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Application of Activated Coconut Husk as an Adsorbent in Slow-sand Filtration for Iron Removal

Ogunkeyede A. O.[1,*], Adebayo, A. A.[1], Emegha C.[2], Olomu S.[1]

[1]Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

[2]Department of Chemistry, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

Abstract

The world suffers from water pollution because of anthropogenic and industrial activities. Groundwater sources are polluted with iron, causing an unpleasant taste in water and threatening human lives in the Niger Delta. The permissible limit for iron by WHO is 0.3 mg/L, but the groundwater aquifers in the Niger delta possess 3-6 mg/L. Several methods for iron removal such as ion exchange, oxidation with oxidizing agents such as chlorine and potassium permanganate, supercritical fluid extraction, bioremediation and treatment with limestone are widely documented and practised. However, attention to promising low investment-cost technologies, such as slow sand filtration (SSF) techniques, is surprisingly diminutive. This study explores the application of natural absorbents (coconut husk) in iron removal from prepared solutions of different iron concentrations within and above the suspected groundwater iron concentration range in the Niger Delta aquifer. Concentrations of 3ppm, 6ppm, 9ppm and 12 ppm of iron (III) chloride were prepared, filtered with a slow sand filter labelled (A, B, C) containing different formulations of sand: and activated carbon from coconut husk. The filtrates or eluents were analyzed with an atomic absorption spectrometer with APHA and ASTM standard methods. The activated carbon of coconut husk removed iron to below 0.3 ppm without increasing the pH above the acceptable limit in the experimental tank labelled C. The optimum values for iron removal are 0.35-2.04 ppm, 1.15-1.65 and 0.23- 0.69 0.26- 0.57, a flow rate of 1.83 – 7.13m3/min, which is the contact time with activated carbon with solutions having [Fe] of 3ppm, 6ppm, 9ppm and 12 ppm respectively. The SSF labelled C had the best performance as it removed 89%, 83%, 97% and 98% of iron from 3, 6, 9 and 12 ppm solutions, respectively. The constructed iron removing slow sand filtration system is envisaged to be suitable for household use.

Keywords

Iron; pH; Activated Coconut Husk; Slow Sand Filter; Niger Delta.

1. Introduction

Water pollution arises from both anthropogenic and industrial processes that model the release of toxic substances into the environment. Furthermore, these toxins seep into the aquifer of groundwater sources through infiltration, thereby impairing its quality and posing a threat to all-natural receptors and life forms [1]. Iron in rural groundwater supplies is a common problem. The occurrence of Iron is natural in aquifers, but their concentrations in groundwater can be amplified by the dissolution of ferrous borehole and handpump components. Iron-bearing groundwater is often markedly orange in colour, causing discolouration of laundry, and has an unpleasant taste, which is apparent in drinking and food preparation. Iron dissolved in

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groundwater is in the reduced form of iron II. However, iron oxides formed in reservoirs upon aerial oxidation of dissolved iron promote micro-organism growth in water. Several methods for iron removal, such as the ion-exchange method, oxidation with oxidizing agents such as chlorine and potassium permanganate and aeration, are widely practised [2]. The use of natural resources and traditional methods should be embraced in water purification. Low investment-cost technologies, such as slow sand filtration (SSF) techniques, are promising in water purification. Rural dwellers intermittently apply this method in the removal of contaminants from water. Specifically, iron is a significant contaminant affecting rural areas, and a modification of this slow sand filtration (SSF) system would suffice [3].

Hence, the use of activated carbon from coconut husk in iron removal. Coconut husk constitutes a light, fluffy material generated in separating the fibre from the coconut [4]. Activated carbons from coconut husk have good porosity and high surface area. The adsorption properties of coconut shells are due to the presence of some functional groups, such as carboxylic, hydroxyl, and lactone, which have a high affinity for metal ions. Activated carbon from natural sources is an environmentally friendly approach for iron removal because it does not require chemicals. It is cheap, easy to source, simple to execute, and the process is relatively rapid [5]. It can also be considered a sustainable means for water treatment because it harnesses agricultural waste as a natural adsorbent and develops a cost-effective technology to prevent health disorders due to excess iron in the water [6]. This study investigates the suitability of the activated coconut husk slow sand filtration system for the removal of iron and the effectiveness of the activated carbon coconut husk sand filtration system at removing iron ions from water.

