PREPARATION OF ACTIVATED CARBONS FROM DATE STONES BY CHEMICAL ACTIVATION METHOD USING $FeCl_3$ and $ZnCl_2$ as ACTIVATING AGENTS

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ABSTRACT

Date stones were used as precursor for the preparation of activated carbons by chemical activation with ferric chloride and zinc chloride. The effects of operating conditions represented by the activation time, activation temperature, and impregnation ratio on the yield and adsorption capacity towards methylene blue (MB) of prepared activated carbon by ferric chloride activation (FAC) and zinc chloride activation (ZAC) were studied. For FAC, an optimum conditions of 1.25 h activation time, 700 ˚C activation temperature, and 1.5 impregnation ratio gave 185.15 mg/g MB uptake and 47.08 % yield, while for ZAC, 240.77 mg/g MB uptake and 40.46 % yield were obtained at the optimum conditions of 1.25 h activation time, 500 ˚C activation temperature, and 2 impregnation ratio. The equilibrium data for MB adsorption on prepared activated carbons at optimum conditions were well represented by the Langmuir isotherm model, giving maximum MB uptake of 304.51 and 387.54 mg/g for FAC and ZAC, respectively. Also, the results showed that the surface area and iodine number of activated carbon prepared by activation with ferric chloride at optimum conditions were 780.06 m^2/g and 761.40 mg/g, respectively. While 1045.61 m^2/g surface area and 1008.86 mg/g iodine number were obtained for ZAC prepared at optimum conditions.

الخلاصة

يهدف البحث إلى إنتاج الكاربون المنشط من نوى التمر بطريقه التنشيط الكيميائي وباستعمال كلوريد الحديد وكلوريد الزنك كعوامل منشطه. تم دراسة تأثير زمن التنشيط ، درجة حرارة التنشيط ، ونسبة المنشط الكيميائي الى نوى التمر على إنتاجية الكاربون وسعه امتزازه لماده صبغه المثلين الزرقاء. بينت النتائج انه في حاله استخدام كلوريد الحديد كعامل منشط تم الحصول على انتاجيه (47.08 %) وسعه امتزاز (185.15 ملغم/غرام) عند الظروف التشغيليه المثلى والمتمثله بزمن تنشيط (1.25 ساعه) ، درجه حراره تنشيط (700 °م) ، ونسبه عامل منشط الى نوى التمر (1.5). في حين استخدام كلوريد الزنك كعامل منشط اعطى انتاجيه (44.46 %) وسعه امتزاز (240.77 ملغم/غرام) عند الظروف التشغيليه المثلى والمتمثله بزمن تنشيط (1.25 ساعه) ، درجه حراره تنشيط (500 °م) ، ونسبه عامل منشط الى نوى التمر (2). تم تمثيل نتائج امتزاز صبغه المثلين الزرقاء على الكاربون المنشط المحضر بشكل جيد جدا بواسطه معادله لانكماير ، حيث تم الحصول على اعلى سعه امتزاز (304.51ملغم/غرام) للكاربون المحضر باستخدام كلوريد الحديد واعلى سعه امتزاز (387.54 ملغم/غرام) للكاربون المحضر باستخدام كلوريد الزنك. ايضا بينت النتائج ان التنشيط بكلوريد الحديد اعطى كاربون منشط ذو مساحه سطحيه (780.06 متر^2 /غرام) ونسبه امتزاز لليود (761.40 ملغرام/غرام). بينما الكاربون المنشط الناتج باستخدام كلوريد الزنك كعامل منشط كان ذو مسحه سطحيه (1045.61 متر^2 /غرام) ونسبه امتزاز لليود (1008.86 ملغرام / غرام).

KEYWORDS: Activated carbon, chemical activation, ferric chloride, zinc chloride, date stones

1. INTRODUCTION

Activated carbon is commonly defined as a carbonaceous material showing a well-developed surface area and porous texture. As a consequence, activated carbon has been widely used as adsorbent, and in catalysis or separation processes (Kalderis et al., 2008; Tamai et al., 2009). The characteristics of activated carbon depend on the physical and chemical properties of the precursor as well as on the activation method (Demiral et al., 2008).

Activated carbon can be produced from any carbonaceous solid precursor which may be either natural or synthetic. The choice of precursor is largely dependent on its availability, cost and purity, but the manufacturing process and intended of application of the product are also important considerations. Due to environmental considerations, agricultural wastes are considered to be a very important precursor because they are cheap, renewable, safe, available at large quantities and easily accusable sources; in addition they have high carbon and low ash content (Kalderis et al., 2008; Mestre et al., 2009).

Date stones as a raw material for the production of activated carbon can be considered as one of the best candidate among the agricultural wastes because it is cheap and quite abundant, especially in Mediterranean countries. They are composed of 42% cellulose, 18% hemi cellulose, 25% sugar and other compounds, 11% lignin and 4% ash. This lignocellulosic composition promotes the preparation of activated carbon from these precursors (Bouchelta et al., 2008).

There are two processes for the preparation of activated carbon: physical activation and chemical activation. Physical activation involves carbonization of a carbonaceous materials followed by activation of the resulting char in the presence of activating agents such as CO_2 or steam. In chemical activation, a raw material is impregnated with an activating reagent such as $ZnCl_2$, H_3PO_4, KOH, etc…, and the impregnated material is heated in an inert atmosphere. There will be a reaction between the precursor and the activating agent used in activation which leads to developments in porosity. Chemical activation is preferred over physical activation owing to the higher yield, simplicity, lower temperature and shorter time needed for activating material, and good development of the porous structure (Guo and Rockstraw, 2007).

The chemical activation process has been widely used by many researchers to prepare low cost activated carbons from different agricultural wastes by various chemical activating agents such as olive stones by H_3PO_4 (Yavuz et al., 2010), pomegranate seeds by $ZnCl_2$ (Ucar et al., 2009), durian shell by KOH (Chandra et al., 2009), Jatropha Curcas fruit shell by NaOH (Tongpoothorn et al., 2011), pissava fibers by H_3PO_4 and $ZnCl_2$ (Avelar et al., 2010), corn grain by KOH (Balathanigaimani et al., 2009), kenaf natural fibers by K_2HPO_4 (Aber et al., 2009), date stones by $ZnCl_2$, H_3PO_4 and KOH (Alhamed , 2009; Haimour and Emeish, 2006; Hameed et al., 2009).

