# Separation Efficiency of Glucose and Maltose from Industrial Effluent by Granular Activated Carbon

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**ABSTRACT:** *This paper describes the performance of Granular Activated Carbon (GAC) to adsorb and separate glucose and maltose solutes from the industrial effluents by adsorption process. In this study, the capability of Granular Activated Carbon (GAC) to adsorb glucose and maltose were experimentally examined. Commercial GAC (mesh 12-20), supplied by Sigma Aldrich company in the UK was used in this work. The parameters affecting the sorbate adsorption such as the pH of the solution, initial solution concentration, shaking time and speed, sorbent dose and temperature were tested. Additionally, the adsorption equilibrium isotherm was also tested using the common isotherm modules; Langmuir and Freundlich. GAC exhibited a capability to adsorb glucose and maltose from the industrial effluent. Also, the glucose adsorption process was physical and in good agreement with the Freundlich isotherm model, while, the maltose adsorption process was a physical and the adsorption data can be adequately described by the Freundlich and Langmuir models.*


**KEYWORDS:** *GAC; Adsorption; Isotherm; Glucose; Maltose.*

## INTRODUCTION

Separation of sugars is often a relatively difficult and costly task. Chromatography is the mostly used method for separation of sugars in the commercial world. This type of process is currently applied to enrich the fructose content in High Fructose Corn Syrup (HFCS).

For separation of maltose and other compounds from starch hydrolysate and the separation of sucrose and other compounds from molasses [1], batch processes are normally used which have expensive installations, low productivity and low yields of the desired products.

Alternative processes have been proposed for separation of sugars by using zeolite adsorption [3], reverse osmosis membrane [4], ion exchange membranes [5], liquid membranes [6-12], and processes based on the chemical affinity of sugars including electrodialysis using borates to complex the sugars [13].

The liquid membrane process is a technology that combines both solvent extraction and striping processes in one step. The transport mechanism in a liquid membrane is usually based on facilitated diffusion [14]. From the different liquid membrane configuration, the most attractive for industrial applications is the Supported Liquid Membrane (SLM), a polymeric micro porous membrane whose pores are impregnated with a water immiscible organic solvent containing a transport carrier. Addition to the usual advantages of membrane processes, such as low energy demand, low capital, and operating costs, easy scale up and continues operation, liquid membrane processes are highly selective, due to the specificity of the carrier [15]. The main drawback with SLMs is membrane instability, owing to the partition of the organic solvent/ carrier to the aqueous phases.

Recently, *Kim et al.* (1983) investigated the possibility of separating various organic solutes types such as sugars, alcohols, amino acids, urea, and surfactants by reverse osmosis using Cellulose Acetate (CA) and poly(vinyl alcohol) (PVA) membranes. It was found that there is a permeability difference between glucose and fructose in cellulose acetate membranes which may be due to the affinity difference between the solution and the membrane. This phenomenon is similar to that in liquid-solid chromatography where the functional groups in the resin matrix control the retention times of solutes to be separated (*Matsuura* and *Sourirajan*, 1978[16].

In previous work *Sami Al-aibi* and his workers conducted experimental work to evaluate the separation efficiency of sucrose draw solution using HR3155P reverses osmosis membrane [17]. This work is indicated that this membrane is not reliable to separate the sugar from their aqueous solution due to the viscosity of sugar. However, the research still continues to select the proper membrane type or other efficient processes. The main target of the present study was to experimentally investigate the GAC efficiency to adsorb glucose and maltose solutes from the industrial effluent solutions.

Moreover, the parameters affecting the adsorption process are also examined in this work**.**

## METHODOLOGY AND BACKGROUND

Adsorptions of many organic substances by Granular Activated Carbon (GAC) result from specific interactions between functional groups on the sorbate and on the surface of the sorbent [18-20]. These interactions may be designated as 'specific adsorptions' concentrated at a surface, until the amount of solute remaining in solution is in equilibrium with that at the surface. This equilibrium is described by expressing (q), the amount of solute absorbed per unit weight of adsorbent as a function of the concentration of solute remaining in solution ($C_e$). An expression of this type is termed an adsorption isotherm. The adsorption isotherm is useful for representing the capacity of activated carbon for adsorbing organics from waste, and provides a description of the functional dependence of capacity on the concentration of a pollutant.