1.1. Construction Mechanism and Materials for Slow Sand Filter

The traditional slow sand filter is a simple filtration system that is a cost-effective way of treating polluted water without requiring a high degree of operational skill or attention. The filter medium consists of a column filled with sand ranging from 0.3mm to 3 mm in diameter. The sand medium is supported by coarse gravel (0.15m) and (0.1m) fine gravel [7]. The water to be cleaned is pumped into the column from the top, and treated water is recovered at the bottom. The influent (water/wastewater/rainwater) is poured into the column at a flow rate through a diffuser plate. Underdrain gravels serve as a filter support material. The physicochemical and microbiological water quality parameters are affected by the depth of the sand bed. To maintain a consistent flow rate, a peristaltic pump and effluent pipe linked to a T with valves on both sides can be employed [8]. To keep the pressure up, a peristaltic pump might be employed. The exact purpose can be accomplished with a simple pressure transmitter with flush diaphragms [9].

1.2. Adsorption Capacity of the Activated Coconut Husk in the Slow Sand Filter Batches A, B and C

The adsorption mechanism is of two types: physical and chemical. The physical adsorption is the binding of the adsorbed species to the binding surface of an adsorbent, while chemical involves reactions between the surface of the adsorbent and the adsorbed substance [10]. The detailed of the adsorption process that occurred in the removal of the of iron from the prepared solution is beyond the scope of the current study. However, the amount of adsorbate binding to the surface of the absorbent per unit mass of the adsorbent called adsorption capacity (AC) will be considered as described with equation 1.

$$\text{Adsorption capacity} = (C_i - C_f) * (V(ml)/W(g)) \quad (1)$$

The adsorption capacity of the adsorbent surfaces used for each batch labelled A, B and C were calculated relative to the quantities of adsorbent used in each batch, which is invariably the quantities of adsorption binding site on the adsorbent. The adsorption capacity of the activated coconut husk was measured against the removal efficiency and pH of each batch set up in this study because it was reported that pH has effect on the adsorption capacity of an adsorbent. Also, it has linear accumulation with metal ion concentration.

2. Materials and Methods

2.1. Raw Materials

Coconut husk and filtration sand are the primary raw materials used in this study.

2.2. Reagents Used

The reagents used are Sodium hydroxide (NaOH), Acetic acid, buffer solutions and iron (III) chloride. They are all Analar Grade

2.3. Instrumentation

The instruments used are a small-scale rotary kiln, Jenway pH meter and Atomic Absorption spectrophotometer (AAS).

2.4. Sourcing and Pre-treatment of Material to Form Activated Carbon

The coconut husks used for preparing activated carbon were prepared following [11] procedure. The coconut husks were gathered from Hausa quarters in Warri, Delta State, Nigeria and washed numerous times using de-ionized water to remove all traces of impurities, oil, dirt, dust, and other contaminants. The material was allowed to dry until a constant weight was obtained. According to past report [12], the carbon preparation was activated by the carbonization of the materials at 700℃ in a small-scale rotary kiln. After cooling to room temperature, the products were soaked with NaOH for 2-3 hours and rinsed with distilled water severally. Then, acetic acid was used to wash the materials to remove excess NaOH before rinsing severally with distilled water until the pH is around 7, and dried at 110℃ for 5 hours before grinding it and sieved through a mesh to obtain 200μm particle size [5].

2.5. Preparation of Iron Solutions in PPM

The 3ppm, 6ppm, 9ppm and 12 ppm iron solutions were prepared by adding the calculated amount of Iron (III) chloride in distilled water. All ppm concentrations were prepared in a 5-litre solution.

2.6. Sampling

The filters were designed and constructed using locally sourced materials such as sand and activated carbon from coconut husk at different layers and quantities. Three different formulations of the sand filter components labelled A, B and C were set up to determine the most efficient formulation for iron polluted water. 50ml of the prepared 3ppm, 6ppm, 9pmm and 12ppm iron solution was passed through the filters at intervals, and the flow rate/contact time was recorded. This sampling exercise was performed in triplicate. These samples were analysed before and after treatment with the modified slow sand filtration techniques. The pH of the prepared iron solution from the outlet was investigated with a handheld pH meter (Jenway pH meter). The iron concentration removed was measured using an atomic absorption spectrometer (Perkin Elmer 1100 model).

