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Effectiveness of granular activated carbon prepared from dates pits as adsorbent in forward osmosis desalination process

Sami Al-Aibi*, Adel O. Sharif, Ghazi Derwish

Centre for Osmosis Research and Applications, Chemical and Process Engineering Department, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford GU2 7XH, UK, Tel. +447450098360; email: sami.al-aibi@surrey.ac.uk (S. Al-Aibi), Tel. +44(0)1483683610; email: a.sharif@surrey.ac.uk (A.O. Sharif), Tel. +44(0)7762614993; email: gderwish@hotmail.com (G. Derwish)

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ABSTRACT

This paper describes the preparation and characterization of different granular activated carbon (GAC) structures from date pits and also investigates their sorption efficiency to adsorb glucose and maltose draw solutions in forward osmosis (FO) desalination process. The dates pits chars were chemically activated using sulphuric acid, phosphoric acid and zinc chloride as dehydrating agents. Activation affected parameters such as temperature, time, impregnation ratios and the chars particle sizes were examined. Scanning electron microscopy and Fourier transform infrared spectroscopy techniques were used to determine the products surface morphology and types of functional groups, respectively. The activation increased pores networks and changed the surface morphology and functional groups. $ZnCl_2$ activated GAC showed the highest capacity to adsorb glucose and maltose from their aqueous solutions.

Keywords: Granular activated carbon; Activation; Adsorption; Forward osmosis; Draw solutions; Glucose; Maltose

1. Introduction

Activated carbon is an amorphous material with excellent adsorption capacity. It may be considered as molecular sieve with high degree of porosity and extended inter-particulate surface area. It can be prepared from almost any organic substance with high carbon content, commonly with at least 72%–90% carbon contents [1]. Usually, the activation process is commenced with initial carbonization of the raw material so as to obtain chars product with high carbon content.

Many agricultural by-products are used as sources for activated carbon, such as coconut shell, almond shells, olive stones, dates pits, cherry stones and pecan shells. The physical properties and chemical composition of the precursor, besides the methods and process conditions used, affect the type and degree of activation as well as the physical and chemical properties of the products such as pore size and distribution and adsorption capabilities which can be utilized for wide variety of processes such as filtration, purification, deodorization, decolourization and separation [2]. Activated carbons are commonly used worldwide for water treatment, wastewater reclamation, gas purification and also as catalyst support [3–5].

The adsorption capacity of activated carbons depends mainly on the preparation methods and the structural properties of the raw materials. Generally, there are two different methods to prepare activated carbon; the physical or thermal and the chemical activation. Initially, the material is carbonized, this step can be accomplished in an oxygen free medium and this needs a temperature about 700°C [4]. Simply, carbonization process means making charcoal from the raw material and the product normally has low surface area and therefore it is not considered active material. The resulting volatile materials are removed or reduced by the

* Corresponding author.

carbonization process and the residual components are then activated in the presence of air at high temperatures of more than 800°C, or activation can be achieved in the presence of an activating agent but at lower temperatures. According to Jung et al. [5], activation can be performed using physical method in the presence of air, carbon dioxide or water vapour at high temperature. It also can be accomplished by chemical process using activating agents such as phosphoric acid (H_3PO_4), sulphuric acid (H_2SO_4) or zinc chloride ($ZnCl_2$). In the chemical activation, it is possible to make activated carbon in a one-step process. Pyrolysis and activation are achieved simultaneously in the presence of the dehydrating agents (e.g., $ZnCl_2$, H_2SO_4 and KCl) [5–9].

About 6.7 million tons of dates were produced in 2004, and the main producers are Egypt, Iraq, Iran, Saudi Arabia, United Arab Emirates, Pakistan, Algeria and some other Mediterranean countries. [3]. It was found that date pits represent approximately 10% in weight of the fruit and according to FAO agricultural services, the composition of the date pits is given in Table 1 [3]. Carbohydrates are the main compounds of date pits, they are mainly cellulose (42%) and hemicellulose (18%) [3]. The lignocellulosics improve the preparation of prepared activated carbon. The mineral contents are mainly K followed by P, Mg, Ca and a trace Na. Other elements are present in trace amount such as Fe, Mn, Zn and Cu which are more important ones. In some places such as the Middle East, dates pits are sometimes crushed and used on dirt roads as a type of road base gravel, and date pits are also used as animal food. Date pits charcoal is used as a filtering medium for automobiles exhaust gases and as an adsorbent of toxic organic and inorganic compounds [3].

Adsorption by activated carbon has become the preferable choice in recently developed process for treating water and waste water. Its ease of application stimulated active interest in preparing activated carbon from agriculture waste and by-products. Kaustubha et al. [9] described and characterized a new chemical activation procedure to prepare the GAC from *Terminalia Arjuna* nuts using zinc chloride as dehydrating agent. Demirbas et al. [10], also prepared and characterized GAC from cornelian cherry and almond shell using sulphuric acid as dehydrating agent. In both studies, the prepared GACs were subjected to characterization by scanning electron microscope (SEM) and FTIR, and the adsorption capability was tested.

Previous investigations elaborated that the solute exchange technique shown in Fig. 1 is reliably used in the manipulated forward osmosis desalination process (MFO) [11,12]. The adsorption capacity of commercial GAC (mesh 12–20) was found adequate for adsorbing the organic compounds such as glucose and maltose when used as draw solutions in forward osmosis membrane stage of MFO. The findings showed that for this type of commercial GAC exhibited a capability to adsorb glucose (11 mg/g) and maltose (27.8 mg/g) from their aqueous solutions at ambient conditions [12].

The purpose of the present study is to prepare and assess different GAC samples from dates pits using sulphuric acid, phosphoric acid and zinc chloride as dehydrating agents. Also, the capability of the prepared GACs for adsorbing specific organic compounds such as glucose and maltose from their aqueous solutions is tested. The prepared GACs are characterized using SEM and FTIR to determine the surface morphology and types of functional groups resulting from the activation process.

Table 1
Approximate % of dry weight chemical composition of dates pits according to FAO [3]

Compound	%
Moisture	5–10
Protein	5–7
Oil	7–10
Ash	1–2
Crude fibre	10–20
Carbohydrates	55–65

2. Experimental work

2.1. Equipment and materials

Equipment and materials used in this investigation are displayed in Table 2.