Although the iron chloride salt has similar characteristics to zinc chloride in aqueous solution the ferric cation is smaller than the zinc cation, and this opens up the possibility of producing activated carbon with smaller pores sizes upon their activation. On the other hand, the zinc cation presented in aqueous solution is a well-known pollutant. Moreover, the ferric salt has a low cost in comparison with the zinc salt. The use of ferric chloride is not completely new. Oliveira et al. (2009) and Rufford et al. (2010) used it to prepare activated carbons from coffee husks and waste coffee grounds, respectively. However, there is no information for the preparation of activated carbon using date stones as the precursor with ferric chloride as chemical activating agent.

The main objective of this research is to test the use of ferric chloride as an alternative activating agent to produce activated carbon starting from date stones. The commonly employed activating agent, zinc chloride, is also used, in order to compare the characteristics and adsorption capacity for methylene blue (MB) of resulting activated carbons. The effects of activation time, activation temperature, and impregnation ratio on the yield and MB uptake of prepared activated carbon are also studied.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Precursor: Date stones were used as the precursor in the preparation of activated carbon. The stones as received were first washed with water to get rid of impurities, dried at 110 ˚C for 24 h, crushed using disk mill, and sieved. Fraction with average particle size, d_p, of 2 mm was selected for this study.

2.1.2 Chemicals: The properties of chemicals used are listed in Table 1.

2.2 Experimental procedure

10 g of dried stones was well mixed with 100 ml of $ZnCl_2$ or $FeCl_3$ solution of different impregnation ratios (weight of activating agent/weight of dried stones) (0.5-2.5) for 24 h at room temperature. The impregnated samples were next dried at 110 ˚C until completely dried and stores in a desiccator. For the carbonization of dried impregnated samples a stainless steal reactor (2.5 cm diameter x 10 cm length) was used, as shown in Fig.1. The reactor was sealed at one end and the other end had a removable cover with 2 mm hole at the center to allow for the escape of the pyrolysis gases. The reactor was placed in a furnace and heated at constant rate of 10 ˚C /min and held at different carbonization temperatures (400-800 ˚C) (Olivares-Marin et al., 2006) for different carbonization times (0.5-3.5 h). At the end of activation time the carbonized samples were withdrawn from the furnace and allowed to cool. For the removal of residual $ZnCl_2$ or $FeCl_3$, the samples were soaked with 0.1 M HCl solution such that the liquid to solid ratio is 10 ml/g. The mixtures were left overnight at room temperature, and then filtered and subsequently the samples were repeatedly washed with distilled water until the pH of filtrate reach 6.5-7 (Tan et al., 2007). After that, the samples were dried at 110 ˚C for 24 h, and subsequently were weighed to determine the yield of the product. Finally the samples were stored in tightly closed bottles. The flow diagram for activation process is shown in Fig.2.

2.3 Performance of activation process

The performance of chemical activation process was determined by the product yield, along with its uptake for MB. The yield and MB uptake are determined as follows:

2.3.1 Yield

The yield is defined as the ratio of final weight of the obtained product after washing and drying to the weight of dried precursor initially used. The yield of activated carbon was calculated based on the following equation:

$$\text{Yield}\,(\%) = \frac{W_f}{W_o} \text{ x } 100 \qquad (1)$$

Where W_f and W_o are the dry weight of final activated carbon product (g) and the dry weight of date stones (g), respectively.

2.3.2 MB uptake

The MB uptake or adsorption capacity of prepared activated carbon was determined by performing batch adsorption tests in 15 set of 100 ml Erlenmeyer flasks where 50 ml MB aqueous solutions with initial concentration of 250 mg/l was placed in each flask (Alhamed, 2006). The pH of the solution was natural without any pH adjustment. 0.05 g of each of the prepared activated carbon, with average particle size of 0.250 mm, was added to each flask and kept in an isothermal shaker of 120 rpm at room temperature for 24 h to reach equilibrium. Aqueous samples were taken from the solutions and the concentrations were analyzed. All samples were filtered prior to analysis in order to minimize interference of the carbon fines with the analysis. The concentrations of MB in the supernatant solutions were determined using UV-Visible Spectrophotometer (Shimadzu UV-160A) at its maximum wave length of 664 nm. The MB uptake at equilibrium, q_e (mg/g), was calculated by the following equation:

$$q_e = \frac{(C_o - C_e)\,V}{W} \qquad (2)$$

Where C_o and C_e are initial and equilibrium concentrations of the MB (mg/l), respectively, V is the volume of the aqueous MB dye solution (l), and W is the weight of activated carbon used (g).

2.4 Characteristics of prepared activated carbon at optimum conditions

The prepared activated carbons at optimum conditions were characterized by selected physical properties including bulk density and surface area, chemical properties including ash content, pH and conductivity, and adsorption properties including iodine number and maximum MB uptake. The details of characterization methods are illustrated as follows.

2.4.1 Bulk density

Bulk or apparent density is a measure of the weight of material that can be contained in a given volume under specified conditions. The volume used in this determination includes, in addition to the volume of the skeletal solids, the volume of voids among the particles and the volume of the pores within the particles. A 10 ml cylinder was filled to a specified volume with activated carbon that had been dried in an oven at 80 ˚C for 24 h (Ahmedna et al., 1997). The bulk density was then calculated as follows:

$$\text{bulk density} = \frac{W_C}{V_C} \qquad (3)$$

Where W_C is the weight of dried activated carbon (g) and V_C is cylinder volume packed with dried activated carbon (ml).

2.4.3 Ash content

The ash content of an activated carbon is the residue that remains when the carbonaceous portion is burned off. The ash content of activated carbon was determined by standard methods (ASTM Designation D-2866-94, 2000). 0.5 g of activated carbon with average particle size of 0.250 mm was dried at 80 ˚C for 24 h and placed into weighted ceramic crucibles. The samples were heated in an electrical furnace at 650 ˚C for 3 h. Then the crucibles were cooled to ambient temperature and weighed. The percent of ash was calculated as follows:

$$\text{ash}\,(\%) = \frac{W_{S3} - W_{S2}}{W_{S1}} \times 100 \qquad (4)$$

Where W_{S3} is the weight of crucible containing ash (g), W_{S2} is the weight of crucible (g), and W_{S1} is the weight of original activated carbon used (g).

