Study of adsorption of methylene blue in aqueous solution onto activated carbon prepared using low cost domestic oven based heating system

Sinmay Sahoo¹, Maya Devi¹ and Susanta Kumar Das²*
¹ Dept. of Physics, School of Applied Sciences, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar-751024, Odisha, India
² School of Physics, Gangadhar Meher University, Sambalpur-768001, Odisha, India

Abstract. In this work activated carbon was prepared from teak wood charcoal using very low-cost oven based heating system. Firstly, charcoals were grinded with a domestic grinder and then activated with 25% CaCl₂ solution and then heated with 250°C for different times. And then experiment was carried out through 2.5×10⁻⁵ methylene blue aqueous solution by taking activated Charcoal into it and kept one hour for adsorption. Adsorption capacity was estimated by taking the different amount of activated carbon. The result indicates that prepared activated carbon be effectively used for water purification application through adsorption of the dye.

1. Introduction
Activated carbon is a form of carbon that has been processed with oxygen to create millions of tiny pores between the carbon atoms. The internal surface area of commercial activated carbon is ranging from 500 to 1500 mm²/g. Because of its large surface area and high adsorption capacity it has been used for various applications like medical uses, adsorption of natural gas, cosmetics use, for removal of heavy metals, water purification etc. As per the demand of human life, industrial revolution polluting our lakes, oceans and rivers. For which it is damaging our planet and organism die very rapidly. So, water Purification is major and is the most essential component for our life. The deficiency to access clean and fresh water can lead many troubles including sickness, malnutrition and death. So, it is becoming most important for future due to the increase in population, changes in climate, expansion of agricultural and industrial activities with enhancing the living standards. The contamination of water occurs because the industries release many toxic organic dyes, heavy metals and micropollutants into water.
Methylene blue used as a traditional dye for silk wool and cotton also used to make certain body fluids and tissues easier to view during surgery, is one of the toxic dye. Consuming water which contains methylene blue may cause vomiting, mild bladder irritation, dizziness, diarrhoea and the burn effect of eyes. Recently different techniques have already been used for the removal of dye from water and wastewater are biodegradation [1], electrochemical oxidation [2], solvent extraction [3], ion exchange biological purification [4], coagulation & sedimentation techniques and adsorption [5]. However, most of these techniques are comparatively expensive and complicated. But adsorption technique has been preferred because it is quite easy and cost effective as adsorbents, porous solids which generally have a high surface area. So now a days it is quite challenging for developing countries to produce high-efficient and low cost activated carbon. But many problems arise at the time of regeneration of used activated carbon. Many commercial activated carbon has been widely used for the adsorption process.
¹ sinmay1990sahoo@gmail.com
However, from economical point of view, it has expensive in production process [6]. So, producing low-cost and effective activated carbon may give a healthy environmental to our society and offer benefits for future commercial applications. The activated carbon prepared from unused biomaterials is very low cost compared to the cost of commercial activated carbon. Many people obtained activated carbons from agricultural by-products including soybean straw [7], coconut shell [8], date pit [9], rattan sawdust [10], and sewage sludge [11]. But to produce activated carbon by using very low cost equipment’s is quite interesting topic for us. Various works have been done to produce low cost activated carbon with good approach. But they don’t look into the matter of low cost oven based heating system. A. Ghanadzadeh Gilani et al prepared the activated carbon for phenol adsorption using sealed ceramic oven [12]. Tchuifon Tchuifon D. Raoul et al used an ISUNU mark electric furnace with automatic regulation to prepare the activated carbon for phenol adsorption [13]. Md. Masuduzzaman et al used infrared cooker to prepare activated carbon for methylene blue adsorption [14]. Sadaf Adhami et al used tubular reactor as the heating system to prepare activated carbon for water treatment [15]. Wankhade Amey A. et al used muffle furnace as the heating system for the carbonisation of activated carbon [16]. However, all these heating systems are little bit expensive. The main aim of this study is to use low cost equipment’s for the preparation of activated carbon and use it for water purification application through adsorption of the dye.