3. Results and Discussion

A. Effect of pH

The parameters of the modified slow sand filter batch set up labelled A to C were presented in Table 1. The quantities of sand used were kept constant at 3.2kg, while the quantities of activated coconut husk used increased from 1.48kn in Batch A to 2.22 kg in Batch C. The pH of the initially prepared iron solutions ranged between 3.4 and 3.7 for all the batches set up. The concentration of all iron solutions was acidic; however, there was an increase in the pH levels after filtration. The increase in the pH values indicated the adsorption of the iron by the adsorbent used in this study. The pH directly relates to the solubility of the metal ions, functional groups of the adsorbent, and the degree of ionization of the adsorbate during the reaction [13]. Batch C had the highest pH values after treatment for all the concentrations prepared (3ppm, 6ppm, 9ppm and 12 ppm), ranging from 6.6 to 7.0. The results indicated that the modified slow sand filter could remove the pH of polluted water with Iron ions.

B. Effect of activated carbon (coconut husk)

The quantity of activated carbon used increased from Batch A to C, implying a longer contact time between the prepared samples and the adsorbents, see Table 1. For each prepared iron concentration solution (3ppm, 6ppm, 9ppm and 12 ppm), the concentrations after treatments change after treatments depend on the quantities of adsorbents (activated carbon coconut husk) in each batch labelled A to C. The iron removal efficiency increases by increasing the adsorbent dosage, and more binding sites are available; hence, the efficiency increases, see Fig. 1.

Table 1. The parameters of the modified slow sand filtres for Batch leachates A to C

Batch Set up		A	B	C
Sand (Kg)		3.2	3.2	3.2
Activated carbon (Coconut husk) (Kg)		1.48	1.85	2.22
Flow rate (m^3/min)		7.13±0.97	5.57±2.69	1.82±0.54
Initial pH	3ppm	3.4	3.4	3.4
Final pH		6.5	6.7	6.8
Initial pH	6ppm	3.6	3.6	3.6
Final pH		6.4	6.5	6.6
Initial pH	9ppm	3.5	3.5	3.5
Final pH		6.1	6.7	6.8
Initial pH	12ppm	3.7	3.7	3.7
Final pH		6.5	6.8	7

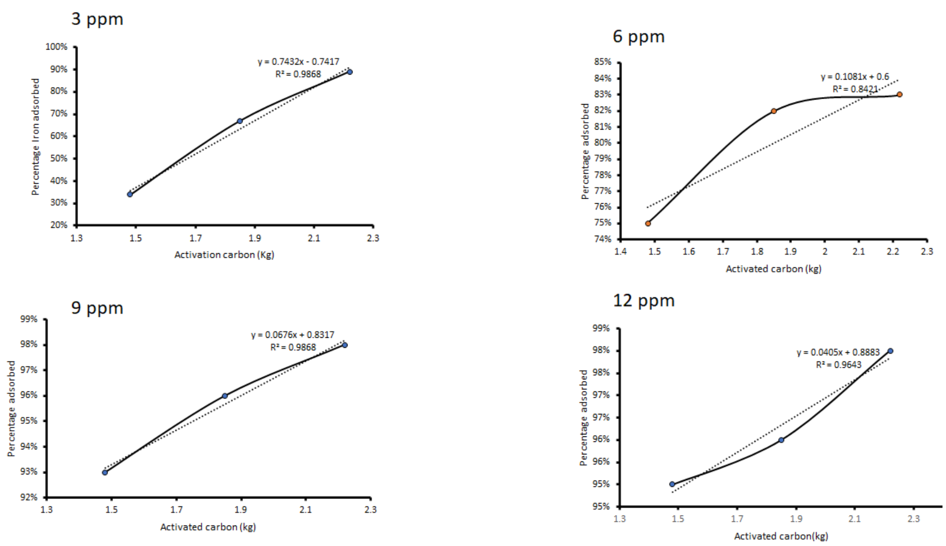

Fig 1. The effect of activated coconut husk carbon on the percentage adsorption of iron at varied concentrations

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The Iron solution concentrations (3ppm, 6ppm, 9 ppm and 12 ppm) change in the final eluents as the number of activated carbon increases in each batch, as shown in Fig. 1. It was observed in this study that Batch C, with the highest quantity of coconut husk (2.22kg), had the maximum percentage amount of iron adsorbed across all the concentrations prepared.