The sorption capacity ($q_t$) can be calculated from material balance using the equation [20]:

$$q_t = \frac{[C_i - C_t]}{M} V \qquad (1)$$

Where:

$q_t$ : adsorption capacity of adsorbent at time t, (mg /gm)

$C_i$, adsorbate initial concentration, (mg /L)

$C_t$: adsorbate concentration in solution at time t, (mg/L)

M: is the weight of adsorbent, in (gm)

V : is the volume of bearing solution used for sorption, (L)

Also the percentage $R_E$ of solute removed from bearing solutions using adsorbent can be calculated using bellow Equation [21]:

$$\% R_E = \frac{(C_i - C_t)}{C_i} x100 \qquad (2)$$

While the adsorption fraction $Y_t$ at any time t, can be calculated from the following Equation [21,22]:

$$Y_t = \frac{(C_i - C_t)}{(C_i - C_e)} \qquad (3)$$

Where:

$Y_t$ **:** the adsorption fraction at time t,

$C_e$ : the concentration of ion at equilibrium, i.e., infinity sorption $[C_\alpha = C_e]$,

Most importantly, at equilibrium, the thermodynamic parameters, such as free energy ($\Delta G$), enthalpy change ($\Delta H$), and entropy change ($\Delta S$) can be calculated from the following equations [23-34].

$$K_e = \frac{C_{Ac}}{C_e} \qquad (4)$$

Where:

$K_e$ : the equilibrium constant,

$C_{Ac}$ & $C_e$: are the equilibrium concentrations of solute on the adsorbent and in solution respectively, (mg/L).

The free energy ($\Delta G$) change can be calculated from the relation:

$$\Delta G = -RT\ln K_e \qquad (5)$$

Where:

T  : temperature in Kelvin (k),

R  : gas constant, (8.314x10$^{-3}$ kJ/mol.k)

The enthalpy and entropy changes $\Delta G$ & $\Delta S$ can be calculated respectively, from the equations:

$$\Delta G = \Delta H - T\Delta S \qquad (6)$$

$$\log K_e = \frac{\Delta S}{2.303R} - \frac{\Delta H}{2.303RT} \qquad (7)$$

Where $\Delta S$ and $\Delta H$ can be determined from the slope and intercept by plotting log $K_e$ versus 1/T. A positive value of $\Delta H$, indicates that the adsorption is an endothermic process, and the negative value of $\Delta S$ indicates, the feasibility and spontaneous nature of ion adsorption onto the adsorbent. The adsorption isotherm indicates how the adsorbed molecules are distributed between the liquid and solid phase when the adsorption process reaches an equilibrium state. Also, an adsorption isotherm is important to describe how solutes interact with adsorbent and are critical in optimizing the use of adsorbents. The analysis of isotherm data by fitting them to different isotherm models is an important step to find out the suitable model that can be used for design purposes [22]. Reference is made in the present study to two such isotherms, mainly Langmuir and Freundlich

• Langmuir isotherm model

Basically, the Langmuir adsorption model is based on that a maximum limiting uptake exists, corresponding to a saturated monolayer of adsorbate molecules at the adsorbent surface. In this model, all the adsorption sites have the same sorption activation energy [23, 35]. The linear form of Langmuir's isotherm model is given by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{Q_o b} + \left(\frac{1}{Q_o}\right)C_e \qquad (8)$$

Where:

$C_e$ : the equilibrium concentration of adsorbate, (mg/l)

$q_e$ : the amount of adsorbate adsorbed per unit mass of adsorbent, (mg/g).

$Q_O$ : the maximum uptake per unit mass, (mg/g)

 b : the Langmuir constant related to the adsorption energy, (l/g).

