

HUSSEIN I. ABDEL-SHAFY*, IBRAHIM M. EL-GAMAL**,
M. F. ABDEL-SABOUR*, OMBAREK ABO-EL-WAFA***

REMOVAL OF CADMIUM AND LEAD FROM WATER BY ACTIVATED CARBON

Adsorption of cadmium and lead from water by carbon was studied using powdered or granular carbon. The studied water was artificially contaminated by cadmium and lead amounting to 1 mg/dm^3 each. Batch as well as continuous system studies were carried out. The batch system was used to determine the time to maintain equilibrium followed by adsorption isotherm. Results obtained by using the powdered carbon were found to match with Freundlich's equation where $1/n$ was 2.12 and 2.096 for Cd and Pb, respectively. Corresponding constants (K) were $4.2 \cdot 10^{-2}$ and $76.0 \cdot 10^{-2}$. The amounts of powdered activated carbon required to reduce residual Cd and Pb concentration to 0.01 mg/dm^3 for each are 26.98 and 2.86 mg, respectively. Similar batch system study was carried out for the granular carbon. When granular carbon was used in a continuous system, two different contact times, namely 10 and 20 min., were examined. The results obtained showed that increasing the contact time from 10 to 20 min. increases the metal to carbon removal efficiency. The overall results indicated that the breakthrough point for either Cd or Pb is the reverse of their adsorption as indicated by K values.

1. INTRODUCTION

Throughout the world, an increasing interest is focused on the quality of drinking water. Recently, attempts have been made to relate the occurrence of certain cancers and cardiovascular disease to the presence of trace metals in drinking water [1], [2]. Therefore, information on the accumulation, release and removal of these metals in water and wastewater is becoming highly desirable [3]–[6].

In Egypt, the discharge of industrial wastewater to the River Nile without adequate treatment has increased significantly in the last decade as a result of a wide industrial expansion [7], [8]. The presence of metals such as cadmium and lead is known to cause severe health problems to animals and human beings [1], [9].

* Water Pollution Control Laboratory, National Research Centre, Dokki, Cairo, Egypt.

** Institute of Environmental Studies and Research, Ain Shams University, Cairo, Egypt.

*** Chemistry Department, Faculty of Science, Suez Canal University, Ismailia, Egypt.

The activated carbon process appears particularly competitive and effective in the removal of trace pollutants [10]–[12]. Granular activated carbon is most effective in removing organic mercury, and powdered carbon is almost equally effective for both inorganic and organic mercury removal [13], [14].

The present study is designed to investigate the efficiency of activated carbon in cadmium and lead removal. Both powdered and granular activated carbons were used. In addition, both batch and continuous systems studies were carried out. In the batch system, the time necessary to maintain equilibrium followed by adsorption isotherm was determined, whereas in continuous system, the effect of different contact times on the removal efficiency was studied. During the test, the time required to reach the breakthrough point at each contact time for each metal was also determined. Further study was carried out to investigate the relationship between the breakthrough point and the volume of treated water for removal of cadmium and lead.

2. MATERIALS AND METHODS

Tap water used was aerated in order to remove the dissolved chlorine. The water was artificially contaminated by cadmium and lead amounting to 1.0 mg/dm^3 each. The salts of these metals were added as nitrates.

2.1. BATCH TREATMENT

Powdered activated carbon and filtrasorb-granular carbon (size 0.9–1.1 mm) were used in this study.

2.1.1. POWDERED ACTIVATED CARBON

In order to study the effect of activated carbon addition, its different doses were added to the aerated tap water.

Adsorption equilibria. Accurately 0.05 g of powdered activated carbon was placed in "Teflon" bottles, each containing 100 cm^3 of tap water, to which a mixture of 1 mg of Cd/dm^3 and 1 mg of Pb/dm^3 was added. The bottles were then placed on a laboratory shaker at room temperature ($25 \pm 2^\circ\text{C}$) together with ten other bottles containing the contaminated tap water as a control for the experiments without carbon addition. At successive time intervals, one of the examined bottles and one from control bottles were removed from the shaker. After filtration through Whatman filter paper No. 4 and acidification by nitric acid, residual concentrations of cadmium and lead were determined in each bottle.