According to report [5], the tendency of iron removal is low at low pH values because of the protonation of its functional groups or competition of H^+ with metal ions for binding sites, as shown in Fig 1. However, activated carbon from coconut husk will ensure an adequate concentration of iron at higher initial concentrations of 9 and 12 ppm. The limited binding site of the activated carbon from coconut husk in Batch A, competing with the protonation of its functional group, resulted in the low tendency of removing iron from the prepared solution (3ppm – 34%, 6 ppm- 75%, 9 ppm- 93 % and 12 ppm- 95%) compared with other batches with increased activated coconut husk carbon. Batch C has the highest adsorbent, and the pH values after treatment were reported for all the concentrations prepared. Moreover, pH 7 and 6.8 had the highest percentage of adsorption. It was [14] reported that filter depth, size and types of the filtrating agents (activated carbon coconut husk), affect the removal efficiency of the slow sand filter. Therefore, the increase in the adsorbent dose in the batch process increases the removal efficiency of the iron from prepared solutions. The results of the variation of the adsorbent active coconut husk with percentage removal of iron from the prepared solution agree with the report of [15] states that there is a linear correlation between metal accumulation and quantities of biomass or adsorbent used for water treatment.

C. Effect of flow rate

The modified slow sand filter batches allow slow movement of the prepared solutions through the bed, which increases the contact time with the adsorption site of the adsorbent used. The flow rate of this study is inversely proportional to the percentage removed from the iron solutions prepared at different initial concentrations of 3 ppm, 6ppm, 9ppm and 12 ppm, respectively. The flow rate of Batch A had the shortest contact time before eluting from the bed, while Batch C had the longest time. The slow filtration *rate of the modified slow sand filter* allows a longer retention time for a supernatant *iron solution* and *water* percolating through the bed, which allows iron ions to be adsorbed to the adsorbent to ensure greater efficiency of the modified slow sand filters. The highest percentage removal was 89%, 83%, 98% for 3ppm, 6pmm, 9ppm and 12 ppm, respectively, which occurred at the lowest flow rate of 1.82±0.54m^3/min in the slow sand filter labelled C. This is in agreement with past [16] reported that an increase in the flow rate decreases the removal efficiency of a filter bed, see Fig. 2.

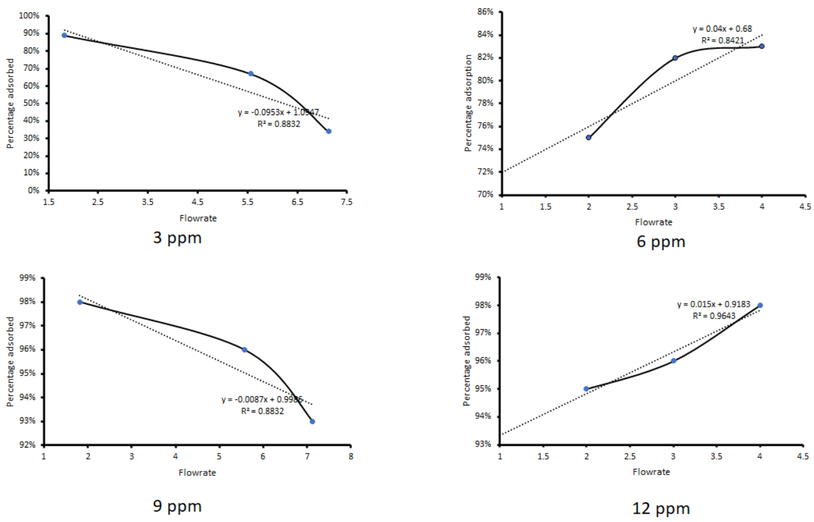

Fig 2. Effect of flow rate on iron removal from prepared iron solutions of 3, 6, 9 and 12ppm concentrations

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D. Effect of adsorption capacity

The adsorption capacity of Batch A increases with the increase in the quantities of adsorbent, which suggested that the adsorption site on the surface adsorbent increases. Similar observation occurred in Batch B and C, see Fig. 3. The adsorption capacity increases with increase in the concentration of the prepared solution. The observation is expected since the final pH of the prepared solutions that eluted from the filtration bed increases with quantities of adsorbent used. It was observed that adsorption capacity of the adsorbent increases with increase in the pH of the solution for 3ppm solution across Batches A, B and C. The phenomenon suggested that the optimum pH was not reached as previously reported by [17]. Figure 4 further shown that there was a declined in the adsorption capacity despite increase in the pH values for other concentration 6 ppm 9 ppm and 12 ppm because the optimum pH of the adsorbent has been reached [17].