• Freundlich isotherm model

The Freundlich expression is based on an exponential relationship and is generally applicable to the adsorption on the heterogeneous surface with the interaction between adsorbed molecules and it can be employed to describe the heterogeneous systems and may be written as [23, 36].

$$q_e = K_f C_e^{1/n} \qquad (9)$$

Where:

$q_e$ : amount adsorbed at equilibrium, (mg/gm)

$Ce$ : equilibrium concentration of adsorbate, (mg/l)

$K_f$  : Freundlich constant related to adsorption capacity, (mg/gm .(mg/L)$^{1/n}$)

$n$  : gives an indication of how favourable the adsorption process, or (the empirical parameter representing the energetic heterogeneity of adsorption sites).

$K_f$ can be defined as the adsorption distribution coefficient and represents the quantity of adsorbate on the adsorbent for a unit equilibrium concentration. The logarithmic form of Freundlich is given by the following equation [22, 29]:

$$\log q_e = \log K_f + \left(\frac{1}{n}\right)\log C_e \qquad (10)$$

$K_f$ and $n$ can be determined from the slope and intercept of a plot of log $q_e$ against log$C_e$. The slop 1/n ranging between 0 and 1 is a measure of adsorption intensity or surface heterogeneity, becoming more

heterogonous as its value gets closer to zero. A value for $1/n$ below one indicates a normal Langmuir isotherm while $1/n$ above 1 is indicative of cooperative adsorption [22]. On the other hand, n is the heterogeneity factor represents the deviation from linearity of adsorption as follow: if the value of n =1, the adsorption is linear; n<1, the adsorption process is chemical; if n >1 the adsorption is a favourable physical process [22].

### *Equipment*

A four digit weight balance (Sartorius research type) was used in this investigation. For pH measurements, a pH- meter (Mettler-Toledo Company in the UK) was used with a standard electrode. All experiments were carried out using a variable speed water- bath shaker (Mickle Laboratory Eng. Co England) with a shaking speed from 112 to 200 rpm, at a temperature varied between 20-40ºC. The concentration of glucose and maltose were determined using an HPLC instrument (Varian 385-LC ELSD with Evaporative Light Scattering Detector Column and with mobile phase 80% acetonitrile, the flow rate of 3.0 mL/min).

### *Materials and reagents*

Commercial Granular Activated Carbon (GAC) Darco, with mesh (12-20), D-(+) maltose monohydrate and D-(+) glucose compounds with good purity (≥99.5%) supplied by Sigma Aldrich Co. in the UK were used in this study.  All solutions and reagents were prepared by dissolving the weighed amount of these chemicals in deionized water. Also, analytical reagent grade of sodium hydroxide (Assay: 98.05 %) and hydrochloric acid solution laboratory reagent grade (Assay: 35.38%) supplied by Fisher Scientific. Co in the UK were used to alter the pH of solutions**.**

### *Parameters affecting glucose and maltose adsorption onto GAC*

There are several parameters affecting the adsorption of glucose and maltose onto GAC, such as; pH solution, shaking time and speed, initial concentration of the solution, sorbent dose, and temperature. These parameters were tested in this study as follows.

### • *pH effect*

The effect of initial solution pH values on the adsorption capacity of glucose and maltose onto GAC was investigated in this study. A number of glucose and maltose solutions with different pH values (1-9) were prepared separately. The glucose initial concentration range was 5252-5761 mg/L, while the concentration, for maltose, was 1000 mg/L. One gram of GAC was placed separately in 100 mL of prepared glucose and maltose solutions. All the mixtures were shaken at a speed of 142 rpm for 6 hours at an ambient temperature of 22ºC. After that, the samples were segregated by filtration using Whatman filter papers grade-1. The glucose and maltose concentrations in both initial and filtrate solutions were determined using HPLC. The adsorption amount was then calculated from a material balance using Eq. (1). The results of this study are presented in Fig. 1.

### • *Shaking speed effect*

In this study, the effect of shaking speed on the adsorption capacity of solutes was tested using different shaking speeds from 110 to 173 rpm. Five GAC samples with 1gm were mixed separately in 100 ml of 4891 mg/L glucose concentration solution at pH range 7-8 for 8 h. Also, five GAC samples with 1g were shaken separately in 100 mL of 6160 mg/L maltose concentration solution at pH 7 for 8 h. The samples were then separated by filtration and all experiments were conducted at an ambient temperature of 22ºC. The results of these experiments are presented in Fig. 2.