2.1.2. GRANULAR ACTIVATED CARBON

To define the optimum operating conditions of activated carbon, batch experiments were carried out. Filtrasorb-20 granular carbon (size 0.9–1.1 mm) was used for this purpose. Aliquots of aerated tap water were mixed with weighed amount of granular activated carbon in "Teflon" bottles. These bottles were shaken at room temperature ($25 \pm 2^\circ\text{C}$) for 24 h to

reach the equilibrium conditions. The adsorbent was then removed by filtration through Whatman filter paper No. 4. The equilibrium cadmium and lead concentration was determined. As a control, aliquots of the determined metal concentration by the end of each run were taken as the initial ones. The amount of metal adsorbed (X) was calculated as the difference between the residual and initial metal concentrations (C and C_0). The time limit necessary to maintain equilibrium was obtained by plotting the amount of metal adsorbed per unit weight of carbon (X/m) versus the exposure time, where m is the weight of carbon.

2.2. CONTINUOUS TREATMENT

A glass column (50 cm in length and 2 cm in inner diameter) was used. The effective depth of the carbon bed was 40 cm (fig. 1). To study the effect of the contact time, different detention periods, namely 10 and 20 min., were examined.

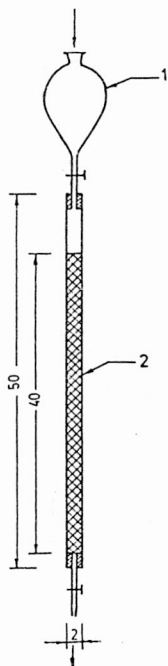


Fig. 1. Fixed bed laboratory column
1 - separatory funnel, 2 - carbon column

The granular carbon used in this study (grain size of 0.9–1.1 mm) was at first washed with redistilled water and then dried for 24 h at 105°C before use. The column (fig. 1) was packed with 49.28 g of carbon in the form of slurry to obtain an effective depth of 40 cm. The slurry was then deaerated carefully to eliminate air bubbles.

The amount of granular carbon required for the continuous system studies was calculated from Freundlich's equation [15]:

$$X/m = K \cdot C^{1/n} \quad (1)$$

where K and $1/n$ are constants, which can be determined by plotting the adsorbed mass $(C_0 - C)/m$ as the function of the equilibrium concentration in log-log relationship. $1/n$ is the slope of the line to the ordinate when $\log C = 0$. The only unknown in eq. (1) is the value m which has been calculated.

2.3. DETERMINATION OF CADMIUM AND LEAD CONCENTRATIONS

Determination of cadmium and lead concentrations was carried out in acidified samples using a Perkin-Elmer atomic absorption spectrophotometer (Model 370) equipped with a heated graphite atomizer (HGA), model 2100, and deuterium being a background corrector.

3. RESULTS AND DISCUSSION

3.1. USE OF POWDERED ACTIVATED CARBON

3.1.1. ADSORPTION EQUILIBRIA

The results obtained as a relationship between the amount of cadmium and lead adsorbed and time of exposure are presented in fig. 2. The results show that an initial rapid uptake of the metals studied was observed within the first 20 min., and after this time the removal efficiency increases slowly but gradually till an equilibrium is attained after 2 h.

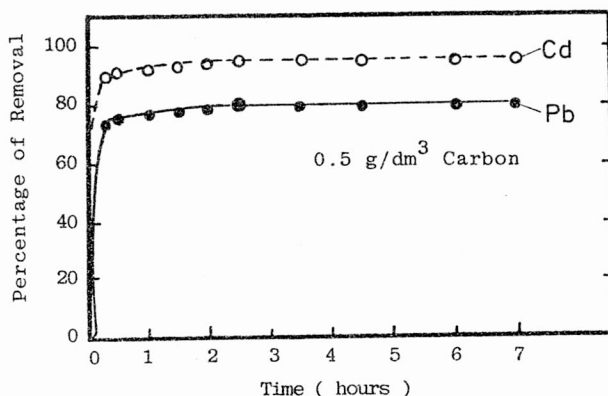


Fig. 2. Effect of time on the adsorption of cadmium and lead on powdered carbon

3.1.2. ADSORPTION ISOTHERM

In order to determine the optimal dosages of powdered carbon required to remove cadmium and lead from the contaminated water, adsorption isotherms were obtained in the manner

described before. The rate of metal adsorption as a function of the corresponding amount of carbon used is presented in fig. 3.

