ESTIMATION OF CRITICAL BED DEPTH IN FIXED BED OF GRANULAR ACTIVATED CARBON

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ABSTRACT

The aim of this study is estimating the critical bed depth in adsorption process through a fixed-bed of granular activated carbon at different bed depths of 0.03, 0.05, 0.08and 0.11m at influent furfural concentration in waste water of 0.2 kg/m^3, with constant flow rate of (16.66) $\times 10^{-5}$ m^3/min and adsorbent particle size (0.5-1.5) mm. the changing of flow rate and furfural influent concentration had been studied to determine their effects on the critical bed depth value by using bed depth- service time method (BDST). Length of unused bed (LUB) and length of equivalent section of bed had been estimated mathematically during process of the adsorption at different bed depths and during changing the flow rate(8.3×10^{-5} m^3/min) and influent concentration at same bed depth (0.05m).

الخلاصة:

الهدف من هذه الدراسة هو احتساب عمق الحشوة الحرج لعملية الامتزاز في حشوة ثابتة من الفحم المنشط الحبيبي ذات اعماق متنوعة هي (٠,٠٣، ٠,٠٥ ، ٠,٠٨، ٠,١١) م بثبوت كل من معدل الجريان بقيمة (١٦,٦٦) × 10^{-5} م٣/ دقيقة ، وتركيز الفورفورال الداخل في المياه المختلفة (٠,٢) كغم/م٣ وحجم حبيبات الفحم (١,٥ – ٠,٥) ملم. تغير معدل الجريان وتغير تركيز المادة الداخلة تم دراستها لغرض تحديد تأثير عمق الحشوة الحرج باستخدام طريقة عمق الحشوة – زمن الخدمة) . طول الحشوة الغير مستخدم والطول المكافئ للحشوة المستخدمة تم تحديدها رياضياً خلال عملية الامتزاز للظروف اعلاه ودراسة تأثير تغير معدل الجريان وتركيز المادة الداخلة عند ثبوت اعماق الحشوات المستخدمة.

KEY WORDS: Adsorption, furfural, break through, exhausting point, length of unused bed, length of equivalent section, critical bed depth.

INTRODUCTION

In fixed – bed, dynamic adsorption system a liquid rich in sorbable component (adsorbate) flows through bed or zone containing adsorbent particles (Lukchis, 1973). The contact time between adsorbate and adsorbent is limited by the rate and geometry of the bed (Crittenden and Thomas, 1998). Granular activated carbon (GAC) in fixed – bed column is generally preferred to use in powdered form, where continuous application is required. GAC allows a more complete use of adsorption capacity of the carbon and prevent clogging in the bed thus reducing make-up costs (Casey, 1992).
Empirical or short – cut methods were still used extensively for the design of fixed bed column which are, length of unused bed (LUB), mass transfer zone length (MTZL), empty bed contact time (EBCT), bed depth – service time (BDST) and capacity of break point (Crittenden and Thomas, 1998). Bed Depth Service Time (BDST) method is used extensively by the water industry and can be applied to other situation where (BDST) is a common method for evaluating pilots column data from graphical analysis of the break through curve and analysis of granular – carbon system (Richard, 1998) (Ray, 1973). Length of unused bed (LUB) represents the part of the total bed at the end equilibrium zone (break through time) therefore increasing the bed size beyond the length of the mass transfer zone (MTZ) (critical bed depth) (Crittenden and Thomas, 1998) able equilibrium capacity – adsorbent that provides 100% use due to increasing break through time (Lukchis, 1973)that help to determine the active bed.

EXPERMINTAL WORK

Down flow fixed – bed vertical polyvinyl chloride (PVC) column with inside diameter (0.04) m was used for the experiments at different bed depths of 0.03, 0.05, 0.08and 0.11 m and constant flow rate (16.66)$\times 10^{-5}$ m^3/min , influent furfural concentration 0.2 kg/m^3, carbon particle size (0.5–1.5) mm. Adsorbate is a furfural (OSHA, 2000) in industrial waste water obtained from Al- Dora refinery treatment plant after the primary treatment stage (Akrawi, 1988). Adsorbate is granular activated carbon (Provided by UniCarbo CO. Italia) with bulk density 460-480 kg/ m^3 and mesh number 0.4–1.6 mm with high surface area 1100 – 1200 m^2/gm (Carbo- chem`s report, 2004) (Lyderson, 1983). The samples were taken from the bottom of the column at each 15 min. each sample (5 ml) was analyzed by using calorimetric (type Jenway, 6030, UK.) at wave length 430 nm after adding 65 ml of 27.5 vol.% ethanol, 5 ml of 10 vol. % .acetic acid and 0.5 ml of distilled aniline as an indicator (Foste and Leslie, 1971).