2.2. Activation procedures

Chemical activation procedure utilized in the present work is in accordance with the works done by Kaustubha et al. [9] and Demirbas et al. [10]. The dates pits chars were activated by concentrated sulphuric acid, concentrated phosphoric acid or zinc chloride solution. The acid activation differed slightly from that used for activation by $ZnCl_2$ as shown in Fig. 2.

2.3. Experimental procedure

2.3.1. Dates pits drying

An experiment was performed to determine the effect of drying temperature on dates pits weight loss during carbonization process. A sample 143 g of clean dates pits was dried at different temperatures from 100°C to 200°C for 24 h. After each drying process, the percentage weight loss was determined and dried chars hardness was physically tested by hand as well. Finally, the produced chars were crushed using a coffee crusher machine and was sieved into two particle

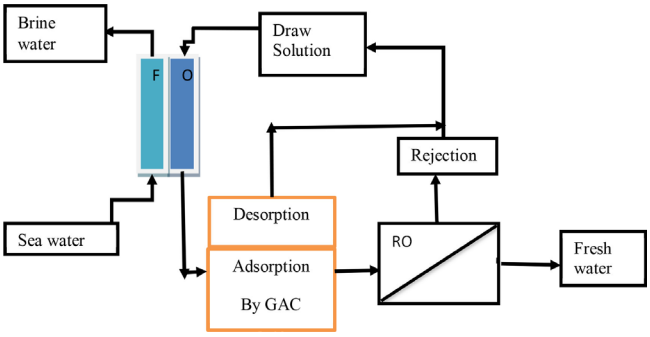

Fig. 1. Illustrates the solute exchange technique process combined with MFO.

Table 2
Illustrates the equipments and materials used in this investigation

Items type	Specifications and purposes
Equipments	(1) Hot box oven (Weiss Gallenkamp, UK) with temperature range of 0°C–300°C. (2) Coffee crusher type (Krups, China) was used for crushing both the chars and GAC products. (3) Two lab test sieves (Endecotts; less than 0.5 mm and from 0.5 to 1.40 mm). (4) A small lab distillation unit for recovering ethanol and in determining quantity of palm oil. (5) pH meter (Mettler Toledo, UK) with standard electrode. (6) Hitachi (Japan) S3200N scanning electron microscope (SEM) operating in variable pressure mode and with the accelerating voltage 20 kV and the magnifications of 50× and 250×. (7) Fourier transform infrared spectrometer (FTIR) system 2000 (PerkinElmer, USA) to determine the functional group types on the surface of chars and GAC. (8) Water bath (Mickle Laboratory Engineering, UK) with variable speed shaker (112 to 162.4 rpm) at temperature varied between 20°C and 40°C. (9) Concentration of glucose and maltose aqueous solution was determined using high-performance liquid chromatography with Varian 385-LC ELSD with evaporative light scattering detector column and with mobile phase 80% acetonitrile, flow rate 3.0 mL/min.
Materials	(1) Dates pits from south Iraq as the raw material. (2) Ethanol 96% (v/v), analytical reagent grade. (3) Concentrated sulphuric acid (98%), concentrated phosphoric acid (85%) and zinc chloride assay (98%) all supplied by Fisher Scientific. (4) Sodium bicarbonate laboratory reagent assay (99.5%) supplied by British (UK) Drug Houses. (5) D-(+)-Maltose monohydrate and glucose analytical reagents supplied by Sigma-Aldrich (UK).

sizes, coarse (<0.5 mm) and fine (0.5–1.4 mm). The percentage weight loss found was 29.1%. Moreover, the carbonized date pits samples remained hard and difficult to crush by hand where drying is carried out for 24 h.

2.3.2. Palm oil and ethanol recovery

To extract the palm oil from dates pits, the crushed chars were mixed and soaked in 98% ethanol. Several experiments were performed in this study to determine the chars weight loss and quantity of palm oil. Two fine particles samples (<0.5 mm) of 25 g weight were separately mixed in ethanol at weight ratios (ethanol/sample) 1:1 and 2:1 and then left to soak in tightly sealed polyethylene containers for 24 h. Similarly, at same mixing ratios, two coarse particles samples (0.5–1.4 mm) of 50 g weight were also used. All these experiments were conducted at room temperature. Afterwards the samples were separated by filtration using Whatman filter papers grade 1. To remove the residual ethanol from chars, samples were placed and dried in an oven at 50°C for 5 h. The dried samples were kept in hermetically sealed polyethylene containers to be used in the activation process. Whilst, the palm oil percentage in filtrate solution and experiment was determined by distilling 250 mL in a small distillation unit. The results are presented in Table 3. It was noted that the ratio 2:1 sample was the minimum ratio to soak and cover the chars samples entirely with alcohol.

The distillation work showed that the distillate was entirely composed of alcohol (225 mL) and palm oil (25 mL). The advantage of the ethanol recovery process was to reduce the cost of GAC preparation process by recycling the alcohol and the palm oil could be collected and used in different industrial process such as making soaps.

2.3.3. Studying the effects of activation parameters

Effective activation parameters: activation temperature, activation time, impregnation ratio (IR) and particle size of date pits chars are studied to find out the optimum conditions to produce GAC. Nine samples of chars with 15 g weight each of particles size 0.5–1.4 mm were divided into three equal groups. Samples in each group were activated at different IRs (weight of solution/weight of chars) 1, 1.5 and 2 for 24 h. The first group of samples was placed in an oven at 200°C, while the second and third group at 250°C and 300°C, respectively. The results are presented in Figs. 3–5.

Similar treatment was carried out at 200°C on nine samples of chars with 15 g of particle size range 0.5–1.4 mm using different activation times 24, 48 and 72 h. The results are shown in Figs. 6–8. Also, the effect of IR on GAC percentage yield can be shown from the activation temperature and time effect studies for all dehydrating agents used as presented in Figs. 9–11. Moreover, the effect of chars particle sizes on the GAC yield was also investigated. Thus, three samples with 15 g and particle size less than 0.5 mm were activated at different IRs 1, 1.5 and 2 at 200°C for 24 h. The results are displayed in Fig. 12. The yield of activated carbon is defined as the ratio of the mass of activated carbon produced to the mass of the raw material used and can be calculated as a percentage shown in the following equation [4,13–25]:

$$\%Y = (M_{GAC}/M_{RM}) \times 100 \quad (1)$$

where M_{GAC} is the mass of produced GAC and M_{RM} is the mass of raw material.