### • *Sample weight and sorbate concentration effects*

Several experiments were carried out to study the effect of initial concentration solution on the adsorption process. Two GAC doses (0.5 and 1.0gm) were shaken separately with 100ml of glucose solution with a concentration range from 2593 to 15785 mg/L, at pH range 7-8. Similarly, two GAC doses (0.5, 1gm) were shaken separately with 100 mL of maltose solution concentration range (366- 16265 mg/L) at pH 7. The experiments were conducted at an ambient temperature of 22ºC with a shaking speed of 142 rpm for 8hrs. All the samples were separated by filtration and concentrations of initial and remaining solutions were determined. However, based on the results of these experiments, sorbent dose effect on GAC adsorption capacity was tested and all the results of these experiments are presented in Fig. 3.
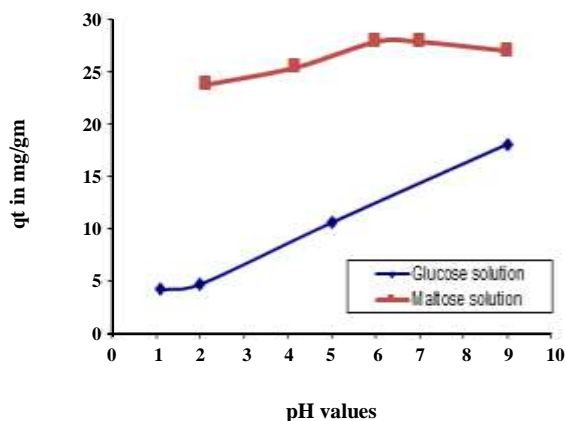
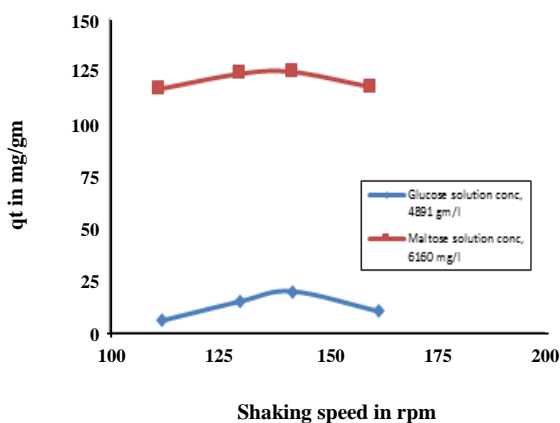***Fig.1: pH effect on GAC adsorption capacity when using 10 gm/l sample dose.***



***Fig. 2: The effect of shaking speed on glucose and maltose adsorption capacity onto 10gm/l GAC sample dose.***
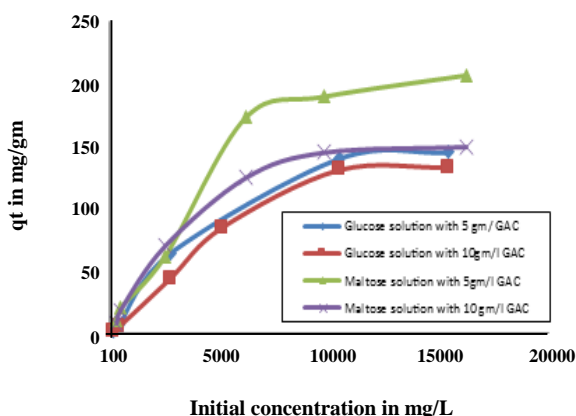


***Fig. 3: Initial concentration effect on glucose and maltose adsorption amount onto GAC.***

● *Shaking time effect*

In this investigation, two experiments were carried out. In the first experiment, three GAC samples of 0.5gm were shaken separately with 100ml of 5040 mg/L glucose concentration solution at pH range 7-8. In the second experiment, three GAC samples of 1.0gm were shaken separately with 100 ml of 5463 mg/L maltose concentration solution at pH 7.0. In each experiment, the first mixture was shaken for 2 h, whilst the remaining mixtures were shaken for 4,6 and 8 hrs respectively. All the samples were shaken at an ambient temperature of 22°C with a constant shaking speed of 142 rpm. The samples were then separated by filtration and concentrations of glucose and maltose were determined. The results of this study are presented in Fig. 4.