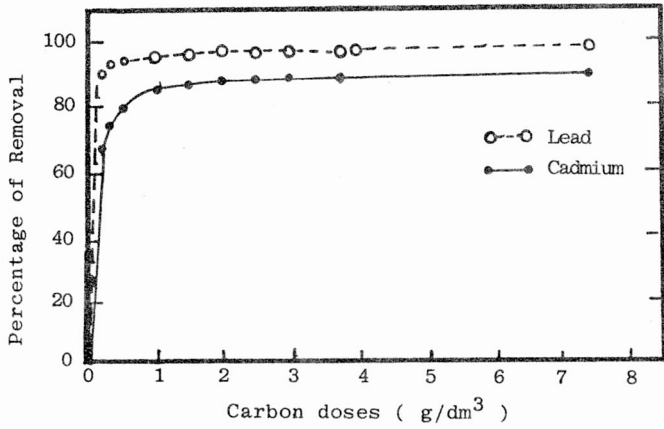


Fig. 3. Effect of powdered carbon doses on cadmium and lead adsorption

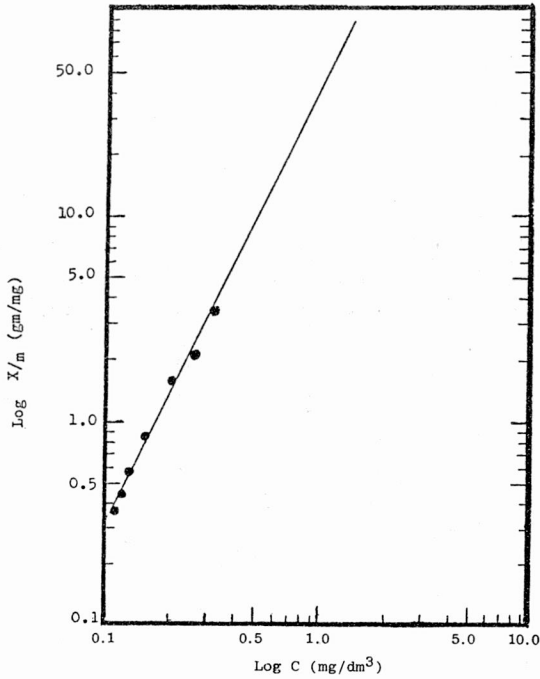


Fig. 4. Freundlich isotherm for adsorption of cadmium on powdered carbon

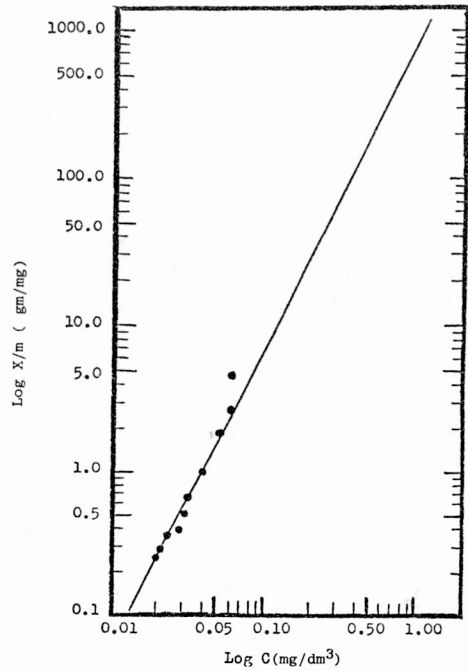


Fig. 5. Freundlich isotherm for adsorption of lead on powdered carbon

Adsorption isotherms were obtained by plotting the amount of the metal adsorbed (in mg per mg of powdered activated carbon (X/m)) versus the corresponding equilibrium concentration (C) of cadmium and lead.

The results obtained reveal that the adsorption of cadmium and lead follows Freundlich's equation (1) [15]. According to this equation, straight lines were obtained by plotting $\log X/m$ versus $\log (C)$ (figs. 4 and 5).

Adsorption efficiency can be determined on the basis of Freundlich's constants. In general, the higher the K value, the greater the capacity of the adsorbent. However, the dosages of carbon required for the removal of either lead or cadmium are dependent on both parameters (K and $1/n$), initial concentration of metals, and final concentration required in treated water.

The results obtained show that lead is more liable to be adsorbed on powdered carbon than cadmium. Such a conclusion is based on the statement that the adsorption parameters K and $1/n$ are in favour of lead and that the dose of carbon required for removal of similar concentrations of these two metals is much less in the case of lead.

The slope of Freundlich's isotherm ($1/n$) was found to be 2.12 and 2.096 for cadmium and lead, respectively. Corresponding constants K were $4.2 \cdot 10^{-2}$ and $76.0 \cdot 10^{-2}$.

The amounts of powdered activated carbon required to reduce residual cadmium and lead concentration to 0.01 mg/dm^3 are 26.98 and 2.86 mg, respectively.

3.2. GRANULAR ACTIVATED CARBON

In water treatment plants, granular carbon is used in the form of bed column.