2.4.4 Moisture content

The moisture content of prepared activated carbon was determined using oven drying method (Adekola and Adegoke, 2005). 0.5 g of activated carbon with average particle size of 250 mm was placed into weighed ceramic crucible. The samples were dried at 110 ˚C to constant weight.

Then the samples were cooled to ambient temperature and weighed. The moisture content was calculated by the following equation:

$$\text{mositure}\,(\%) = \frac{W_{m3} - W_{m2}}{W_{m1}} \times 100 \quad (5)$$

Where W_{m3} is the weight of crucible containing original sample (g), W_{m2} is the weight of crucible containing dried sample (g), and W_{m1} is the weight of original sample used (g).

2.4.5 pH measurement

The pH value of prepared activated carbon was determined by immersing 1 g sample in 100 ml deionized water and stirring at 150 rpm for 1 h and the pH of slurry taken (Egwaikhide et al., 2007).

2.4.6 Conductivity measurement

Electrical conductivity was measured by using the method of Ahmedna et al. (1997). A 1 wt% solution of sample in deionized water was stirred at 150 rpm at room temperature for 20 min. Electrical conductivity was measured using an EDT instrument BA 380 conductivity meter with values micro siemens per meter (µs/m).

2.4.7 Maximum MB uptake

The maximum MB adsorption capacity of the activated carbon prepared at optimum conditions were determined by performing adsorption tests in a set of 100 ml Erlenmeyer flasks where 50 ml of MB solutions with initial concentrations of 50-450 mg/l were placed in these flasks. Other operating parameters such as activated carbon dosage, solution temperature and agitation speed were similar as the adsorption studies carried out for determining MB uptake. The concentrations of MB solutions were similarly measured and the amount of adsorption at equilibrium, q_e (mg/g) was calculated using Eq. (2). To determine the maximum MB adsorption capacity of each prepared activated carbon, the experimental adsorption data obtained were fitted to the Langmuir isotherm model, which can be written as follows:

$$q_e = \frac{q_m\, BC_e}{1 + BC_e} \quad (6)$$

Where q_e is the amount of MB adsorbed per unit mass of activated carbon (mg/g), q_m is the maximum amount of MB adsorbed per unit mass of activated carbon (mg/g), C_e is the equilibrium concentration of the MB (mg/l), and B is the Langmuir constant (l/mg). The Langmuir isotherm model was used to fit the experimental data because from the literature and also from the preliminary studies carried out, most of the equilibrium data obtained for adsorption of dyes on activated carbons were found to be the best represented by this model (Hameed et al., 2007).

2.4.8 Iodine number

Iodine number is defined as the milligrams of iodine adsorbed by one gram of activated carbon. Basically, iodine number is a measure of the micropore content of activated carbon (0 to 20 Å) by adsorption of iodine from solution. Iodine number of the prepared carbon was determined as follows: 10 ml of 0.1 N iodine solution in a conical flask is titrate with 0.1 N sodium thiosulfate solution in the presence of 2 drops of 1 wt% starch solution as an indicator, till it becomes colourless. The burette reading is corresponding to V_b. Then weigh very accurately 0.05 g of activated carbon and add it to conical flask containing 15 ml of 0.1 N iodine solution, shake the flask for 4 min and filter it, then titrate 10 ml of filtrate with standard sodium thiosulfate solution using 2 drops of starch solution as indicator, now the burette reading is corresponding to Vs. The iodine number was then calculated by using the following equation (Lubrizol, 2007):

$$IN = \frac{(V_b - Vs).N.(126.9).(15/10)}{M} \quad (7)$$

Where IN is iodine number (mg/g), V_b and Vs are volumes of sodium thiosulfate solution required for blank and sample titrations (ml), respectively, N is the normality of sodium thiosulfate solution (mole/l), 126.9 is atomic weight of iodine, and M is the mass of activated carbon used (g).

. 2.4.9. Surface area

The surface areas of the prepared activated carbons were estimated through a calibration curve which has a correlation coefficient of 0.997 between the iodine numbers and BET surface area of some established activated carbons from the literature (Fadhil et al., 2008) as shown in Fig. 3.

3. RESULTS AND DISCUSSION

3.1 Effect of operating conditions

A set of experiments was carried out in order to study the effect of activation time (0.5-3.5 h), activation temperature (400-800 ˚C) and impregnation ratio (R), activator to precursor weight ratio, (0.5-2.5) on the yield and MB uptake of prepared activated carbon using ferric chloride (FAC) and zinc chloride (ZAC).

3.1.1 Effect of activation time

The effect of activation time on yield and MB uptake of prepared activated carbon are shown in Figs. 4 and 5, respectively.

Fig. 4 shows that the yield of FAC and ZAC decreases with increasing activation time. An increase in time from 0.5 to 3.5 h at 600 ˚C and 1.5 impregnation ratio leads to a decrease in yield from 61 to 41 % and 43 to 29 % for FAC and ZAC, respectively. A steep decrease occurs within the first 1.25 h for both FAC and ZAC; this is due to rapid evolution of volatile materials to form stable compounds as explained by Haimour and Emeish (2006).They showed that a steep decrease in yield occurs within the first 1 h for production of activated carbon from date stones using zinc chloride and phosphoric acid. Since zinc chloride removes more volatile materials from the particles compared to ferric chloride, the yield of ZAC was lower than that of FAC as shown in this figure.