● *Temperature effect*

To investigate the temperature effect, three GAC samples of 1.0gm were shaken separately with 100ml of 5072 mg/L glucose concentration solutions at pH range 7-8. The first sample was shaken at 25°C, while the second and third samples were shaken at 30 and 35°C respectively. For maltose, three GAC samples of 1g were shaken separately with 100 mL of 5397 mg/L of maltose concentration solutions with pH 7. The first sample was shaken at 20°C while the second and third samples were shaken at 30 and 35°C respectively. A shaking speed of 142 rpm was kept constant during the shaking time of 8hrs. The GAC samples were then sequestered by filtration from the solutions. Also, glucose and maltose solute concentrations were measured, and the results of this study are presented in Fig. 5.

**RESULTS AND DISCUSSION**

***The parameters affecting the adsorption onto GAC***

From Fig. 1 it can be observed that the amount of glucose adsorbed was affected by changing the pH value of the initial solution. The glucose uptake was found to increase as the solution pH increased from 4.20 to 18.1 mg/g for an increase in pH from 1 to 9. This may be attributed to a number of reasons. The surface of GAC may contain a large number of active sites and the solute uptake can be related to the active site and also to the chemistry of the solute in the solution. At a lower pH, the surface may get positively charged, thus making $H^+$ ions compete effectively with

glucose molecules causing a decrease in the amount of glucose adsorbed (mg/gm). However, at a higher pH, the surface of GAC may get negatively charged, which enhances sorption of the positively charged glucose ions through the electrostatic force of attraction. From this Figure (Fig. 1), it can be observed that the maltose uptake increases as pH increases, to attain maximum absorption at pH 7 and thereafter it decreases with any further increases in pH. The maximum adsorption amount of maltose at pH 7 was found to be 27.86 mg/gm. With an increase of pH from 2 to 7, the surface of GAC may contain a large number of active sites and the solute uptake can be related to the active sites and also to the chemistry of the solute in the solution. Then, at a higher pH, increase in $OH^-$ concentration causes a decrease in adsorption of maltose. Alternatively, an increase in pH value causes a decrease in protonation of the surface which leads to a decrease in the net positive surface potential of the sorbent. This reduces electrostatic forces between sorbent and sorbate that leads to reduce sorption capacity. Additionally, with increased pH value, the competition between $OH^-$ and maltose was increased. Finally, pH 7 could be represented as an optimum value in maltose adsorption onto commercial GAC.

From Fig. 1, it can be seen that the adsorption amount of glucose onto GAC was increased moderately from 6 to 19.9 mg/gm when the shaking speed increases from 112 to 142 rpm. This may be attributed in a reduction in external resistance with increasing the shaking speed. Afterwards, the glucose uptake amount was decreased rapidly with increasing the shaking speed higher than 142rpm. This may be due to desorption occurrence or glucose molecules not taking sufficient time to fix on the surface of GAC. Hence, the shaking speed of 142 rpm could be represented as an optimum value for glucose adsorption onto GAC.

From Fig. 2, it can be seen that the maltose uptake amount onto GAC was also increased moderately from 116.5 to 124.7 mg/gm when the shaking speed increased from 112 to 142 rpm, then this uptake was decreased by increasing the shaking speed beyond 142 rpm. The increase of uptake with increasing the shaking speed may owe to reduce the external resistance on the surface of GAC. While the decreasing uptake when shaking speed is higher than 142 rpm may be due to desorption occurrence or the mixing not allowing maltose molecules sufficient

time to fix on the surface of GAC. From the above the shaking speed 142 rpm represents an optimum value of maltose uptake onto GAC.