3.2.1. BATCH ADSORPTION SYSTEM

In order to measure quantitatively the adsorption capacity of granular for the removal of cadmium and lead from the contaminated waters, the batch technique was tested for the first time. Such a technique also permits the prediction of adsorption parameters which control the uptake process.

Time required to reach equilibrium was at first assessed. A contact time of 20 h was found sufficient to maintain equilibrium under the prevailing experimental conditions (fig. 6) for cadmium and lead, respectively.

Furthermore, the effect of carbon to cadmium ratio (C/Cd) and carbon to lead ratio (C/Pb) on the equilibrium adsorption capacity at different contact times was calculated. The results are given in tab. 1. These results indicate that higher C/Cd ratio increases the equilibrium cadmium adsorption capacity. Similar results were obtained for lead (C/Pb). Higher carbon to metal (Cd and Pb) ratio increases the initial removal efficiency, however, the time necessary for reaching equilibrium adsorption was unchanged. The results are in a good agreement with the findings of CHIN-PAO HUANG and F. B. OSTOVIC [16].

The adsorption isotherm for cadmium and lead adsorbed on granular carbon of particle size ranging within 0.9–1.1 mm at the predetermined equilibrium time was studied.

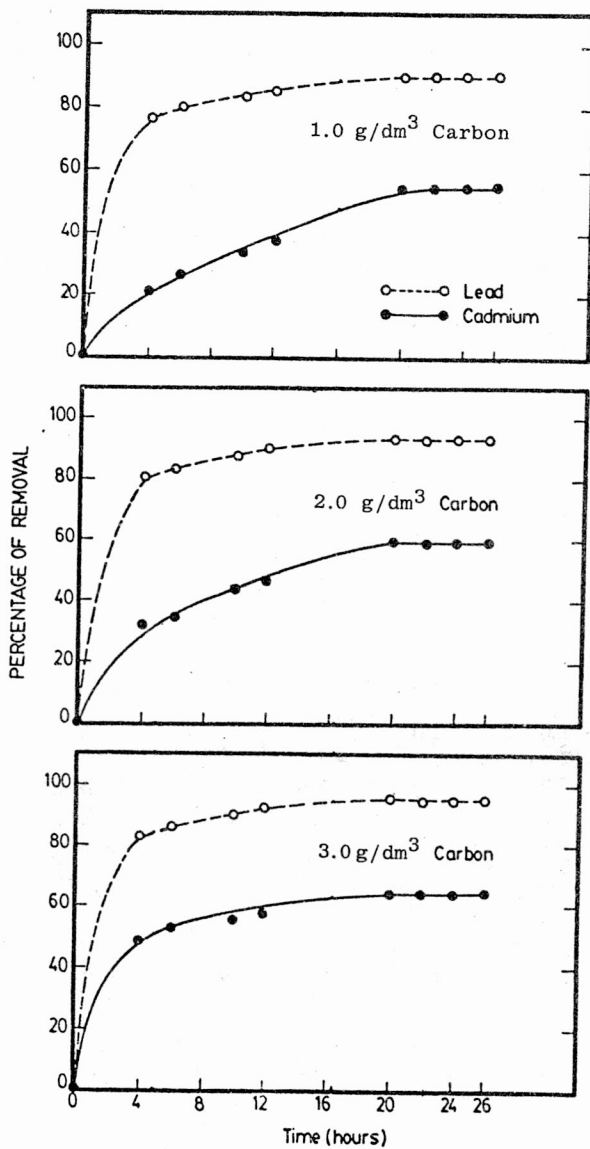


Fig. 6. Effect of time on adsorption of cadmium and lead on granular carbon

Table 1

Effect of carbon to metal ratio on the adsorption capacity

Metal	Amount of carbon $\text{mg} \cdot 10^{-3}$	Initial conc. mg/dm^3	Contact* time h	$C/m \cdot 10^{-3}$ ratio	Residual conc. mg/dm^3	Amount adsorbed mg/dm^3	% R (capacity)	
Cadmium	1.0	1.0	4	1.0	0.80	0.20	20.0	
	2.0	1.0	4	2.0	0.69	0.31	31.0	
	3.0	1.0	4	3.0	0.52	0.48	48.0	
	1.0	1.0	6	1.0	0.74	0.26	26.0	
	2.0	1.0	6	2.0	0.66	0.34	34.0	
	3.0	1.0	6	3.0	0.48	0.52	52.0	
	1.0	1.0	10	1.0	0.68	0.32	32.0	
	2.0	1.0	10	2.0	0.57	0.43	43.0	
	3.0	1.0	10	3.0	0.46	0.54	54.0	
	1.0	1.0	12	1.0	0.65	0.35	35.0	
	2.0	1.0	12	2.0	0.55	0.45	45.0	
	3.0	1.0	12	3.0	0.43	0.57	57.0	
	1.0	1.0	20	1.0	0.46	0.54	54.0	
	2.0	1.0	20	2.0	0.41	0.59	59.0	
	3.0	1.0	20	3.0	0.36	0.64	64.0	
	Lead	1.0	1.0	4	1.0	0.24	0.76	76.0
		2.0	1.0	4	2.0	0.20	0.80	80.0
		3.0	1.0	4	3.0	0.17	0.83	83.0
1.0		1.0	6	1.0	0.20	0.80	80.0	
2.0		1.0	6	2.0	0.17	0.83	83.0	
3.0		1.0	6	3.0	0.14	0.86	86.0	
1.0		1.0	10	1.0	0.17	0.83	83.0	
2.0		1.0	10	2.0	0.13	0.87	87.0	