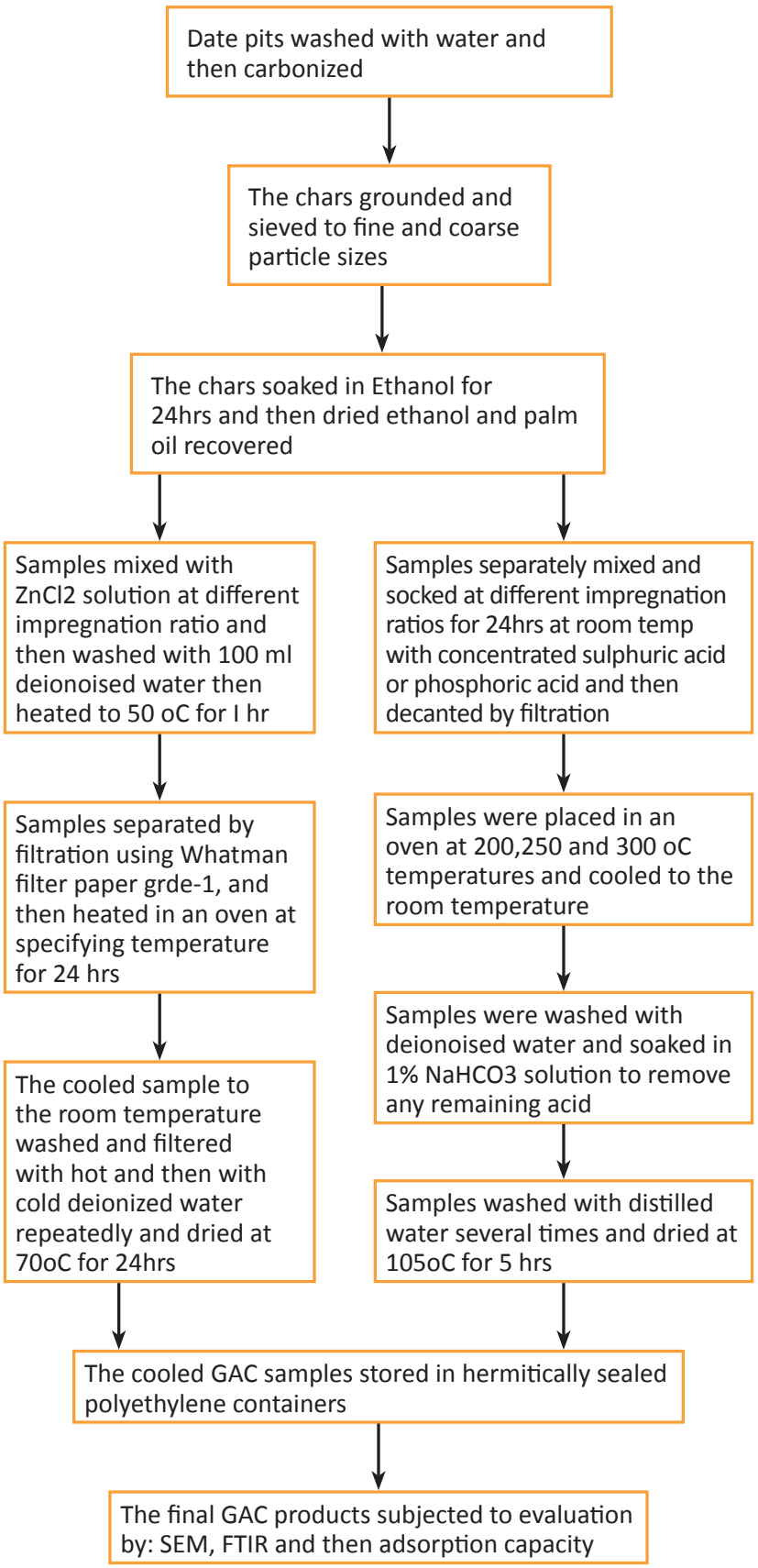

Fig. 2. Activation procedure of dates pits to produce GAC.

Table 3
Effect of the ethanol solution (98%) on chars weight loss percentages

Particles size of chars sample (mm)	98% ethanol to chars sample weight ratio	% Chars sample weight loss
<0.5 (fine)	1	*
<0.5 (fine)	2	9.6
0.5–1.4 (coarse)	1	2.6
0.5–1.4 (coarse)	2	3.0

*The weight ratio was not sufficient to soak the sample completely.

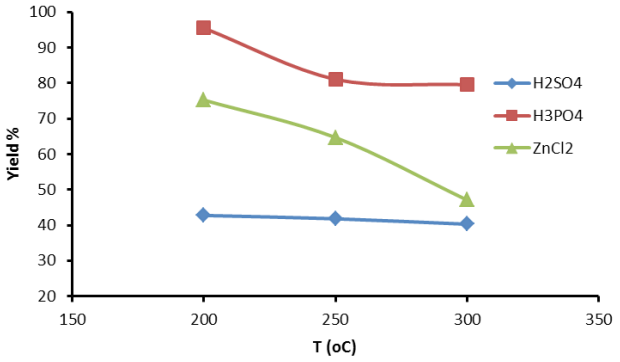

Fig. 3. Variations of percentage yield of GAC with activation temperature when using sulphuric acid, phosphoric acid and zinc chloride, IR = 1 and heated for 24 h.

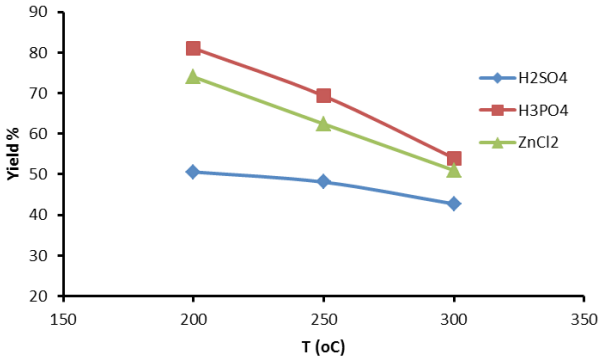

Fig. 4. Variations of percentage yield of GAC with the activation temperature using sulphuric acid, phosphoric acid and zinc chloride as dehydrating agents, IR = 1.5, heated for 24 h.