Fig. 5 shows that the MB uptake of FAC and ZAC increases with activation time and reaches at maximum of 225.08 mg/g for ZAC and 130.01 mg/g for FAC, at 1.25 h and thereafter it decreases. Activation until 1.25 h probably increases the formation of mesopores that are more effective in adsorption process, but with applying extended activation times, the wall of mesopores perhaps collapses and they turns into macrospores (Budinova et al., 2008). Therefore, the time of 1.25 h was chosen as optimum activation time for both activators. Alhamed (2006) showed that a maximum MB removal of 90 % was obtained at optimum activation time of 1 h for chemical activation of date stones by zinc chloride. Also it can be noted from this figure that MB uptake of ZAC was higher than that of FAC. This may due to higher activity of zinc chloride, as compared with ferric chloride, to produce activated carbon with higher developed pores (Rufford et al., 2010).

3.1.2 Effect of activation temperature

The effect of activation temperature on yield and MB uptake of prepared activated carbon are shown in Figs. 6 and 7, respectively.

It can be seen from Fig.6 that, as the activation temperature increases from 400 to 800 ˚C, the yield decreases from 51 to 37 % and 43 to 27 % for FAC and ZAC, respectively. This is due to the loss of the volatile materials with increasing temperature. Beyond 700 ˚C a lower rate of yield decrease was noticed where a stable structure is formed. This behavior agrees with results obtained from activation of date stones using phosphoric acid (Girgis and El-Hendawy, 2002).

Fig. 7 shows that the MB uptake increases with activation temperature up to 500 ˚C and 700 ˚C for ZAC and FAC, respectively. Therefore, the temperatures of 500 and 700 ˚C were chosen as optimum activation temperatures for ZAC and FAC, respectively. The decrease in adsorption ability of prepared activated carbon with further increase in temperature might be due to the sintering effect at high temperature, followed by shrinkage of the char, and realignment of the carbon structure which resulted in reduced pore areas as well as volume (Mohanty et al., 2006; Lua et al., 2006). These results are in agreements with that of Olivares-Marin et al. (2006) who showed that 500 ˚C was the optimum activation temperature for preparation of activated carbon from cherry stones by chemical activation with zinc chloride.

3.1.3 Effect of impregnation ratio

Figs. 8 and 9 show the effects of impregnation ratio, activator to precursor weight ratio, on yield and MB uptake of prepared activated carbon, respectively.

It was noticed that, as the impregnation ratio increases the yield decreases, as shown in Fig. 8. An increase in impregnation ratio from 0.5 to 2.5 leads to a decrease in yield from 61.03 to 33.97 % and 45.06 to 28.63 % for FAC and ZAC, respectively. This decrease is due to the continuous removal of tar material from the pores. The decreasing rate of yield is lowered beyond an impregnation ratio of 2 where a stable structure is formed, as explained by Sudaryanto et al. (2006) for activated carbon production from cassava peel by chemical activation with potassium hydroxide.

Fig. 9 shows that the MB uptake increases with impregnation ratio up to 2 for ZAC and 1.5 for FAC. For ZAC, an increase in impregnation ratio from 0.5 to 2 leads to an increase in MB uptake from 190.8 to 224.77 mg/g while for FAC, the increase from 0.5 to 1.5 leads to an increase from 63 to 118.15 mg/g. Therefore, the ratios of 2 and 1.5 were chosen as optimum impregnation ratios for ZAC and FAC, respectively. More increase in the concentration of activator perhaps leads to the excessive dehydration and destruction of mesopores and turning them to larger pores which reduces the adsorption efficiency (Kim et al., 2001).

3.2. MB adsorption isotherm on activated carbons prepared at optimum conditions

According to section 3.1, optimum operating conditions were selected as 1.25 h activation time, 500 ˚C activation temperatures, 2 and impregnation ratio for ZAC, and 1.25 h activation time, 700 ˚C activation temperatures, and 1.5 impregnation ratio for FAC.

The experimental equilibrium data for MB adsorption on ZAC and FAC prepared at optimum conditions are compared with that for MB adsorption on two types of commercial activated carbon (CAC1) and (CAC2). These data, calculated from Eq. (2), are fitted with Langmuir isotherm model, Eq. (6), and presented in Fig. 10. This figure shows that the MB adsorption capacity of four samples is in the order CAC1 > ZAC > FAC > CAC2. The calculated constants of Langmuir isotherm equation for the four samples along with the correlations coefficients values R^2 are presented in Table 2. This table shows that the maximum MB uptake of ZAC, FAC, CAC1, and CAC2 are 387.54, 304.51, 395.56 and 155.80 mg/g, respectively. This result for ZAC is higher than that reported by Alhamed (2006), 286 mg/g, for activated carbon produced from date stones by chemical activation with zinc chloride. Fig. 10 shows that the MB uptake of ZAC at a given MB concentration is higher than that of FAC. This is in agreement with Olivera et al. (2009) who found that the maximum MB uptake of activated carbons prepared from coffee husks by activation with ferric chloride and zinc chloride were 260 and 75 mg/g, respectively.

3.3 Characterization of activated carbons prepared at optimum conditions

According to section 2.4, the characteristics of FAC and ZAC prepared at optimum conditions were determined and compared with the characteristics of two types of commercial activated carbons, as summarized in Table 3. The results of this table show that the surface areas of ZAC and FAC are 1045.61 and 780.06 m^2/g, respectively. These results are in agreement with that of Rufford et al. (2010). They showed that the surface area of activated carbon prepared by chemical activation of coffee grounds with zinc chloride and ferric chloride were 977 and 846 m^2/g, respectively. The iodine numbers of ZAC and FAC in this study are higher than reported by Haimour and Emeish (2006), 495 mg/g for activated carbon prepared by chemical activation of date stones using phosphoric acid.

4. CONCLUSSIONS

1. MB uptake of 244.77 mg/g with corresponding yield of 40 % were obtained at optimum conditions of 1.25 h activation time, 500 °C activation temperature, and 2 impregnation ratio, for activated carbon prepared by chemical activation with zinc chloride.

2. Optimum conditions of 1.25 h activation time, 700 °C activation temperatures, and 1.5 impregnation ratio produced activated carbon with 185.15 mg/g MB uptake and 47.08 % yield for chemical activation of date stones with ferric chloride.

3. The maximum MB uptake of activated carbons prepared by ferric chloride and zinc chloride, as calculated from Langmuir isotherm model, were 304.51 and 387.54 mg/g, respectively.