3.0		1.0	10	3.0	0.10	0.90	90.0	
1.0		1.0	12	1.0	0.15	0.85	85.0	
2.0		1.0	12	2.0	0.10	0.90	90.0	
3.0		1.0	12	3.0	0.08	0.92	92.0	
1.0		1.0	20	1.0	0.10	0.90	90.0	
2.0		1.0	20	2.0	0.07	0.93	93.0	
3.0		1.0	20	3.0	0.05	0.95	95.0	

*M - cadmium or lead.

The data concerning the adsorption isotherm are given in tab. 2. The effect of different granular carbon doses on the removal efficiency of cadmium and lead at the equilibrium time is illustrated graphically in fig. 7. From these results it can be seen that higher carbon doses, from 0.5 to 30.0 g/dm³, raised cadmium removal efficiency from 4.7 to 67.0%, whereas at the carbon dose of 0.5 mg/dm³ lead removal was 67.9%. Increasing the carbon dose to 5.0 mg/dm³ increased lead removal up to 99.3%. Further increase in the carbon dose showed no significant effect on lead removal.

Table 2

Adsorption of cadmium and lead on granular activated carbon at the equilibrium time

Metal	Initial conc. mg/dm ³	Residual equilibrium conc. <i>C</i> mg/dm ³	Amount adsorbed <i>X</i> mg	Carbon added g/dm ³	<i>X/m</i> (mg/mg) · 10 ⁻³	% <i>R</i>
Cadmium	1.00	0.953	0.047	0.5	0.094	4.7
		0.914	0.086	1.0	0.084	8.6
		0.796	0.204	2.5	0.0816	20.4
		0.724	0.276	5.0	0.0552	27.6
		0.655	0.345	7.5	0.0460	34.5
		0.571	0.429	10.0	0.0429	42.9
		0.426	0.574	15.0	0.0383	57.4
		0.405	0.595	20.0	0.0298	59.5
		0.341	0.659	25.0	0.0264	65.9
		0.330	0.670	30.0	0.2230	67.0
Lead	1.00	0.321	0.679	0.5	1.358	67.9
		0.05	0.950	1.0	0.9500	95.0
		0.014	0.986	2.5	0.3944	98.6
		0.007	0.993	5.0	0.1986	99.3
		0.005	0.995	7.5	0.1327	99.5
		0.003	0.997	10.0	0.0997	99.7
		0.002	0.998	15.0	0.0665	99.80
		0.0015	0.9985	20.0	0.0499	99.85
		0.0011	0.8989	25.0	0.0400	99.89
		0.0010	0.9990	30.0	0.0333	99.90

The adsorption results were then applied to LANGMUIR [17], BRUNAUER, EMMETT and TELLER (BET) [18] and FREUNDLICH [15] equations to determine the mode of adsorption according to the relation between *X/m* and *C*. It was found that the adsorption isotherm is confirmed by Freundlich equation rather than Langmuir or BET. When log *X/m* was plotted versus log *C* for either cadmium and lead, a straight line was obtained (figs. 8 and 9). The corresponding (*K*) values for cadmium and lead were 0.043 · 10⁻³ and 19.2 · 10⁻³, respectively. The corresponding 1/*n* values were 1.364 and 0.8497. According to Freundlich, *K* values of these two metals indicated the stronger tendency of lead to be adsorbed on carbon compared to cadmium.