2.3.4. Characterization of prepared GAC by SEM and FTIR

Generally, the pore structure development is affected by many factors such as inorganic impurities and the initial structure of carbon precursor. However, to investigate this, several images were taken using Hitachi S3200N SEM for selected samples GAC as shown in Figs. 13(A)–(E), 14(A)–(D), 15(A)–(D). The adsorption capacity of GAC depends heavily upon porosity as well as the chemical reactivity of functional groups at the surface. This reactivity creates an imbalance between forces at the surface as compared

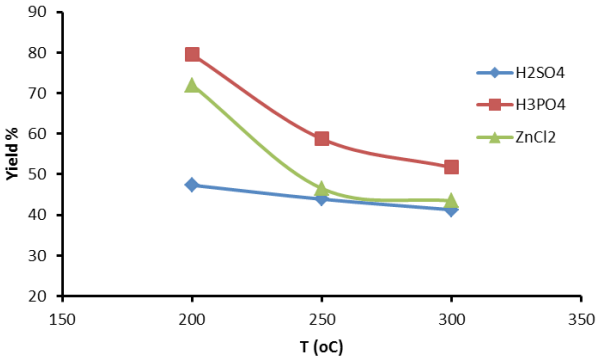

Fig. 5. Variations of GAC percentage yield with the activation temperature when using sulphuric acid, phosphoric acid and zinc chloride as dehydrating agents, IR = 2, heated for 24 h.

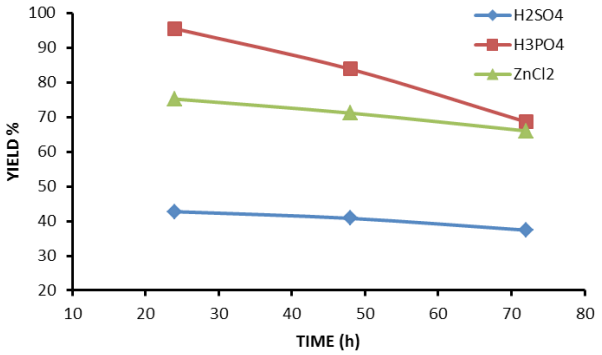

Fig. 6. Variations of GAC percentage yield with activation time using sulphuric acid, phosphoric acid and zinc chloride, at IR = 1 and at 200°C.

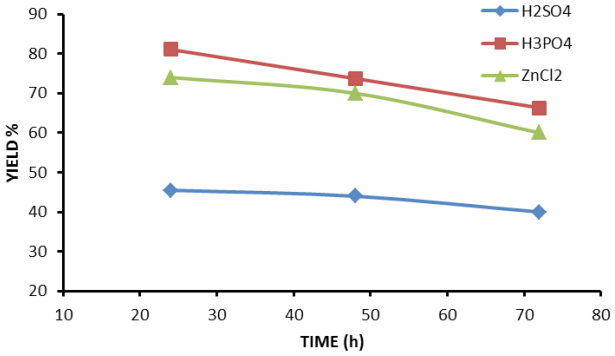

Fig. 7. Variations of GAC percentage yield with activation time using sulphuric acid, phosphoric acid and zinc chloride at IR = 1.5 and at 200°C.

with those within the body, which is influenced by van der Waals forces. However, knowledge of surface functional groups would explain into the adsorption capability of the activated carbon. The FTIR spectra were collected for qualitative characterization of functional groups on the surface of chars and activated carbon products as shown in Tables 4–6.

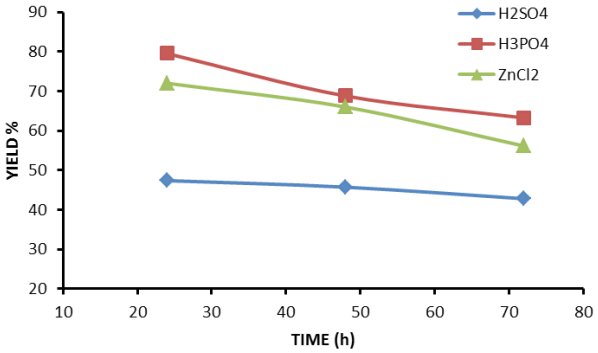

Fig. 8. Variations of GAC percentage yield with activation time using sulphuric acid, phosphoric acid and zinc chloride, at IR = 2 and at 200°C.

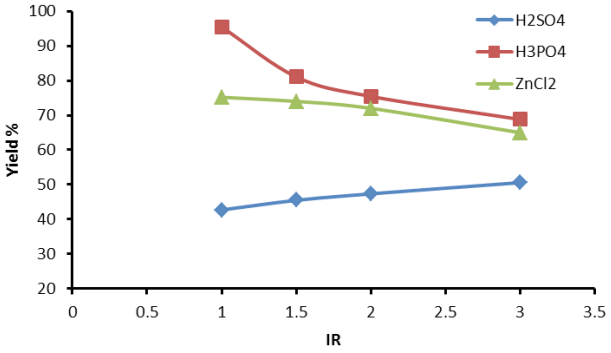

Fig. 9. Variations of GAC percentage yield with IR using sulphuric acid, phosphoric acid and zinc chloride, with 24 h activation time and heated at 200°C.

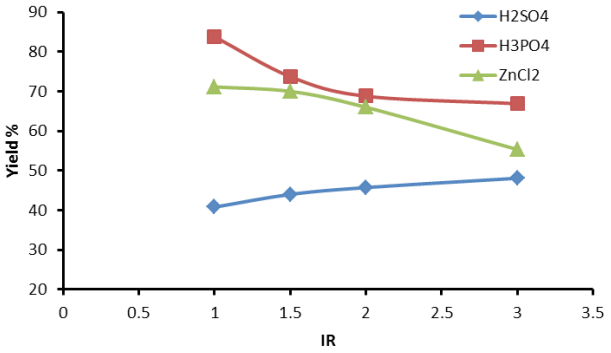

Fig. 10. Variations of GAC percentage yield with IR using sulphuric acid, phosphoric acid and zinc chloride, with 48 h activation time and heated at 200°C.