RESULT AND DISCUSSION

<u>Break through curves</u>:

Break through curves were plotted between effluent furfural concentration C/Co vs. time at different bed depth and constant other variables **Figure (1)** (Abood, 2005)
Fig (1) shows the increasing the bed depth leads to the increasing break through time (Tb) with clear S – shape of curve for mass transfer that is due to the provide of extra surface area for more adsorbate to carry on. (Martin and Al- Bahrani, 1978).

- Bed Depth Service Times:

Horizontal lines of (C / Co = 0.1) and (C / Co = 0.9) were plotted as shown in **Figure (1)** in order to determine of break through point and exhaustion point respectively for each curve **Table -1-**.

Table (1) Bed Depth Service Time

Bed depth (m)	0.03	0.05	0.08	0.11
Break point time (min)	15	120	277.5	435
Exhaustion point time (min)	187.5	285	457.5	625

Fig(2) was plotted as service time vs. bed depth at flow rate $(16.66\times10^{-5})m^3/min$, influent concentration 0.2 kg/m^3 and particle size (0.5–1.5) mm.

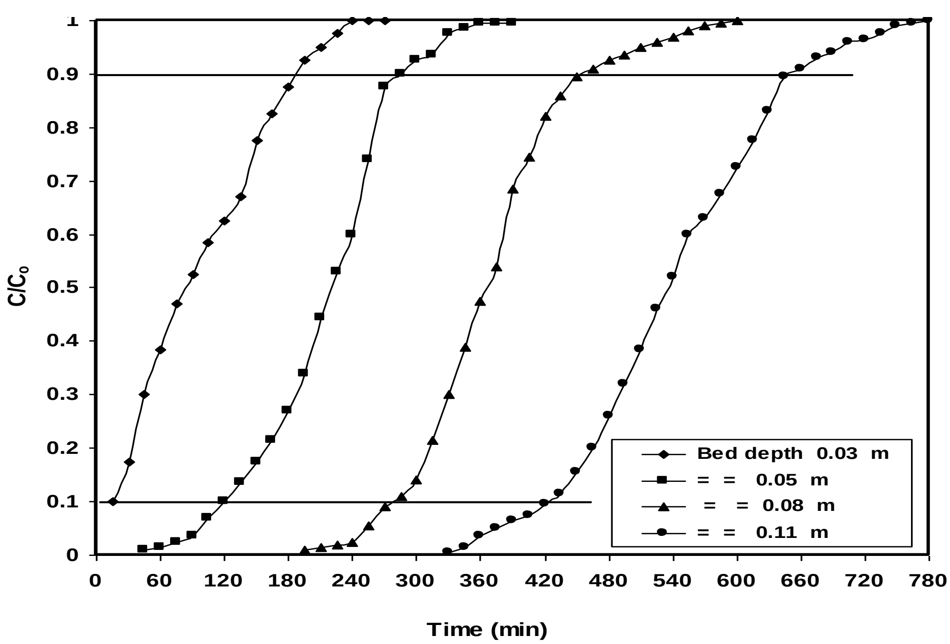

Fig. (1) Plot of (C/C_o) vs. time at different bed depth

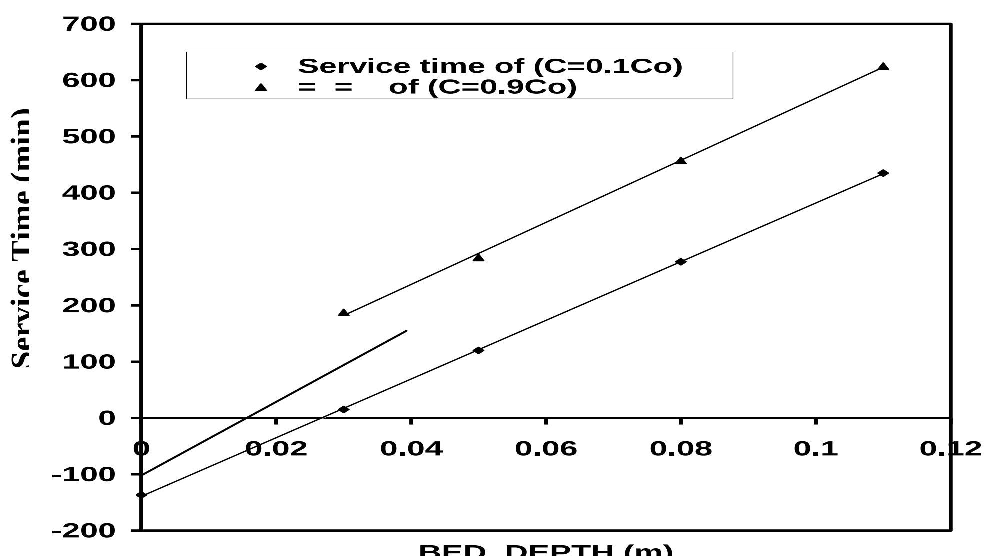

Fig. (2) Plot of service time as a function of bed depth

By fitting the lines which represent the best result in **Fig (2)** the regression equation was determined as follow:

$$\text{Time} = A\,X + B \qquad \ldots\ldots\ldots\ldots(1)$$

Where: X= Bed depth m.
A = the slope (min/ m) or (day / m) = 4 day / m
B = intercept of (C / Co = 0.1) line with Y – axis (Service time) (min) or (day) = - 0.095 day.
The intercept of (C / Co = 0.1) line with the X – axis (bed depth) represents the critical bed depth which approximately with the lowest value of experimental bed depth which means the mass transfer zone length without equilibrium zone (Crittenden and Thomas, 1998) (Richard, 1998)

EFFECT OF CHANGING FLOW RATE ON CRITICAL BED DEPTH

For changing the operating criteria like flow rate at constant influent concentration, particle size and different bed depth, equation (1) becomes as follow:

$$\text{Time} = A'\,X + B \qquad \ldots\ldots\ldots\ldots(2)$$

At same B.

$$A' = A\,(Q_{old} / Q_{new}) \qquad \ldots\ldots\ldots\ldots(3)$$

A′ = new slope of (C / Co = 0.1) line (day / m) at flow rate (8.3×10^{-5})m^3 / min the A′ value equal to 8 day / m at constant B value. **Fig (3)**.
Q = flow rate (m^3/min).

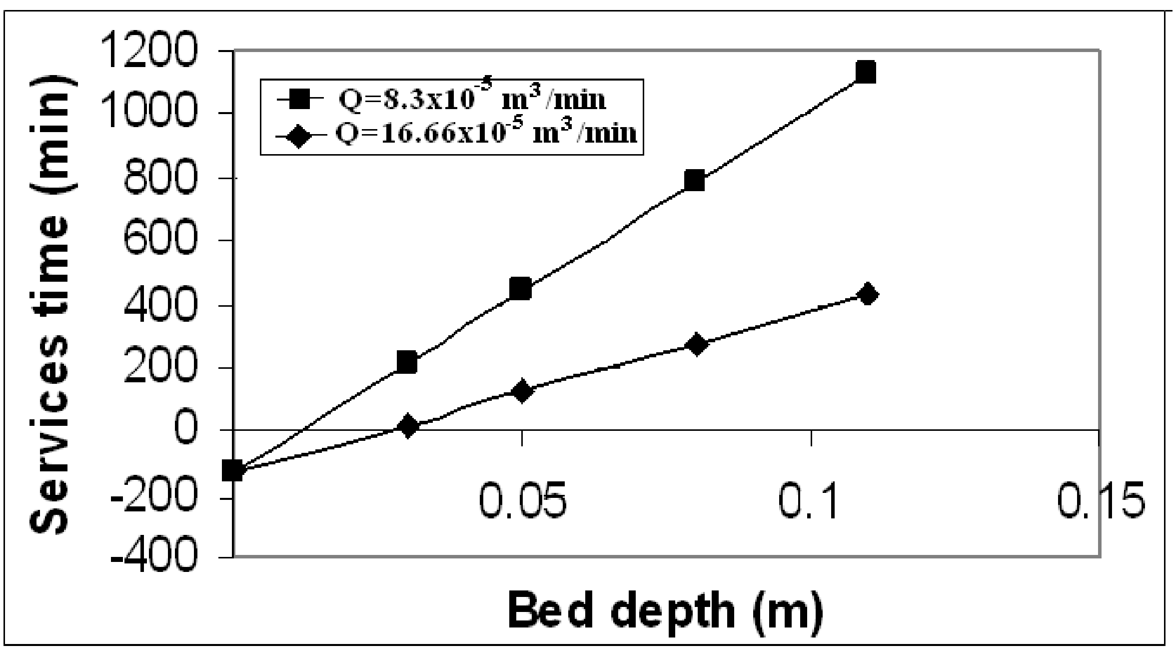

Fig (3) Bed depth service time at different flow rate

(C/Co = 0.1) line in **Fig (3)** which shows the intercept of the line with x– axis to determine the new critical bed depth, decreasing flow rate will decrease the critical bed depth this is due to the more contact time at constant cross section area and bed depth and increasing break through point time therefore the flow rate per section area must be not more than (0.132 m^3/m^2.min (Cassy, 1992)**Table – 2 –**.