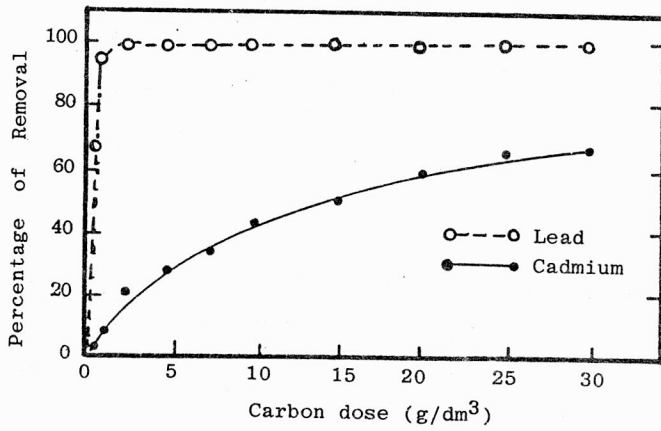


Fig. 7. Effect of granular carbon doses on cadmium and lead adsorption

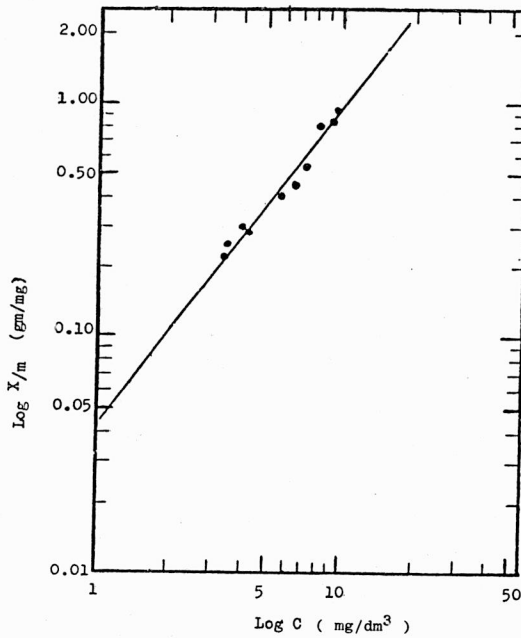


Fig. 8. Freundlich isotherm for adsorption of cadmium on granular carbon

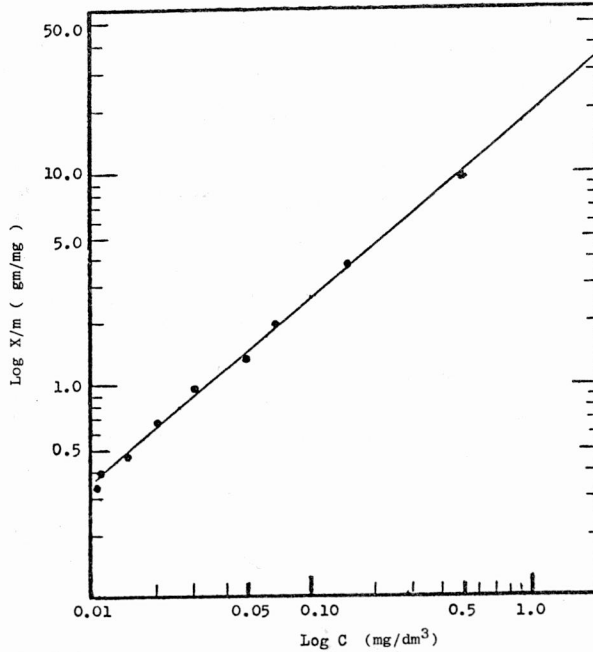


Fig. 9. Freundlich isotherm for adsorption of lead on granular carbon

3.2.2. CONTINUOUS SYSTEM

A granular activated carbon column was used to investigate the removal capacity of granular carbon under continuous flow conditions. Such studies can throw light on the data necessary for optimum design of adsorbers.

To study the contact time effect on the adsorptive capacity, different contact times of 10 and 20 min. were examined. The rest of the variables were kept constant. The concentrations of cadmium and lead in the contaminated tap water were 1.0 mg/dm³ each. The experiment for each system has been carried out for seven days. The operating conditions are given in tab. 3.

Table 3

Operating conditions of the carbon column

Contact time min	Flow rate cm ³ /min	Carbon depth cm	Bed volume cm ³	Total carbon weight g
20	6.28	40	125.66	49.28
10	12.57	40	125.66	49.28

Breakthrough curves for cadmium and lead at different contact times are shown in fig. 10, tabs. 4 and 5. The results obtained indicated that the breakthrough curves of cadmium and lead are the reverse of their adsorption as indicated by the corresponding K values. The breakthrough points of cadmium were reached after 1 and 6 h, while the breakthrough points of lead were reached after 2 and 64 h.