All functional groups has been identified in this work according to the work done by Williams and Fleming [26].

2.3.5. Adsorption efficiency

In this study, the adsorption capacity for glucose and maltose from their aqueous solutions was examined. Samples 1.0 g

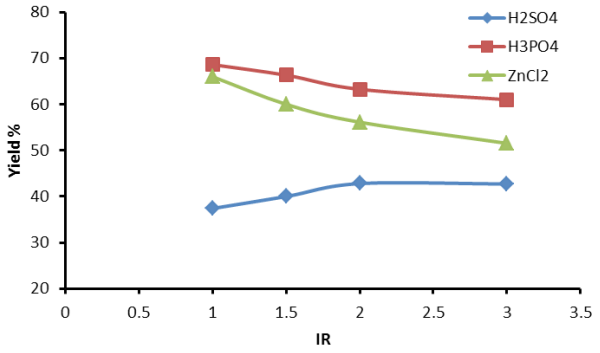

Fig. 11. Variations of GAC percentage yield with IR using sulphuric acid, phosphoric acid and zinc chloride, with 72 h activation time and heated at 200°C.

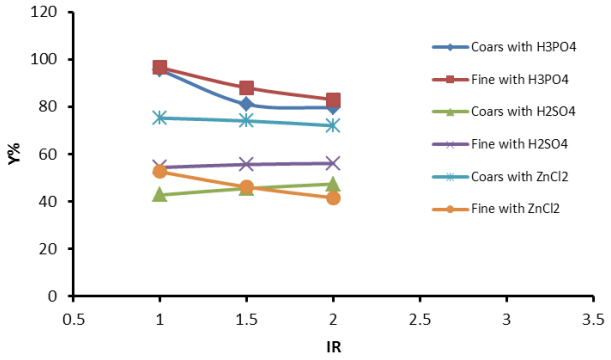

Fig. 12. Char particle size effect on GAC yield percentage when activated at temperature 200°C and time 24 h for all dehydrating agents.

of each GAC which were characterized by SEM and FTIR were shaken separately with 100 mL of 4.823 g/L glucose solution concentration at ambient temperatures of 22°C and pH 5.5. Similarly, 1 g sample from the same selected GAC was shaken separately with 100 mL of 5.023 g/L maltose solution. All mixtures were shaken at 142 rpm for 6 h. The samples were then sequestered by filtration using Whatman filter papers grade 1. The concentrations of the bearing and filtrate solutions were determined using HPLC. The results are displayed in Table 7.

3. Results and discussion

Table 3 shows the effect of ethanol/chars sample weight ratio on the percentage weight loss of chars. For coarse samples, the percentage weight loss is between 2.6% and 3%, while it is 9.6% for the fine samples. This disparity may be due to surface area difference.

It can be seen from Figs. 3–5 that for all the dehydrating agents used, as the activation temperature increased from 200°C to 350°C the percentage yield decreased for all IRs used. This could be attributed to increase in the loss of the volatile materials with rise in temperature. Also, from these figures, it is clear that the activation with H_3PO_4 gave the highest percentage yield compared with the other two agents. This behaviour is in agreement with the findings obtained