2. Experimental

2.1. Preparation of Activated Carbon

The activated carbon was prepared from the teak wood charcoals by following the standard procedure. This procedure consists of 5 steps.

Step 1- Collection of charcoals:
The teak charcoals (Figure 1(a)) were purchased from a local vendor.

Step 2- Grind up the charcoals:
The charcoals were cleaned by water. 250 gm of cleaned charcoal were grinded by using a domestic mixture grinder. The charcoal powder is left for 24 hours to air dried completely.

Step 3- Preparation of solution for activating the charcoal powder:
For activation of the charcoal, a solution was prepared by mixing calcium chloride and water in 1:3 ratio. For ours case 50 gm of calcium chloride was mixed with 150 ml of water.

Step 4- Preparation of charcoal paste:
A slurry type of paste was prepared. First 50 gm of dry charcoal powder was taken in a beaker. 50 ml of calcium chloride solution was added to it and stirring was done with a spoon until getting slurry paste. Then this paste was kept for 24 hours in dark.

Step 5- Activation of the sample by the low cost oven based heating system:
After 24 hours these paste was first dried in the sunlight for 3 hours, then rinsed with clean water. Then it was heated at 250 degrees Celsius for certain time. Three set of samples S1, S2 and S3 were prepared with heating time of 30 min, 60 min and 90 min respectively. A domestic oven-based heating system was used for this propose. Figure 1(b) was the prepared activated carbon.
2.2. Water purification application

Water purification experiments were done by exploiting the adsorption properties of activated carbon. For this experiment, every time 50 ml of aqueous solution of methylene blue (MB) (molar concentration = 2.5 x 10^{-5} M) and some specific amount of activated carbon were taken in a beaker. This mixture was then stirred gently for adsorption. This process continued till getting the appropriate amount of activated carbon for complete adsorption of methylene blue dye. The adsorption capacity of methylene blue q (mg of adsorbate/g of adsorbent) was calculated by using the following equation

\[ q = \frac{(C_0 - C_m)V}{m} \]  

(1)

where V is the volume of the solution in terms of L, C₀ the initial concentration (mg l⁻¹), Cₘ the final concentration (mg l⁻¹), and m is the weight of the adsorbent (g).

And % of removal of MB = \( \frac{(C_0 - C)}{C_0} \times 100 \)  

(2)

Where C₀ is the initial concentration and C is the concentration of the aqueous solution at the time of measurement.

The absorbance spectroscopy of the dye solutions were done to find the ratio of the dye concentration.

3. Results and Discussion

3.1 Study of removal of MB by using different amount of activated carbon prepared by heating for 30 min.

The Figure 2 shows the percentage of the dye removal with different amount of activated carbon prepared by heating for 30 min. From this it is found that when we added more amount of adsorbent (activated carbon) more percentage of removal of methylene blue dye has taken place. This figure also shows that for complete removal of dye the minimum required amount of activated carbon is 0.06g. We got a flat curve after this weight. This indicates that further addition of the activated carbon is not required. The color of the dye solution without adsorption of the dye (for the case of no activated carbon) and complete adsorption of dye are shown in Figure 3(a) and 3(b) respectively. It is to be informed here that without activation no significant amount of dye adsorption has been found in the similar experimental condition.
Figure 2. Percentage of the dye removal with different amount of activated carbon.

3.2 Comparison of adsorption capacity of activated carbon prepared by heating for 30 min, 60 min., 90 min.

Considering the data of incremental region of % of dye removal (Please ref. data points corresponding to activated carbon of weight within the range of 0-0.06 gm of Figure 2), the adsorption capacity for the activated carbon prepared by heating for 30 min is found to be 6.66 mg/g. In the same manner the adsorption capacity for the case for 60 min and 90 min were found to be 6.15 mg/g and 2.85 mg/g respectively. In other word we can say, the adsorption capacity for 60 min of heating case was almost found to be same as the case of 30 min heating. But for 90 min of heating process it is found to be less than half of that for the case of 30 min heating. The most probable cause for this is probably because of
reduction of surface area due to coagulation. Further investigation is going on this regards.