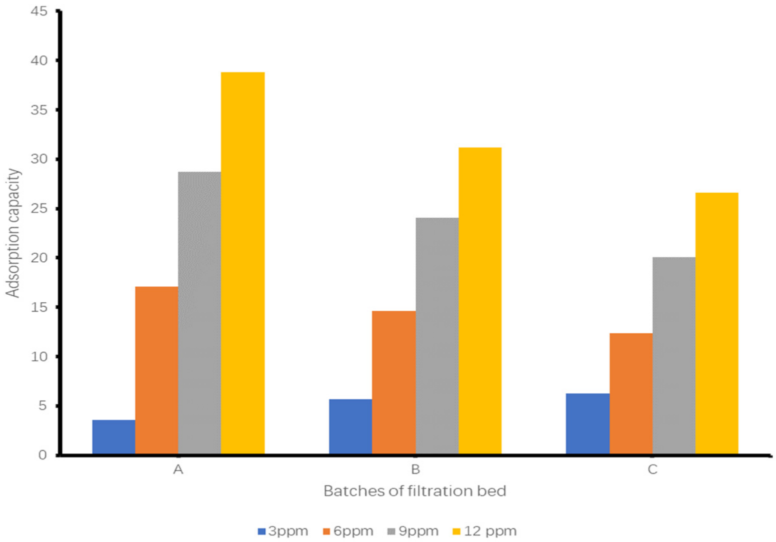

Fig 3. The effect of adsorption capacity per batches of the modified slow sand filtration beds.

The relationship between the adsorption capacity and the percentage adsorbed or removed from the prepared solution depends on the pH, adsorbents and flow rate [14]. Likewise, there is a linear correlation between the percentage of iron removed and the adsorption capacity as demonstrated in Fig. 4. Hence, it means that the increase in the adsorbent quantity in the filter bed, might increase the adsorption capacity and improved the removal efficiency to the modified slow sand filtered bed.

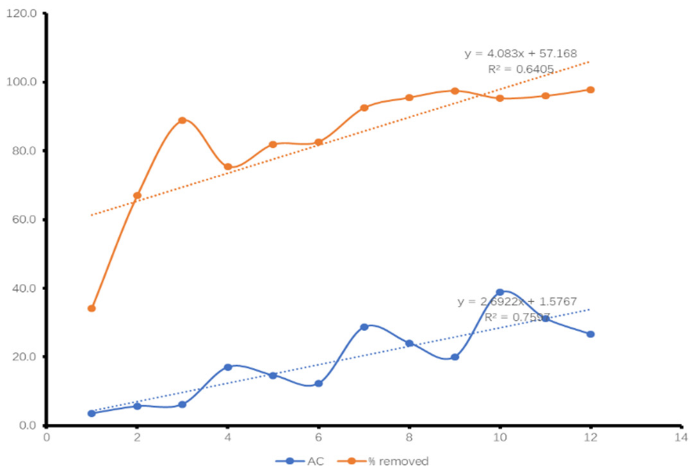

Fig 4. Linear correlation between the adsorption capacity and percentage iron removed from prepared solution

4. Conclusion

This study established that increase in the flow rate of the prepared solution through the adsorbent decreases the removal efficiency of iron in the modified slow sand filtration system, likewise, an increase in the quantity of adsorbent or adsorbent dosage increases the removal efficiency of the modified slow sand filtration system. Also, the quantity of adsorbent used influenced the percentage efficiency of the filter bed because there is a linear relationship between the adsorption capacity of adsorbent and the removal efficiency of the filtration system. Hence, the modified slow sand filter with activated coconut husk carbon as a natural adsorbent is a viable and sustainable technology for iron removal from water. Coconut husk is agricultural waste, easily accessible, eco-friendly and sustainable for removing iron. The filtration process could be scaled up for industrial purposes to reduce wastewater treatment costs.