4. Chemical activation of date stones with zinc chloride, at optimum conditions, produced activated carbon with 1008.86 mg/g iodine number and 1045.61 m^2/g surface area.

5. The iodine number and surface area of activated carbon prepared from date stones by chemical activation with ferric chloride, at optimum conditions, were 761.40 mg/g and 780.06 m^2/g, respectively.

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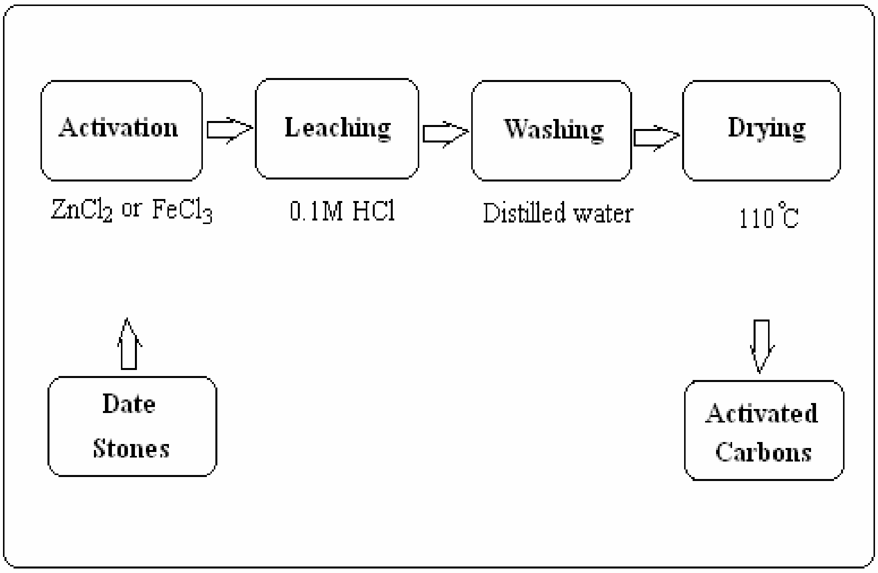