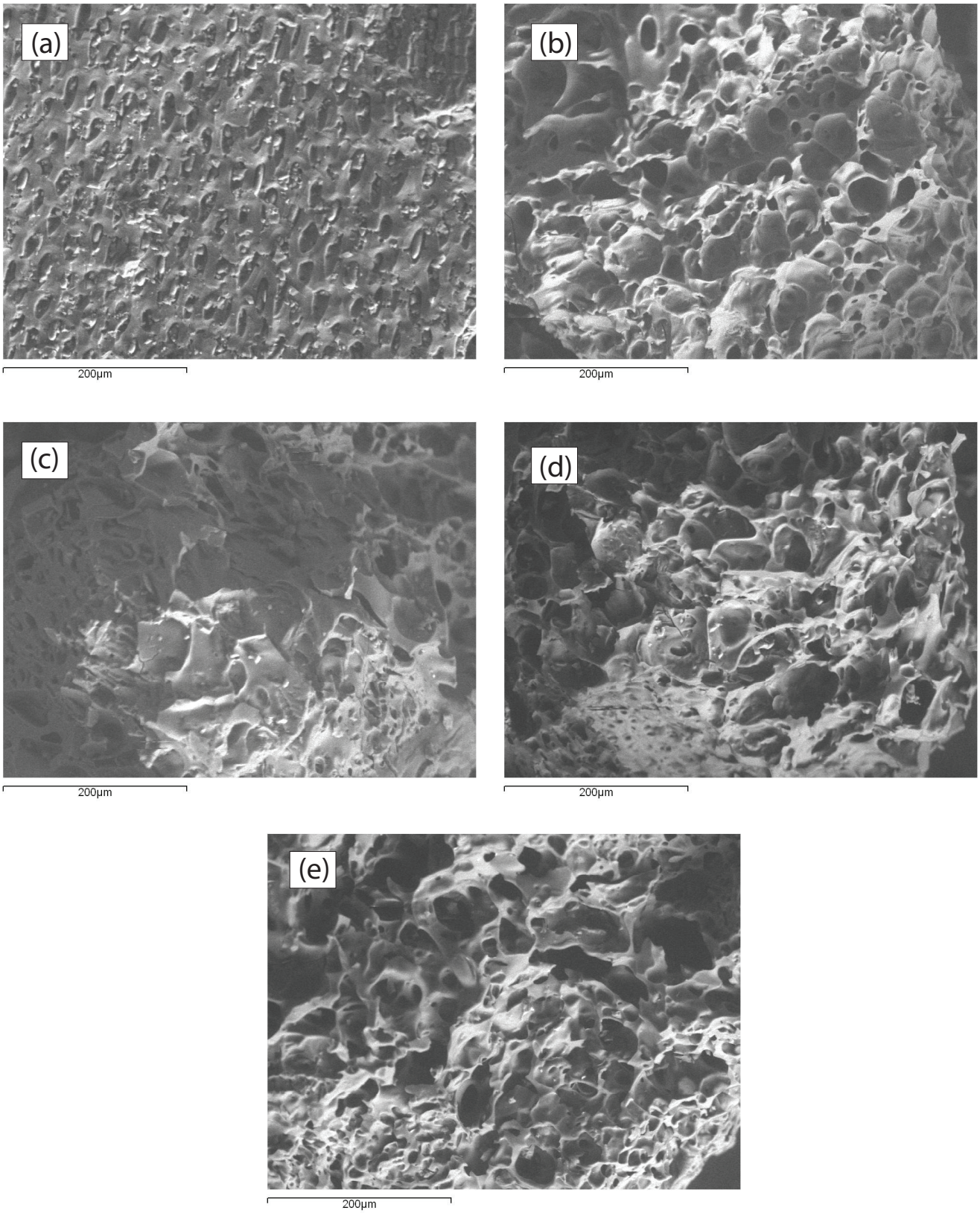

Fig. 13. SEM micrographs of chars and GAC activated by H_2SO_4 at different conditions. (A) Coarse chars (>0.5 mm) before activation process; (B) GAC activated at IR = 1, activation time = 24 h, activation temperature = 200°C; (C) GAC activated at IR = 2, activation time = 24 h, activation temperature = 200°C; (D) GAC activated at IR = 1, activation temperature = 300°C, activation time = 24 h; (E) GAC activated at IR = 1, activation time = 24 h, activation temperature = 200°C, fine chars (<0.5 mm particle size).

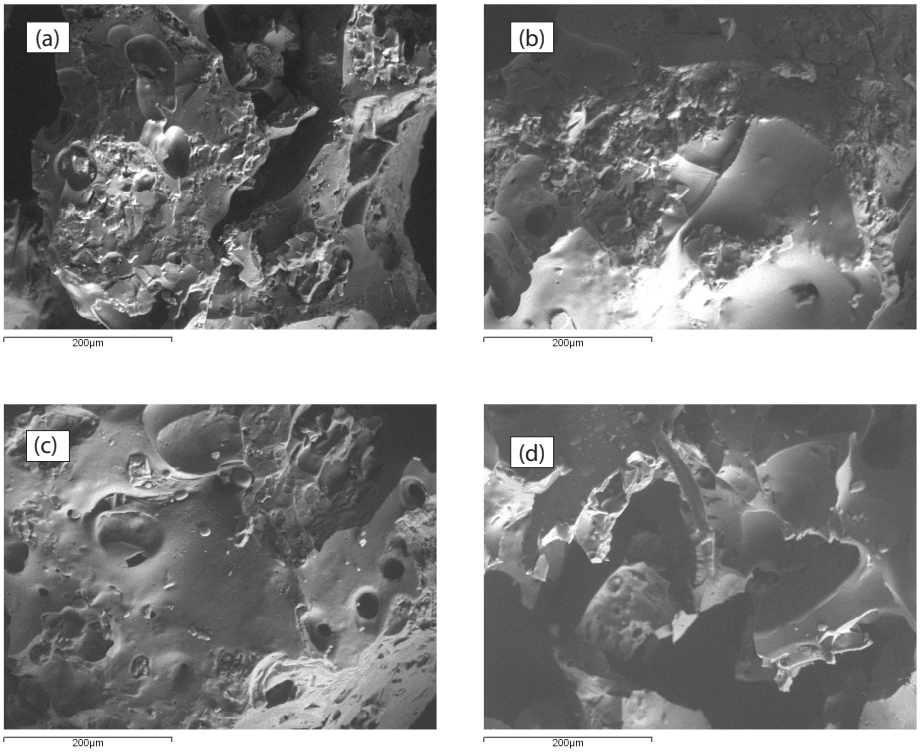

Fig. 14. SEM micrographs of GAC activated by H_3PO_4 at different conditions. (A) GAC activated at IR = 1, activation time = 24 h, activation temperature = 200°C; (B) GAC activated at IR = 2, activation time = 24 h, activation temperature = 200°C; (C) GAC activated at IR = 1, activation temperature = 300°C, activation time = 24 h; (D) GAC activated at IR = 1, activation time = 24 h, activation temperature = 200°C, fine chars (<0.5 mm particle size).

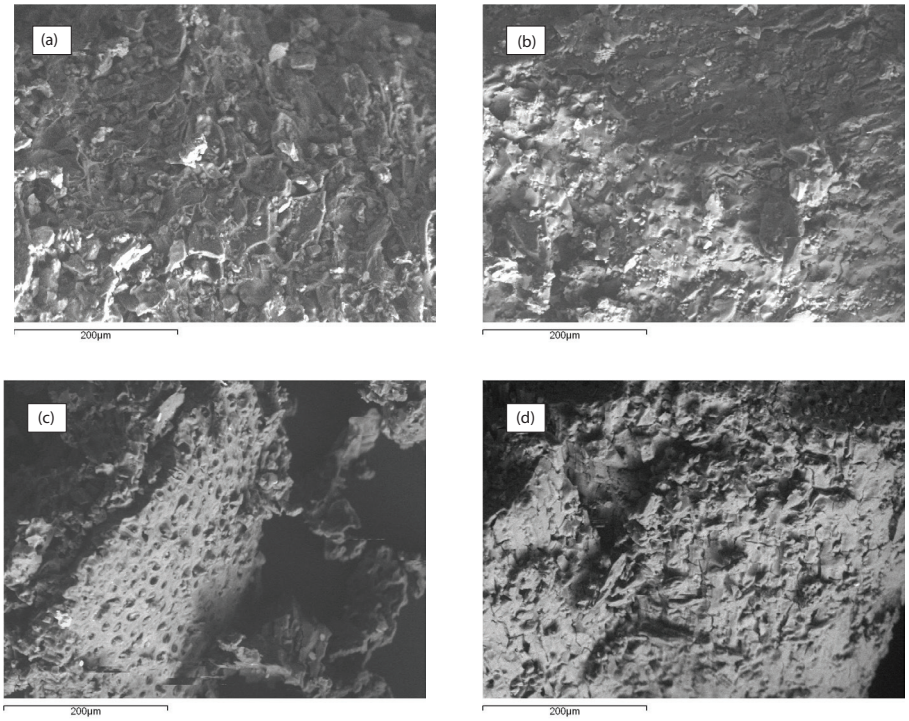

Fig. 15. SEM micrographs of GAC activated by $ZnCl_2$ at different conditions. (A) GAC activated at IR = 1, activation temperature = 200°C, activation time = 24 h; (B) GAC activated at IR = 2, activation time = 24 h, activation temperature = 200°C; (C) GAC activated at IR = 1, activation temperature = 300°C, activation time = 24 h; (D) GAC activated at IR = 1; activation time = 24 h, activation temperature = 200°C, fine chars (<0.5 mm particle size).