Table – 2 – Critical bed depth at different flow rate

Flow rate 10^{-5} (m^3/ min)	A (day / m)	B (day)	Critical bed depth (m)
16.66	4	-0.0 95	0.024
8.3	8	- 0 .095	0.012

Effect of Influent Concentration on the Critical Bed Depth

Changing the influent concentration at different bed depths (0.03, 0.05, 0.08, 0.11) m ,constant flow rate (16.66) × 10^{-5} m^2/min and particle size (0.5 – 1.5)mm, the regression equation (1) will become as follow :

$$\text{Time} = A' X + B' \quad \ldots\ldots\ldots\ldots(2)$$

Where:

A´ = new slope = A (Co /C′o)

new intercept with Y – axis B′ = B (Co /C′o)[ln (Co/Ce -1)/ ln (C′o/ Ce -1)]

Where :

Co = old concentration (kg / m^3)

Co′= new concentration (kg / m^3)

Ce = effluent concentration equal to 0.9 influent concentration

Figure (4) shows the new regression equations and old one where **Table -3-** shows A′ , B′ and critical bed depth for each influent concentration at different bed depths.

Table -3- Critical bed depth values

Co (kg/ m^2)	A (day/m)	B (day)	Critical bed depth (m)
0.3	2.667	-0.0633	0.024
0.2	4	-0.095	0.024
0.1	8	-0.19	0.024
0.05	16	-0.38	0.024

Table -3- shows that the critical bed depth values are same as shown in **Figure (4)** there are same intercepts lines (C/Co= 0.1) with the X– axis.

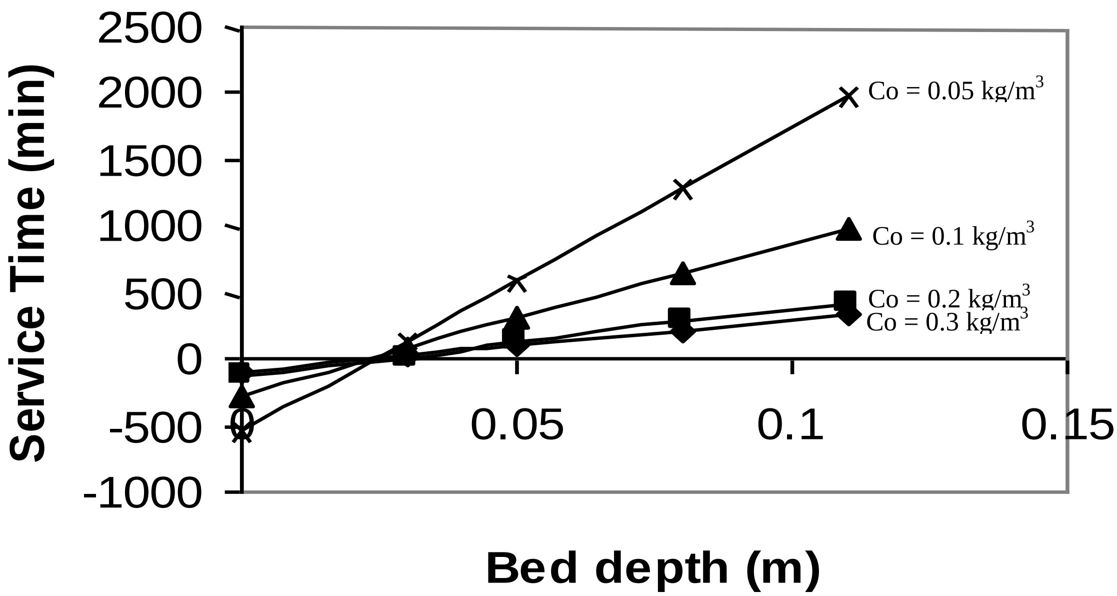

Fig (4) Bed depth Service Time at Different influent concentration

Length of Unused Bed (LUB):

Determination of length of unused bed (LUB) depend on break through times Tb at (C/Co = 0.1) and stiochemitric times Ts where Ts consider the time of mass transfer zone front, equation (5) had been used to estimated (LUB) value:

$$LUB = L_o\,(1 - Tb / Ts) \quad \ldots\ldots\ldots\ldots(5)$$

Time = A´ X + B′ ………….(2)

$$Ts = Tb + (Te - Tb) / 2 \quad \ldots\ldots\ldots\ldots(6)$$

Where :