Fig. 3 shows that when using sorbent dose 5 gm/L the amount of glucose adsorbed onto GAC increased moderately from 10.8 to 93 mg/gm, with an increasing initial concentration from 5115 to 15785 mg/L. Also, it found that this amount increased slightly from 14.2 to 27.5 mg/g with initial glucose concentration increases from 2593 to 10205 mg/L, when using a sorbent dose of 10 gm/L. This may be due to greater coverage of glucose molecules of the active sites on the surface of GAC. However, the above mentioned results indicate that the amount of glucose adsorbed onto GAC increases with an increase in the initial solution concentration. It is observed from this figure that the maltose adsorption amount onto GAC varied with the initial maltose concentration when sorbent dose, pH solution, shaking speed and shaking time are kept constant. From this figure, the maltose adsorption amount increased moderately with an increase in the initial maltose concentration from 366 to 6232 mg/L. After that, it increased slightly for an increase in the initial concentration up to 16265 mg/L. This may be due to greater coverage of maltose molecules on the active sites on the surface of GAC.

Basically, the effect of the sorbent dose was extracted from the data of the initial concentration effect study. From Fig. 3 it can be seen that the glucose and maltose adsorption amounts onto GAC decreased with increased GAC sorbent dose. This could be due to the solute transfer rate on the GAC surface or due to the formation of aggregates at higher mass concentration, which decreases the effective sorption area.

It is evident from Fig. 4 that glucose and maltose adsorption amounts increased with increasing the shaking time. This could be related to increases in the contact time between sorbate and GAC. Moreover, this test provides additional evidence to confirm that the GAC demonstrated a higher capacity for adsorbing maltose compared with glucose.

Fig. 5 indicates that the amount of glucose adsorbed onto GAC increased from 4.8 to 10.2 mg/gm, with an increase in initial solution temperatures, from 25 to 35°C. This indicates that glucose adsorption increases with the increasing temperature of the solution and, accordingly, the adsorption is an endothermic process. Increasing
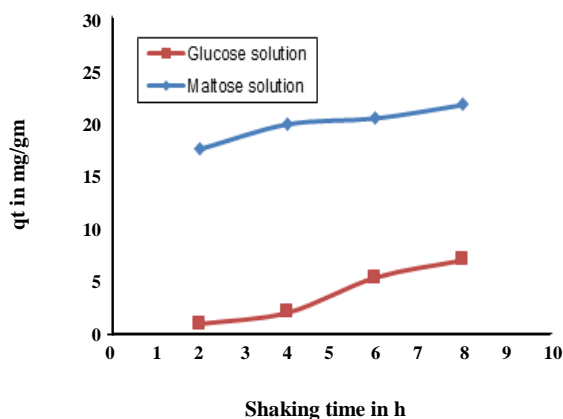
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***Fig. 4: The effect of shaking time on glucose adsorption amount onto GAC when sample doses are 10 gm/l.***



***Fig. 5: The effect of temperature on the glucose adsorption onto GAC when the sample dose is 10gm/l.***

the temperature causes increases in the diffusion rate of the adsorbate molecules across the external boundary layer and in the internal pores of the adsorbent particles as well. This could be due to decreases in the viscosity of the solution. Moreover, changing the temperature will change the equilibrium capacity of the adsorbent. According to thermodynamics, the Gibb's free energy is correlated to the changing of enthalpy ($\Delta H^o$) and entropy ($\Delta S^o$) at constant temperatures as shown in Van't Hoff Equation (7). The values of $\Delta H^o$ and $\Delta S^o$ were estmated from the slope and intercepts of plotting log K against 1/T. The results of thermodynamic studies of glucose adsorption process onto GAC are presented in Table 1. It can be seen from this table, that the values of the enthalpy ($\Delta H^o$) and entropy were positive. A positive value of enthalpy ($\Delta H^o$) indicates that the adsorption process is endothermic. The positive change in entropy indicates increasing the randomness at the solid-liquid interface, during the adsorption of glucose onto GAC. Also, the positive values of $\Delta G^o$ indicate the feasibility and spontaneous nature of the adsorption of glucose onto GAC.