Table 4
FTIR bands of chars and prepared GACs from dates pits using sulphuric acid as dehydrating agent

Sample type	Band	Functional groups
Chars sample particle size 0.5–1.4 mm	2,918	Alkyl C-H
	2,323–1,900	Aromatic C=C
	1,592	C=C or C=O
	1,138–1,026	SO_2
	810	Aromatic C–H
	673	C–Cl
	763–504	C–Br
Activated carbon (0.5–1.4 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 1	2,831	Carboxylic Acid O-H
	1,597	Aromatic C=C bending
	1,150	S–CS–N
	546–510	C=Br
Activated carbon (0.5–1.4 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 2	2,960–2,700	Carboxylic acid O–H
	1,700	C=C, C=O
	1,556	Aromatic C=C
	546–514	C=Br
Activated carbon (0.5–1.4 mm) Activation temperature: 300°C Activation time: 24 h Impregnation ratio: 1	2,929–2,700	Alkyl C–H stretch
	1,697–1,575	Amide C=O, aldehyde C=O
	1,146–506	Ketene C=O
Activated carbon (<0.5 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 1	2,966	Carboxylic acid O–H
	1,697–1,579	Aldehyde C=O
	1,027	Si–O
	574–503	C–Br

for date pits activated by phosphoric acid investigated by Girgis and El-Hendeway [4]. Furthermore as reported by Al-Aibi et al. [11], the percentage yield decreased as the activation temperature increased.

Figs. 6–8 show that as the activation time increased from 24 to 72 h, the percentage yield decreased at different IR values where other parameters were kept constant. This is due to the loss of volatile materials as activation time increased. Additionally, it can be observed from these figures that the use of H_2SO_4 removed more volatile materials from the samples than with either $ZnCl_2$ or H_3PO_4.

Figs. 9–11 show the variation of GAC percentage yield with IR. From these figures, it can be observed that when using H_3PO_4 and zinc chloride dehydrating agents, as the IR increased from 1 to 3, the percentage yield gradually decreased while the activation time and temperature were maintained constant. Similarly, the activation by H_3PO_4 gave the highest percentage yield.

Table 5
FTIR bands of chars and GACs prepared from dates pits using phosphoric acid as dehydrating agent

Sample type	Band	Functional group types
Activated carbon (0.5–1.4 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 1	2,753	Alkyl C–H
	2,287	C≡C
	1,581	C=C
	1,131	P–O–alkyl
	953	P–O–P
	534–505	Si–O
Activated carbon (0.5–1.4 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 2	2,851	Alkyl C-H
	2,324	C≡C
	1,582–1,433	C=O
	959	P–O–P
	539–505	Si- O
Activated carbon (0.5–1.4 mm) Activation temperature: 300°C Activation time: 24 h Impregnation ratio: 1	2,961	O–H
	1,566	Aromatic C=C
	545–505	Si–O
Activated carbon (<0.5 mm) Activation temperature: 200°C Activation time: 24 h Impregnation ratio: 1	2,907	Alkyl C–H
	1,567	Aromatic C=C
	980	P–F
	800	Symmetric
	572–504	Si–O

Fig. 12 presents the effect of chars particle size on the GAC percentage yield. It can be noticed that as the particle size increased the percentage yield decreased for H_2SO_4 and H_3PO_4 dehydrating agents, when other parameters were kept constant. This may be attributed to the low surface area. On the contrary, using $ZnCl_2$, this percentage increased as the particle size increased. This abnormal behaviour could be due to the high diffusion of $ZnCl_2$ into the chars pores.

It can be observed from Figs. 13(A)–(E), 14(A)–(D), 15(A)–(D) that the surfaces show preponderance of grooves, cracks and crevices in the surface matrix after the activation process. The micropores are developed deep inside the surface.

Tables 4–6 illustrate that the functional groups on the surface of chars before the activation were mainly alkyl C–H, aromatic C=C and ketene C=O. After activation by sulphuric acid under different conditions, the main functional groups created on the surface were mainly carboxylic acid O–H, amide C=O, aldehyde C=O and ketene C=O groups. While, with using phosphoric acid under different operation conditions, the main functional groups were aldehyde C=O, C≡C, P–O–P, Si–O, C = C and alkyl C–H groups. However, after activation by zinc chloride, the functional groups were mainly made up of amine N–H, alkyl C–H, ketene C=O, alkyl C-H, ester C=O and aromatic C=C.

The previous sorption experimental work shows that the glucose sorption onto commercial activated carbon (12–20 mesh) was 11 mg/g, whilst it was 27.8 mg/g for maltose when

Table 6
FTIR band of chars and prepared GACs from date pits using zinc chloride as dehydrating agent