Fig. 1, Flow diagram for activation process

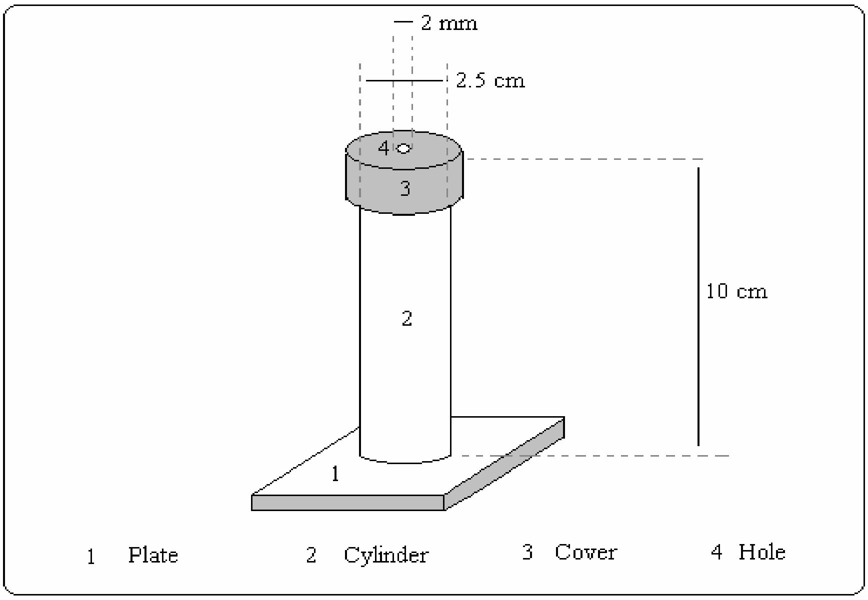

Fig. 2, Dimensions of reactor used for activation process

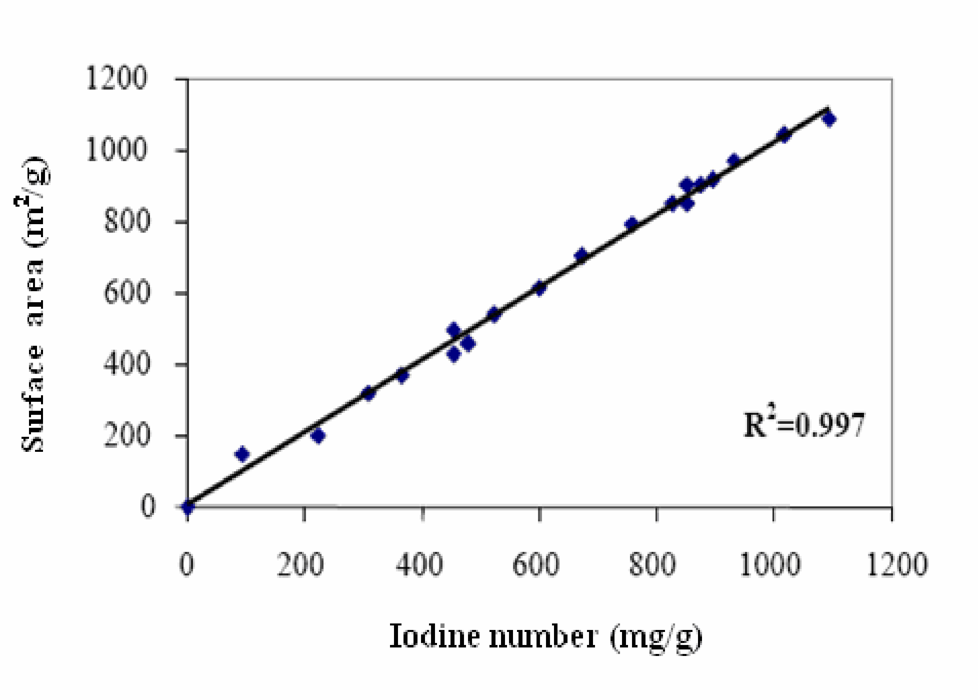

Fig. 3, Estimated surface area calibration curve

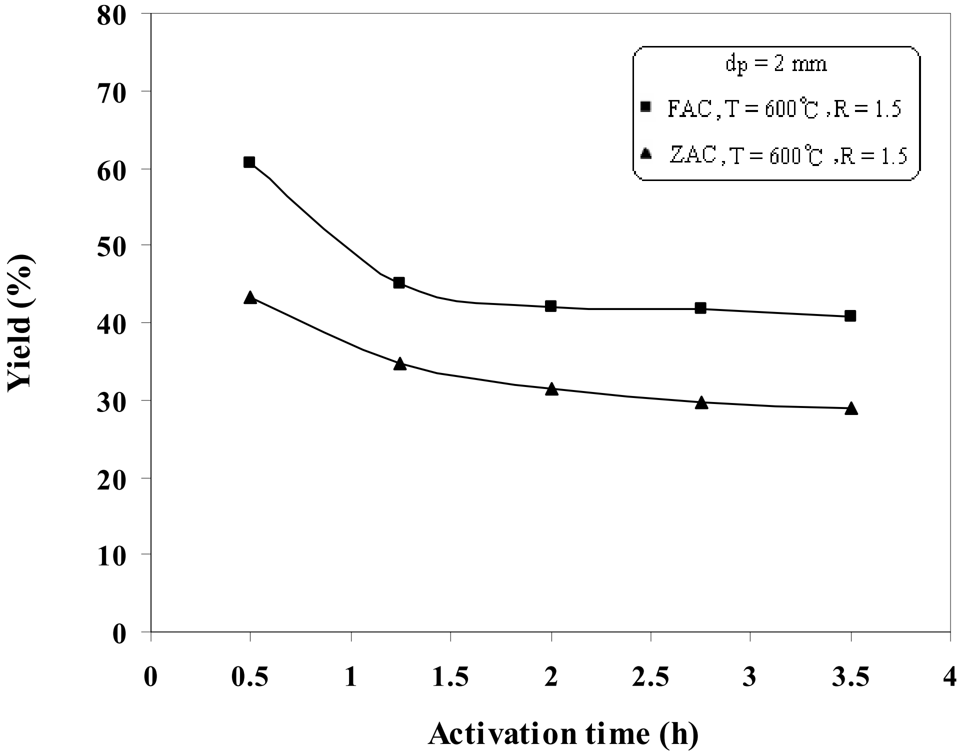

Fig. 4, Effect of activation time on yield of activated carbon

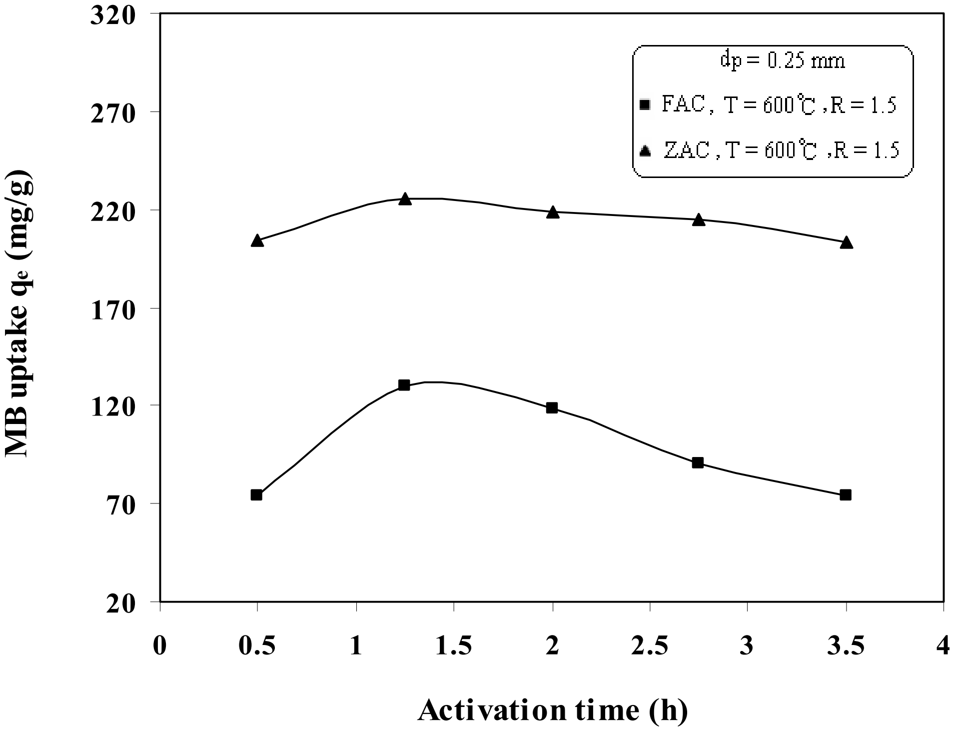

Fig. 5, Effect of activation time on MB uptake of activated carbon

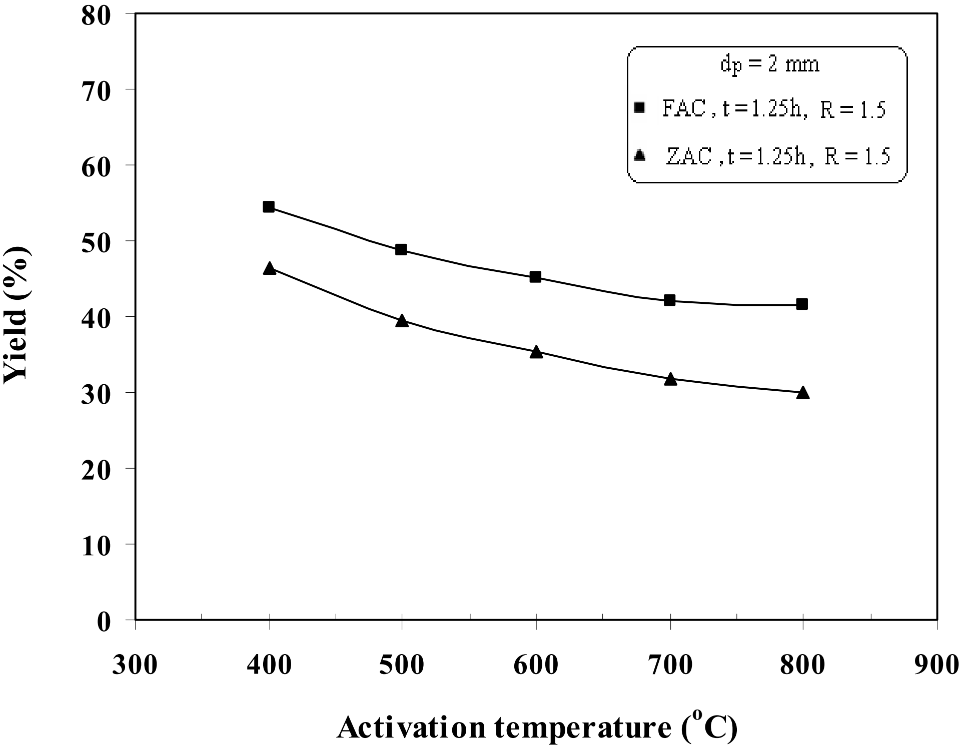

Fig. 6, Effect of activation temperature on yield f activated carbon

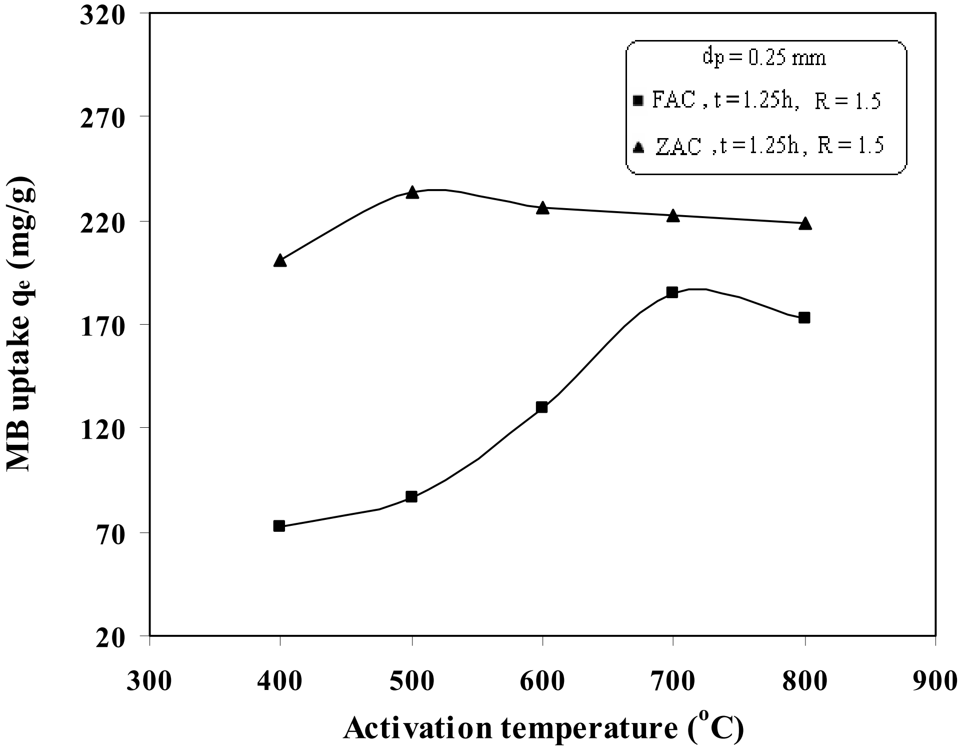

Fig. 7, Effect of activation temperature on MB uptake of activated carbon