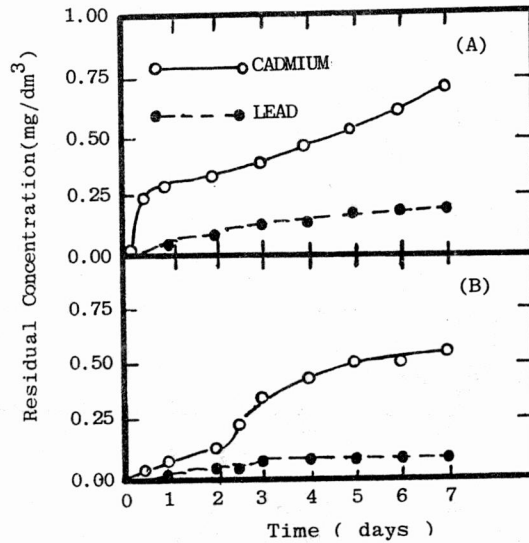


Fig. 10. Breakthrough curves of cadmium and lead at two different contact times: 10 min. (A), 20 min. (B)

Table 4

Breakthrough data of cadmium and lead (retention time is 10 min)

Time h	Initial conc. mg/dm ³	Residual conc. mg/dm ³		% removal		pH value	Effluent volume dm ³
		Cd	Pb	Cd	Pb		
1½	1.0	0.010	0.000	99.0	100	6.75	1.13
3		0.013	0.000	98.7	100	6.80	2.26
6		0.020	0.001	98.0	99.9	6.85	4.52
12		0.260	0.015	74.0	98.5	7.25	9.05
21.2		0.290	0.050	71.0	95.0	7.50	15.84
24		0.310	0.070	69.0	93.0	7.60	18.10
48		0.350	0.110	65.0	89.0	7.65	36.20
72		0.400	0.130	60.0	87.0	7.70	54.30
96		0.480	0.160	52.0	84.0	7.75	72.40
120		0.550	0.179	45.0	82.1	7.80	90.50
144		0.620	0.186	38.0	81.4	7.85	108.60
168		0.740	0.195	26.0	80.5	7.90	126.71

Table 5

Breakthrough data of cadmium and lead (retention time is 20 min)

Time h	Initial conc. mg/dm ³	Residual conc. mg/dm ³		% removal		pH value	Effluent volume dm ³
		Cd	Pb	Cd	Pb		
1	1.0	0.005	0.000	99.5	100	6.75	0.377
5		0.010	0.000	99.0	100	6.95	1.884
6		0.010	0.000	99.0	100	7.00	2.260
12		0.051	0.000	94.9	100	7.05	4.522
24		0.090	0.025	91.0	97.5	7.38	9.043
48		0.137	0.040	86.3	96.0	7.52	18.086
60		0.240	0.048	76.0	95.2	7.58	22.608
64		0.268	0.050	73.2	95.0	7.59	24.128
72		0.360	0.077	64.0	92.3	7.60	27.130
96		0.450	0.083	55.0	91.7	7.65	36.173
120		0.510	0.093	49.0	90.7	7.70	45.216
144		0.520	0.100	48.0	90.0	7.70	54.259
168		0.560	0.107	44.0	89.3	7.80	63.302

Different contact times, i.e., 10 and 20 min., indicated that the adsorption capacity of the granular carbon is increased by increasing the contact time. This fact is in agreement with those reported by GARRISON et al. [19], EPA [20], and CHIN-PAO HUANG et al. [16]. Thus tab. 6 shows the carbon columns characteristics, namely, the contact time and the volume of effluent passing (A) per depth of bed (B) before the breakthrough of cadmium and lead. This table also presents metal concentrations in the influent and effluent at a given time.

Table 6

Carbon column characteristics and adsorption data for cadmium and lead

Metal	Concentration mg/dm ³		(B) Bed depth cm	Contact time min	(A) Through- put volume dm ³	Time h
	Influent	Effluent				
Cadmium	1.0	0.01	40	10	1.13	1½
Lead	1.0	0.05	40	10	15.84	21
Cadmium	1.0	0.01	40	20	2.26	6
Lead	1.0	0.05	40	20	24.128	64

Table 7 shows relation between the removed amount of cadmium and lead at different contact times before breakpoint, on one hand, and the amount of metal removed per amount of carbon (mg/g), on the other hand. The obtained results proved that when extending the

contact time from 10 to 20 min the metal removal increased from 0.023 to 0.045 mg Cd/g and from 0.31 to 0.47 mg Pb/g. This finding is in agreement with previous studies carried out by CHIN-PAO HUANG and F. B. OSTOVIC [16], CRITTENDEN et al. [21] and CHIN B. LEE and L. TAKAMATSU [22].