4. Conclusion

In this work we have demonstrated the complete removal of the methylene blue dye with the activated carbon prepared by domestic oven based heating system. The activated carbon produced at 250°C activation temperature for 30 mins shows the best adsorption behaviour. The cost of the domestic oven used for activation was only about $20. So, in this work demonstrate a cost effective ways of activation.

5. References

[1] El-Naas M H, Al-Muhtaseb S A, Makhlof S, 2009 Biodegradation of phenol by Pseudomonas putida immobilized in polyvinyl alcohol (PVA) gel J. Hazard. Mater. 164 720-725
[2] Yavuz Y, Koparal A S, 2006 Electrochemical oxidation of phenol in a parallel plate reactor using ruthenium mixed metal oxide electrode J. Hazard. Mater. 136 296-302
[3] Yang C, Qian Y, Zhang L, Feng J, 2006 Solvent extraction process development and on-site trial-plant for phenol removal from industrial coal-gasification wastewater Chem. Eng. J. 117 179-185
[4] Caetano M, Valderrama C, Farran A, Cortina J L, 2009 Phenol removal from aqueous solution by adsorption and ion exchange mechanisms onto polymeric resins J. Colloid. Interf. Sci. 338 402-409
[5] Yousef R I, El-Eswed B, Ala’a H, 2011 Adsorption characteristics of natural zeolites as solid adsorbents for phenol removal from aqueous solutions: kinetics, mechanism, and thermodynamics studies Chem. Eng. J. 171 1143-1149
[6] Özkaya B, 2006 Adsorption and desorption of phenol on activated carbon and a comparison of isotherm models J. Hazard. Mater. 129 158-163
[7] Mohammad Y S, Egbenyua M, Sunday B I, Abdul-Raheem G, Charles A O, 2015 Isotherm, kinetics and thermodynamics of phenol adsorption onto rice husk activated carbon Leonardo El. J. Pract. Technol. 14 115-128
[8] Din A T M, Hameed B, Ahmad A L, 2009 Batch adsorption of phenol onto physiochemical-activated coconut shell J. Hazard. Mater. 161 1522-1529
[9] Tseng R L, Wu F C, Juang R S, 2003 Liquid-phase adsorption of dyes and phenols using pine-wood-based activated carbons Carbon 41 487-495
[10] Hameed B, Rahman A, 2008 Removal of phenol from aqueous solutions by adsorption onto activated carbon prepared from biomass material J. Hazard. Mater. 160 576-581
[11] Di L, Wu Y, Feng L, Zhang L, 2012 Surface properties of SAC and its adsorption mechanisms for phenol and nitrobenzene Bioresource Technol. 113 121-126
[12] Ghanadzadeh Gilani A, Ghanadzadeh Gilani H, Azmoon P, Chaibakhsh N, 2019 Phenol Adsorption from Aqueous Phase onto Prepared Low-cost Carbons from Natural Sources: A Comparative Study Phys. Chem. Res. 7 327-346
[13] Tchuiwon Tchuiwon D R, Anagho S G, Ketcha J M, Nche G Ndfor-Angwafor And Ndi J N, 2014 Kinetics and equilibrium studies of adsorption of phenol in aqueous solution onto activated carbon prepared from rice and coffee husks Int. J. Eng. Tech. Research 2 ISSN: 2321-0869
[14] Md. Masuduzzaman, Rajesh Kumar Ghosh, Shuvagata Biswas, Dr. Bodius Salam, 2017 Production of Activated Carbon from charcoal using chemical activation International Conference on Mechanical Engineering and Renewable Energy 2017 (ICMERE 2017-PI-142)
[15] Sadaf adhami , Hamed Ghorbanpoor, Berat azak , Serkan kapucu, Macid Nurbas, Hüseyin AVCI 2018 A Novel Approach For Water Treatment by using Activated Carbon: Apricot Kernel
Shell, *The Journal of Engineering and Architecture Faculty of Eskisehir Osmangazi University* 26(1) 1-7

