J. Appli. Sci.*, vol. 6, pp. 47-50, 2005.
- [16] R. Sivabalan, S. Rengaraj, B. Arabindoo, V. Murugesan, Cashew nut sheath carbon : A new sorbent for defluoridation of water, *Ind. J. Chem. Technol.*, vol. 10, pp. 217-222, 2003.
- [17] M.Immamuglu, O. Tekir, Removal of copper (II) and lead (II) ions from aqueous solutions by adsorption on activated carbon from a new precursor hazelnut husks, *Desalination.*, vol. 228, pp. 108-113, 2008.
- [18] C.S. Liang, Z. Dang, B.H. Mao, W.L. Huang, C.Q. Liu, Equilibrium sorption of phenanthrene by soil humic acids, *Chemosphere.*, vol. 63, pp.1961-1968, 2006.
- [19] M.H. Kalavathy, T. Karthikeyan, S. Rajgopal, L.R. Marinda, Kinetic and isotherm studies of Cu(II) adsorption onto H₃PO₄-activated rubber wood sawdust, *J. Coll. Interface Sci.* vol. 292, pp. 354-362, 2005.
- [20] [20] M.M. Rao, A. Ramesh, G.P.C. Rao, K. Seshiah, Removal of copper and cadmium from the aqueous solutions by activated carbon derived from Ceiba pentandra hulls, *J. Haz. Mat.*, vol. 129, pp. 123-129, 2006.
- [21] M. Machida, R. Yamazaki, M. Aikawa, H. Tatsumoto, Role of minerals in carbonaceous adsorbents for removal of Pb(II) ions from aqueous solution, *Sep. Purif. Technol.*, vol. 46, pp. 88-94, 2005.
- [22] S.K. Srivastava, R. Tyagi, N. Pant., Adsorption of heavy metal ions on carbonaceous material developed from the waste slurry generated in local fertilizer plants, *Water Res.*, vol. 23, pp. 1161-1165, 1989.
- [23] C.J. Moon, J.H. Lee, Use of curdlan and activated carbon composed adsorbents for heavy metal removal, *Process. Biochem.*, vol. 40, pp. 1279-1283, 2005.
- [24] S. Ricordel, S. Taha, I. Cisse, G. Dorange, Heavy metals removal by adsorption onto peanut husks carbon : characterization, kinetic study and modeling, *Sep. Sci. Technol.*, vol. 24, pp. 389-401, 2001.
- [25] V.S.Gomez, J.V. Pastor, J.F. Perez, C.V. Duran, C.C. Valenzuela, FT-IR study of rockrose and of char and activated carbon, *J. Anal. Appl. Pyro.*, vol. 36, pp. 71-80, 1996.
- [26] T. Nabarawy, N.S. Petro, S. Abdel-Aziz, Adsorption characteristics of coal-based activated carbons. II. Adsorption of Water Vapor, Pyridine and Benzene, *Adsorp. Sci. Technol.*, vol. 15, pp. 47-57, 1997.
- [27] J.L. Figueiredo, M.F.R. Ereira, M.M.A. Freitas, J.J.M. Orfao, Modification of the surface chemistry of activated carbons, *Carbon.* vol. 37, pp. 1379-1389, 1999.
- [28] M.M.J. Davila, M.P.G. Elizalde, A.A.C. Pelaez, Adsorption interaction between natural adsorbents and textile dyes in aqueous solution , *Coll. Surface A.*, vol. 254, pp. 107-114, 2005.
- [29] H.P. Boehm, Some aspects of the surface chemistry of carbon blacks and other carbons, *Carbon.*, vol. 32, pp. 759-769, 1994.
- [30] R. Arriagada, R. Garcia, M.S. Molina, F.R. Rodriguez, Effect of steam activation on the porosity and chemical nature of activated carbons from eucalyptus globulus and peach stone, *Micro. Meso. Mat.*, vol. 8, pp. 123-130, 1997.

- [31] T. Yang, A.C. Lua, Mat. Textural and chemical properties of zinc chloride activated carbons prepared from pistachio-nut shells, *Chem. Phys.*, vol. 100, pp. 438-444, 2006.
- [32] Z. Hu, M.P. Srinivasan, Mesoporous high-surface-area activated carbon, *Micro. Meso. Mat.*, vol. 43, pp. 267-275, 2001.
- [33] Z. Hu, M.P. Srinivasan, Preparation of high-surface-area activated carbons from coconut shell, *Micro. Meso. Mat.*, vol. 27, pp. 11-18, 1999.
- [34] B.V. Babu, S. Gupta, Adsorption of Cr(VI) using activated neem leaves: kinetic studies, *Adsorption.*, vol. 14, pp. 85-92, 2008.
- [35] M. Sekar, V. Sakthi, S. Rengaraj, Kinetics and equilibrium adsorption study of lead(II) onto activated carbon prepared from coconut shell, *J. Coll. Interf. Sci.*, vol. 279, pp. 307-313, 2004.