Sample type	Band	Functional groups type
Chars sample particle size (0.5–1.4 mm)	2,918	Alkyl C–H
	2,323–1,900	Aromatic C=C
	1,592	C=C or C=O
	1,138–1,026	SO_2 (s)
	810	Aromatic C–H(s)
	673	C–Cl
	763–504	C–Br
Activated carbon activation (0.5–1.4 mm)	3,355	Amine N-H
Temperature : 200°C	2,921–2,852	Alkyl C-H
Activation time : 3 h	1,742	Ketene C=O
Impregnation ratio : 1	1,367	SO_2-O-
Nitrogen flow rate : 100 mL/min	1,064	C=S
	1,010–870	Si- O
	804	NO_3^-
	587–511	C-Br
Activated carbon	3,275	Alcohol–phenol O–H stretch
Activation temperature: 200°C	2,922–2,852	Alkyl C–H stretch
Activation time: 24 hr	1,741–1,454	Ketene C=O stretch
Impregnation ratio: 1	1,155	SO_2
Particle size between 0.5 and 1.4 mm	544–513	C–Br
Activated carbon (0.5–1.4 mm)	3,287	Alcohol–phenol O–H
Activation temperature: 200°C	2,923–2,852	Alkyl C–H
Activation time: 24 h	1,741	Ketene C=O
Impregnation ratio: 2	1,598–1,440	Aromatic C=C
	1,154	SO_2
	550–506	C–Br
Activated carbon (0.5–1.4 mm)	2,919	Alcohol–phenol O–H
Activation temperature: 300°C	1,707	Ketene C=O or aldehyde C=O
Activation time: 24 h	1,577	Aromatic C=C
Impregnation ratio: 1	1,157	SO_2
	739	Aromatic C–H
	556–516	C-Br
Activated carbon (>0.5 mm)	2,922	Alkyl C-H
Activation temperature: 200°C	2,852	Ester C= O
Activation time: 24 h	1,739–1,609	Aromatic C=C
Impregnation ratio: 1	1,156	SO_2
	552–504	C-Br

GAC sample was 1 g at pH solution 5.5 at ambient temperature. Also, the glucose adsorption process was chemisorption and in good agreement with the Freundlich isotherm model, while, maltose adsorption process was chemisorption and in good agreement with Langmuir isotherm model [12].

From Table 7, it is evident that the GAC activated by sulphuric acid almost showed the same glucose adsorption capacity. Also, the GAC activated by phosphoric acid showed an ability to adsorb glucose up to 3.8 mg/g. From, this table, it is evident that the GAC activated by $ZnCl_2$ showed almost the same glucose sorption capacity except that GAC type activated at IR = 1, with activation time of 24 h and activation temperature 200°C showed the highest adsorption capacity (5.4 mg/g) compared with others (close to 50% of the commercial type). This could be due to the types of functional groups present on the surface, and the roughness of the surface.

From Table 7, it can be seen that the prepared GAC at 300°C, IR = 1, time 24 h using sulphuric acid was found to be incapable of adsorbing maltose. This could be attributed to that with the increase of activation temperature, the amount of produced ash increased accordingly which could have blocked the pores of GAC and created barrier between the pores and the solutes in the bulk of solution. Whilst, the

Table 7
Glucose and maltose adsorption amount onto prepared GACs from date pits at different temperatures and IR when activation time is 24 h

Dehydrating agent types	IR	Chars particle size in mm	Activation temperatures	Glucose adsorption amount (mg/g)	Maltose adsorption amount (mg/g)
H_2SO_4	1	0.5–1.4	200	3.2	3.1
H_2SO_4	2	0.5–1.4	200	3.2	3.1
H_2SO_4	1	<0.5	200	3.8	3.1
H_2SO_4	1	0.5–1.4	300	3.2	0.0
H_3PO_4	1	0.5–1.4	200	3.2	0.5
H_3PO_4	2	0.5–1.4	200	3.1	0.5
H_3PO_4	1	<0.5	200	2.7	0.5
H_3PO_4	1	0.5–1.4	300	3.2	1.5
$ZnCl_2$	1	0.5–1.4	200	5.4	3.1
$ZnCl_2$	2	0.5–1.4	200	3.15	3.0
$ZnCl_2$	1	<0.5	200	3.2	8.7
$ZnCl_2$	1	0.5–1.4	300	3.2	0.0

GAC activated at 200°C for 24 h (fine and coarse particles) exhibited the same capability to adsorb maltose from their aqueous solutions (3.1 mg/g). From this table, it is clear that, the GAC prepared with IR = 1 at 200°C for 24 h, fine particles size (<0.5 mm) showed the highest sorption capacity of 8.7 mg/g maltose as compared with the others types (31% maltose adsorption capacity onto commercial GAC). This is due to having a high specific surface area compared with other types. Also, it is clear from this table that, the prepared GAC at 300°C was found to be incapable to adsorb maltose. This may be attributed to the functional groups types available and the low specific surface area. It must be stated that the adsorption capacity was determined at the level of adsorption where steady-state condition was reached. Finally, the disparity in adsorption of glucose and maltose onto prepared GAC can be referred to the type and nature of the raw material as well as the activation process use for preparing GAC.

The following points are concluded from the present work:

- The percentage chars weight loss increased with increasing drying temperature up to 200°C. In addition, the drying time was one of the important parameters affecting the hardness of the chars.
- In extracting palm oil from dates pits chars by ethanol, about 96% of used ethanol can be recovered and reused again in the process which reflect positively on process cost.
- The GAC percentage yield decreased with increasing activation temperature when activation time and IRs were kept constant. The activation by H_3PO_4 was shown to produce the highest percentage GAC yield than other dehydrating agents used in this study. The GAC percentage yield decreased as the activation time increased when the activation temperature and IR being constant. When using H_3PO_4 and $ZnCl_2$ dehydrating agent, as the IR increased the GAC percentage yield gradually decreased when other parameters were kept constant, while this percentage increased slightly when H_2SO_4 was used.
- After activation, the pore network increased and the roughness of the surfaces increased. The functional groups on the surface identified to be mainly carboxylic acid O–H, amide C=O, aldehyde C=O and ketene C=O when using H_2SO_4 and H_3PO_4. While, after activation by zinc chloride, the functional groups identified mainly were amine N–H, alkyl C–H, ketene C=O, alcohol- phenol O–H, ester C=O and aromatic C=C.
- Activation process using $ZnCl_2$ as dehydrating agent for chars fine and coarse particles at 200°C, IR = 1 and 24 h activation time exhibited the highest capability to adsorb glucose and maltose solutes compared with the two other dehydrating agents.
- The GACs showed different capacities for adsorbing glucose and maltose, this could be due to the activated carbon raw material type, activation processes (physical/chemical) and the functional groups formed via activation processes.
- It is recommended to extend this study to determine the optimum parameters affecting the adsorption of glucose and maltose solutes onto prepared GACs such as mixing time, temperature, sorbent weight, bearing solution concentration and pH of solutions. Additionally, GAC capability to adsorb other contaminants in polluted water such as heavy metals and toxic elements can be tested.

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