[16] Wankhade Amey A, Ganvir V N, 2003 Preparation of Low Cost Activated Carbon from Tea Waste using Sulphuric Acid as Activating Agent *Int. Res. J. Env. Sci.* 2(4), 53-55

[17] Stasinakis A S, Elia I, Petalas A V, Halvadakis C P, 2008 Removal of total phenols from olive-mill wastewater using an agricultural by-product, olive pomace *J. Hazard. Mater.* 160 408-413

[18] Yahia A A, 2006 Activated carbon from dates stone by ZnCl2 activation *Eng. Sci.* 17(2) 75-100

[19] Yuan C S, Lin H Y, Wu C H, Liu M H, 2004 Preparation of sulfurized powdered activated carbon from waste tires using and innovative compositive impregnation process *J. Air & waste Manage. Assoc.* 54 862-870

[20] Dina D J D, Ntieche A R, Ndi J N, Ketcha M J, 2012 Adsorption of acetic acid onto activated carbons obtained from maize cobs by chemical activation with zinc chloride (ZnCl2) *Res. J. Chem. Sci.* 2(9) 42-49

[21] Bacaoui A, Yaacoubi A, Dahbi A, Bennouna C, Luu R P T, Maldonado-Hodar F J, ... & Moreno-Castilla C, 2001 Optimization of conditions for the preparation of activated carbons from olive-waste cakes *Carbon* 39(3) 425-432

[22] Balci S, Doğu T, Yücel H, 1994 Characterization of activated carbon produced from almond shell and hazelnut shell *J. chem. Tech. biotech.* 60(4) 419-426

[23] Bevla F R, Rico D P, and Gomis A F M, 1984 Activated Carbon from Almond Shells. Chemical Activation. Activating Reagent Selection and Variables Influence *Ind. Eng. Chem. Prod. Res. Dev.* 23 pp.266-269

[24] Alhamed Y A, 2009 Adsorption kinetics and performance of packed bed adsorber for phenol removal using activated carbon from dates’ stones. *J. Hazard. Mater.* 170 763-770

[25] El Hannafi N, Boumahla M, Berkama T, Bendjama Z, 2008 Elimination of phenol by adsorption on activated carbon prepared from the peach cores: modelling and optimisation *Desalination* 223, 264-268

[26] Basso M C, Cerrella E G, Cukierman A L, 2002 Activated carbons developed from a rapidly renewable biosource for removal of cadmium (II) and nickel (II) ions from dilute aqueous solutions *Industrial & Eng. Chem. research* 41(2) 180-189

[27] Subhashree P, 2011 Production and characterization of activated carbon produced from a suitable industrial sludge *Projet report, National Institute of Technology Rourkela*, pp 32-33

[28] Lü G, Hao J, Liu L, Ma H, Fang Q, 2011 The adsorption of phenol by lignite activated carbon *Chinese. J. Chem. Eng.* 19 380-385

[29] Ho Y S, Porter J F, McKay G, 2002 Equilibrium isotherm studies for the adsorption of divalent metals ions onto peat: copper, nickel and lead single component systems *Water, Air and Soil pollut.* 141 1-33

[30] Srihari V, Das A, 2008 The kinetic and thermodynamic studies of phenol-sorption onto three agro-based carbons *Desalination* 255 220-234

[31] Hall K R, Eagleton L C, Acrivos A, Vermeulen T, 1996 Pore and solid-diffusion kinetics in fixed-bed adsorption under constant-pattern conditions *Ind.Eng.Chem.Fund.* 5 212-223