Fig. 5 shows that, when using 10gm/L GAC sorbent doses, the amount of maltose uptake onto the GAC decreased from 124.7 to 93.3 mg/gm with increasing in the solution temperatures from 20 to 35°C. This indicates that the maltose adsorption amount decreases with the temperature of the solution increases and the adsorption process is exothermic. Basically, when the adsorption is governed only by physical phenomena, an increase in the temperature will be followed by a decrease in adsorption
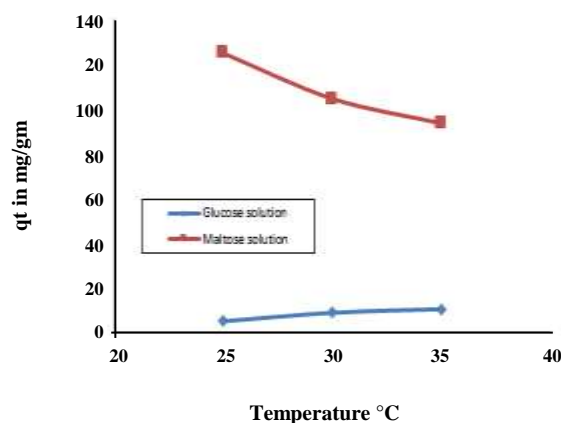
capacity. The temperature could influence the desorption step and, consequently, the reversibility of the sorption equilibrium.

It is evident from Table 2 that the negative value of enthalpy indicates that the maltose adsorption process is exothermic. The negative changes in the entropy ($\Delta S^o$) values indicate a decrease in randomness at the solid-solid interface during the adsorption process. Moreover, the decrease in adsorption capacity with rising temperatures may be due to the weakening of the adsorptive forces between the active sites of adsorbent and adsorbate molecules and also between the adjacent molecules of the adsorbed phase. Finally, the values of Gibb's free energy ($\Delta G^o$) are positive and they decrease in magnitude with an increase in the temperature. The negative values of ($\Delta G^o$) show the feasibility and spontaneous nature of the adsorption process.

From Fig. 6 it can be seen that the GAC was capable of adsorbing the glucose and maltose from their aqueous solutions at different removal percentages depending on GAC sample doses and initial concentration of glucose and maltose solutes. This percentage was generally higher at low initial concentration, which could be due to decrease the viscosity of the glucose and maltose solution with their concentration decreases, while, it increases as the GAC sample doses increase.

***Adsorption isotherm***

In this study, two common models: Langmuir and Freundlich, have been used to investigate the adsorption isotherm of glucose and maltose onto GAC. The analysis

*Table 1: Thermodynamic parameters of glucose adsorption onto GAC when sample dose is 10gm/l.*

| Temperature in °K | Equilibrium constant $K_e$ | Log $K_e$ | 1/T 1/°K | $\Delta G°$ kJ/mol | $\Delta S°$ kJ/mol.°K | $\Delta H°$ kJ/ mol |
|---|---|---|---|---|---|---|
| 298 | 0.0095 | -2.02 | 0.00335 | 11.52 | | |
| 303 | 0.0172 | -1.74 | 0.00330 | 10.22 | 0.156 | 58.073 |
| 308 | 0.0206 | -1.68 | 0.00324 | 9. 93 | | |

*Table 2: Thermodynamic parameters of maltose adsorption onto GAC when sample dose is 10gm/l.*

| Temperature °K | Equilibrium constant $K_e$ | Log $K_e$ | 1/T 1/°K | $\Delta G°$ kJ/mol | $\Delta S°$ kJ/mol.°K | $\Delta H°$ kJ/mole |
|---|---|---|---|---|---|---|
| 293 | 0.250 | -0.602 | 0.00341 | 3.376 | | |
| 303 | 0.240 | -0.619 | 0.00330 | 3.577 | -0.038 | -7.967 |
| 308 | 0.209 | -0.679 | 0.00324 | 4.000 | | |
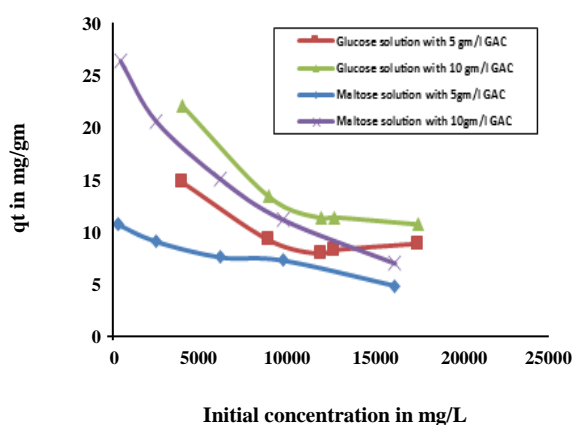


*Fig. 6: Illustrates glucose and maltose removal percentages using 5 and 10gm/l GAC sample dosses.*

of isotherm data by fitting them with these two models is an important step for finding a suitable model that can be used for design purposes.