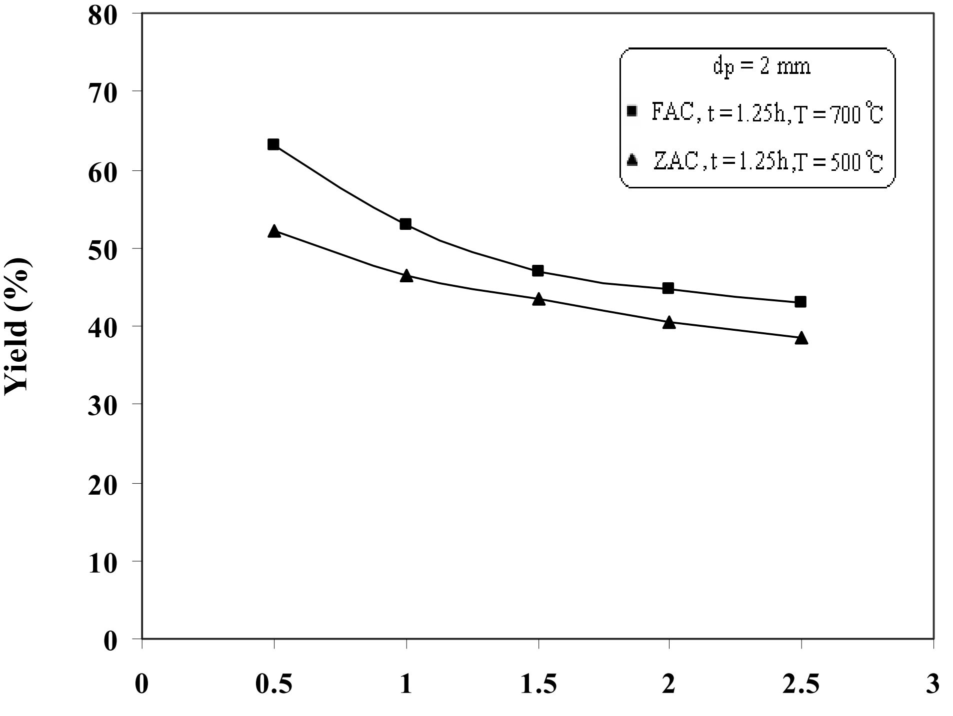

Fig. 8, Effect of impregnation ratio on yield of activated carbon

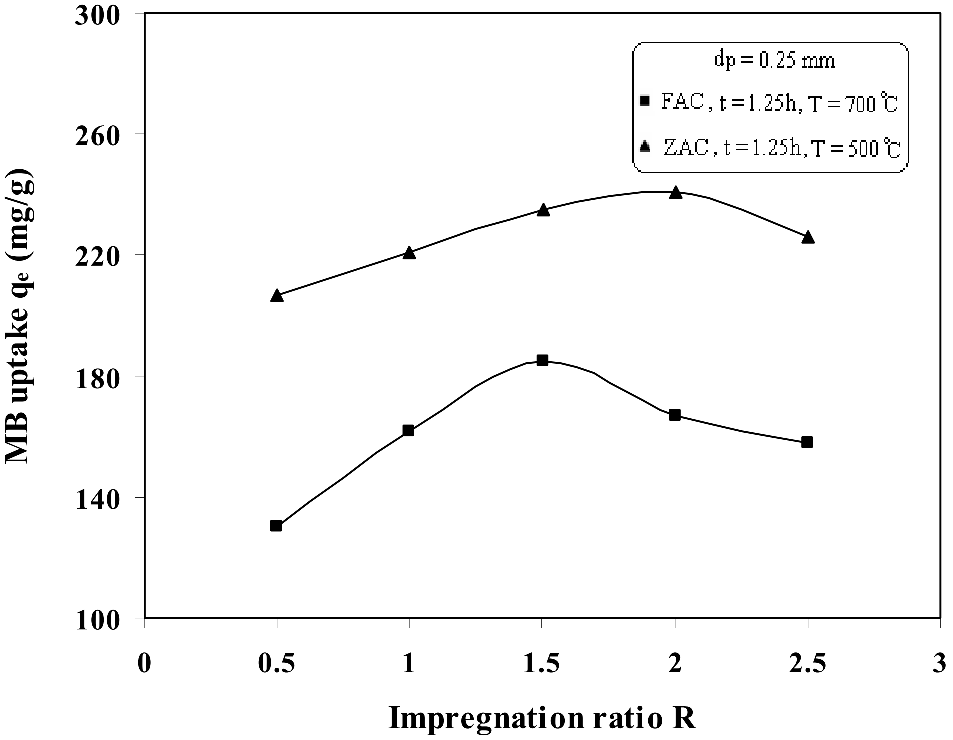

Fig. 9, Effect of impregnation ratio on MB uptake of activated carbon

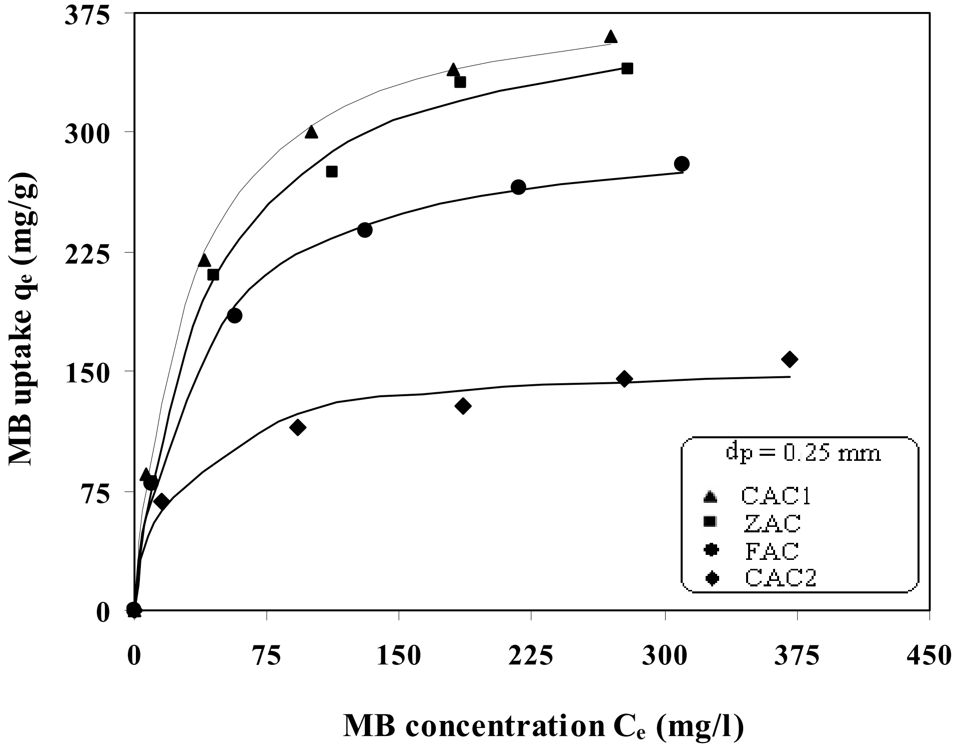

Fig. 10, Equilibrium isotherm of MB adsorption on activated carbons samples correlated with Langmuir equation

Table 1, Properties of chemicals

Compound	Molecular formula	Purity (%)	Source
Zinc Chloride	$ZnCl_2$	98-100	Scharlau Company
Ferric Chloride	$FeCl_3$	99.9	Panreac Company
Methylene Blue	$C_{16}H_{18}N_3SC$	99.9	Fischer Scientific Company
Hydrochloric Acid	HCl	35-38	Poch S.A. Company
Sodium Thiosulfate	$Na_2O_3S_2.5H_2O$	>99	Fluka Chemie AG Company
Iodine	I_2	99.9	Sigma Aldrich Company

Table 2, MB equilibrium isotherm results

MB isotherm results correlated with Langmuir equation			
Sample	q_m (mg/g)	B (l/mg)	R^2
ZAC	387.54	0.0259	0.997
FAC	304.51	0.0298	0.997
CAC1	395.56	0.0333	0.998
CAC2	155.80	0.0413	0.981

Table 3, Characteristics of activated carbons samples

Characteristic	ZAC	FAC	CAC1	CAC2
Yield (%)	40.46	47.08		
bulk density (g/ml)	0.322	0.271	0.454	0.529
surface area (m^2/g)	1045.61	780.06	1080.11	555
ash content (%)	2.04	8.62	4.24	8.80
moisture content (%)	13.86	15.54	11.57	3.51
pH	6.1	6.5	7.3	7
conductivity (µs/m)	330	290	370	330
max. MB uptake (mg/g)	387.54	304.51	395.56	155.80
iodine number (mg/g)	1008.86	761.40	1047.54	552