Time = A´ X + B′ ………….(2)

Lo = length of original bed depth (m)

Te = exhaustion time at (C/C_o = 0.9) (min)

The length of equivalent section (LES) at break through time represent the length of bed when the process of adsorption must be stopped for replacing the bed or regeneration and its calculated as follow (Likchis, 1973).

$$LES = L_o - LUB \quad \ldots\ldots\ldots\ldots(7)$$

Tabl Time = A´ X + B′ ………….(2) l depth when (0.03) m approximately equal to the value of critical bed depth as shown in **Figure (2)** therefore the bed depth must be at least (1.5-3) times of the mass transfer zone length (MTZL) (Lukchis, 1973). **Figure (5)** shows the increasing of percentage used bed with increasing bed depth

Table -4- shows the values of LUB and LES at different bed depth and constant other operation condition.

Bed depth (m)	Tb (min)	Ts (min)	LUB (m)	LES (m)	% used bed
0.03	15	101	0.255	0.0045	14
0.05	120	202	0.2	0.03	60
0.08	277.5	367.5	0.2	0.06	75.5
0.11	435	530	0.2	0.08	82

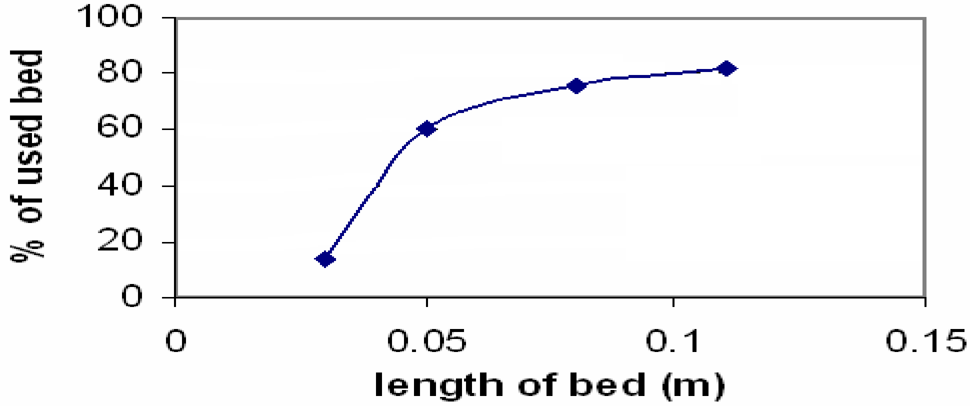

Fig (5) Percentage of used bed

At same bed depths when flow rate had been changed from (16.66 to 8.3)×10^{-5} m^3/min theoretically the LUB and LES will change to as shown in **Table -5-** at (0.05) m bed depth, (0.2)kg/m^3 concentration and (0.5-1.5) particle size.

Table -5- LUB & LES values

Flow rate m3/min	Bed depth (m)	Ts (min)	Tb (min)	LUB (m)	LES (m)
16.66×10^{-5}	0.05	120	202	0.02	0.03
8.3×10^{-5}	0.05	360	477.5	0.012	0.0376

The value of LUB is approximately equal to value of intercept (C / Co =0.1) line in **Figure (3)** at flow rate (8.3 × 10^{-5}) m^3/min which approve that decreasing flow rate increasing break through time.
There is no effect of changing influent concentration on the values of LUB and LES these due to the constant time between the adsorbate- adsorbent is limiting by the rate and geometry of bed (Lukchis, 1973) where **Figure (4)** shows no effect of influent concentration or the critical bed value.

CONCLUSIONS

- Break through time increase with the increase of bed depth and the decrease of flow rate and influent concentration
- The given results from bed depth – service time method approximate with experimental results of the length of critical bed depth.
- Length of equivalent section (LES) increases with the increase of the bed depth and the decrease of the flow rate.
- There is no effect of changing the influent concentration on the critical bed depth at constant flow rate in bed depth service time methods analysis.
- The values of length of unused bed (LUB) is constant even though adds more size of bed was added beyond mass transfer zone and decreases when flow rate decreases.

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NOMENCLATURE

A Slope of regression equation (day/ m)
B Intercept of regression equation with y- axis (day)
C Effluent concentration at given time (kg/m^3)
Ce Equilibrium concentration (kg/m^3)
Co Influent concentration (kg/m^3)
L Length of carbon bed (m)
Q Flow rate (m^3/ min)
Tb Break through time (min)
Te Exhaustion time (min)
Ts Sstoichiometric time (min)