*Langmuir isotherm*

From the experimental data of the glucose and maltose initial concentration effect study using two GAC doses 5 and 10 gm/L, $C_e/q_e$ against $C_e$ is plotted. The linearity of this plot indicated whether the adsorption process is in agreement with Langmuir's isotherm. Also, from the slope and intercept, the Langmuir constants, Qo, and b which represent adsorption capacity and rate of adsorption respectively were determined and the results are presented in Tables 3 and 4.

The applicability of the isotherm model is confirmed by judging the correlation coefficient. From, Tables 3 and 5 and depending on the correlation coefficient values, it is evident that the adsorption of glucose onto GAC agrees with Freundlich's model. Additionally, the values of n were higher than one. This gives an indication that the adsorption of glucose is a favourable physical process. However, from the findings reported in Tables 4 and 6, the correlation coefficient values show that the Langmuir and Freundlich isotherm models can adequately describe the adsorption data.

**CONCLUSIONS**

In this study, the results of glucose and maltose adsorption onto GAC led to conclude the following points:

1. The GAC exhibited a capability to adsorb the glucose and maltose solutes from the industrial effluent.

2. The amount of sorbed glucose was found to increase with an increase in the pH of the effluent solution, shaking time and speed, initial concentration of the glucose, the GAC doses, and temperature of the solution.

3. The isotherm study has demonstrated that adsorption of glucose onto GAC is agreed well with the Freundlich model. Additionally, the thermodynamic study indicates that glucose adsorption onto GAC is endothermic.

4. The amount of the maltose sorbed was found to increase with an increase; the pH of the effluent solution, shaking time and speed for up to 142 rpm, and maltose initial concentration solution However, it decreased with an increase in the GAC dose and the temperature of the effluent solution.

5. The Langmuir and Freundlich isotherm models can adequately described the maltose adsorption data onto GAC.

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*Table 3: Langmuir isotherm constants for glucose adsorption onto GAC.*

| GAC sample dose gm/L | Maximum uptake $Q_o$ mg/g | Langmuir constant b L/g | Correlation coefficient $R^2$ |
|---|---|---|---|
| 5 | 1111 | $3.45 \times 10^{-5}$ | 0.351 |
| 10 | 434.78 | $8.8 \times 10^{-5}$ | 0.788 |

*Table 4: Langmuir isotherm parameters constants for maltose adsorption onto GAC.*

| Sample dose of GAC g/L | Maximum uptake $Q_o$ mg/g | Langmuir constant b L/mg | Correlation coefficient $R^2$ |
|---|---|---|---|
| 5 | 294.11 | $1.38 \times 10^{-4}$ | 0.96 |
| 10 | 175.43 | $3.66 \times 10^{-4}$ | 0.99 |

*Table 5: Experimental results of the Freundlich isotherm model for glucose adsorption onto GAC.*

| Sample dose of GAC gm/L | Freundlich constant $K_f$ | Heterogeneity parameter n | Correlation coefficient $R^2$ |
|---|---|---|---|
| 5 | 1.378 | 1.54 | 0.8718 |
| 10 | 2.51 | 2.51 | 0.915 |

The experimental data indicate that the maltose adsorption process was exothermic.

6. It is recommended to use different types of GAC to adsorb sugars from the effluent solution, also, to enhance the adsorption efficiency via treating the GAC with chemicals (create new functional groups on the surface of GAC). In the next parts and to verify a further reduction in the cost of the adsorption process, different structures of GAC could be prepared using affordable agricultural by- products such as dates pits, date palm fibres, olive stone ect.., Additionally, the best method used to regenerate the exhausted GAC could be investigated in terms of the cost and environmental effects.

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