References

[1] Aniket A. Jinturkar and Parag S. Sadgir removal of iron from aqueous solution using neem leaf powder as an adsorbent, IJIRSET,Vol. 5 (2017), p 8948-8952.

[2] Ellis D., Bouchard C. and Lantagne G. Removal of iron and manganese from groundwater by oxidation and microfiltration, Desalination" Vol. 130 (2000), p 255-264.

[3] Ogeleka, D. F., and Emegha, M. C. Effectiveness of Biosand Filter in rural water purification. Chemistry research journal, Vol 5 (2021) No. 6, p 110-124.

[4] Kadirvelu K. and Namasivayam C., Activated carbon from coconut coir pith as metal adsorbent: adsorption of Cd (II) from aqueous solution, Advances in Environmental Research, Vol. 7 (2002), p 471- 478.

[5] Balaji R., Sasikala S., Muthuraman G. Removal of Iron from drinking/groundwater by using agricultural Waste as Natural adsorbents. International Journal of Engineering and Innovative Technology (IJEIT) Vol. 3(2014) No.12, p 43-46.

[6] Bernard, E., Jimoh, A., and Odigure, J. O. Heavy Metals Removal from Industrial Wastewater by Activated Carbon Prepared from Coconut Shell, Research Journal of Chemical Sciences.Vol.3 (2013) No.8, p 3-9.

[7] Malcolm J. Brandt, K. Michael Johnson, Andrew J. Elphinstonand Don D. Ratnayaka. Water Filtration. Twort's Water Supply (Seventh Edition), (2017) p 367-406.

[8] Keraita B., Drechsel P., Konradsen F. (2008). Potential of simple filters to improve microbial quality of irrigation water used in urban vegetable farming in Ghana. J Environ Sci Heal A. 43:749–755.

[9] Elbana M., de Cartagena F. R., Puig-Bargués J. Effectiveness of sand media filters for removing turbidity and recovering dissolved oxygen from a reclaimed effluent used for micro-irrigation. Agric Water Manage. Vol. 111(2012), p 27–33.

[10] Mokhatab, S., Poe, W. A., and Mak, J. Y. Natural Gas Dehydration and Mercaptans Removal. Handbook of Natural Gas Transmission and Processing, (2019), p 307–348. doi:10.1016/b978-0-12-815817-3.00009-5.

[11] Nwabanne, J.T. and Igbokwe, P.K. Preparation of Activated Carbon from Nipa Palm Nut: Influence of Preparation Conditions. Research Journal of Chemical Sciences, Vol 1(2012), p 53-58.

[12] Yusmartini, eka sri, Setiabudidaya, Dedi, Syarofi, Ridwan, Marsi, Marsi, Faizal, Muhammad. Preparation of Activated Carbons from Coconuts Shell for Pb (II) Adsorption. Advanced Materials Research 869 (2014), p 149-152.

[13] Nomanbhay, S.M. and Palanisamy, K. Removal of heavy metal from industrial wastewater using chitosan coated oil palm shell charcoal. Electron. J. Biotechnol. 8(2005), p 43–53.

[14] Abudi, Z. N. The effect of sand filter characteristics on removal efficiency of organic matter from grey water. Al-Qadisiya Journal for Engineering Sciences, Vol. 4(2011) No. 2, p 143-155.

[15] Muhammad, N. Removal of heavy metals by slow sand filtration, PhD Thesis, Loughborough University, UK 1998.

[16] Muhammad, N., Parr, J., Smith, M. D. and Wheatley, A. D. (2005). Removal of heavy metals from storm and surface water by slow sand filtration: the importance of speciation, Urban Water Journal, Vol. 2(2005) No.1, p 33-37, DOI:10.1080/15730620500042320.

[17] Sheng-Fong Lo, Song-Yung Wang, Ming-Jer Tsai, Lang-Dong Lin. Adsorption capacity and removal efficiency of heavy metal ions by Moso and Ma bamboo activated carbons. Chemical Engineering Research and Design, Vol. 90(2012) No.9, p 1397–1406. doi:10.1016/j.cherd. 2011.11.020.