Table 7

Amount of cadmium and lead removal at different contact times

Metal	Contact time min	Through-put volume* dm ³	Amount of metal removed before breakpoint mg/dm ³	Metal removed per amount of carbon mg/g
Cadmium	10	1.13	1.119	0.023
	20	2.26	2.237	0.045
Lead	10	15.84	15.05	0.31
	20	24.13	22.92	0.47

* Volume of effluent passed before breakthrough at 0.01 mg/dm³ for Cd, and 0.05 mg/dm³ for Pb.

These results indicated that a rapid breakthrough occurred as the contact time decreased from 20 to 10 min.

The overall results indicated that the breakthroughs of cadmium and lead are the reverses of their adsorption as indicated by their *K* values. In addition, the results showed that the adsorption capacity of the granular carbon is increased by extending the contact time. Furthermore, such an extension increases carbon removal efficiency.

4. CONCLUSIONS

The overall conclusions can be summarized as follows:

1. The use of both powdered and granular carbon for the removal of cadmium and lead from water is a promising process.
2. The use of granular carbon column bed in a continuous system showed a remarkable removal efficiency.
3. When the contact time in this continuous system is extended the removal efficiency of carbon increases.
4. The breakthrough points of cadmium and lead in this continuous system are the reverses of their adsorption isotherms.
5. When water supply sources are contaminated by heavy metals, it is recommended to add an activated carbon filter to the conventional water treatment plant.

REFERENCES

- [1] MASIRONI R., *Trace elements and cardiovascular diseases*, Bull. World Health Organ., 40 (1969), pp. 305-312.
- [2] SCHROEDER H. A., NASON P. P., TIPTON I. H., BALASSA J. J., *Essential trace metals in many zinc relations to environmental cadmium*, J. Chron. Dis., 20 (1967), pp. 179-210.
- [3] *U.S.E.P.A. water quality criteria*, Report to the Committee on Wat. Qual. Criteria, EPA-440/9-76-023, Washington, D. C. 1976.
- [4] BROWN H. G. et al., *Efficiency of heavy metals removal in municipal sewage treatment plants*, Environ. Lett., 5. 2. 193 (1973).
- [5] ADAMS C. E., Jr. et al., *The effects and removal of heavy metals in biological treatment*, Aquatic Envir. Conf., Vanderbilt Univ., Nashville, Tenn. 1973.
- [6] PATTERSON J. W. et al., Proc. 2nd Natl. Conf. on Complete Water Reuse, AIChE and USEPA, 210 (1975).
- [7] ABO-EL-WAFA O., ABDEL-SHAFY H. I., *Role of municipal waste water in the contamination of El-Temsah lake by heavy metals*, 1st International Conference on the Environmental Contamination, London, July, 1984.
- [8] ABO-EL-WAFA O., ABDEL-SHAFY H. I., ANWAR Z. M., *Effect of heavy metals on degradation of detergents*, International Conference on Heavy Metals in the Environment, Athens, September, 1985.
- [9] SCHROEDER H. A., BALASSA J. J., TIPTON I. H., *Abnormal trace metals in man-chromium*, J. Chron. Dis., 15 (1962), pp. 941-964.
- [10] O'CONNOR J. T., BADERER D., THEM L., *Removal of cadmium and mercury ions from drinking water using activated carbon*, Prepr. pap-Natl-Meet., Div. Environ. Chem., Am. Chem. Soc., 15 (1975), pp. 64-7.
- [11] KIM JUNG 'I., ZOLTEK J., Jr., *Chromium removal with activated carbon*, Prog. Water Tech., 9 (1977), pp. 143-55.
- [12] TAKAG HITOSHI, HISAMATSU TOKUICH, TOUAMA KENJI, *Adsorption of metal ions by activated carbon at high temperature adsorption of chromium (6+) ion*, Yosui to Haisui, 21 (12) (1979), pp. 1440-8.
- [13] MOTOJINA KENJI, KAWAMURA FUMIO, *Removal of cobalt from radioactive liquid waste by oxime impregnated activated charcoal*, Nihon Genshiryoku Gokkaiishi, 23 (5) (1981), pp. 365-9.
- [14] HUANG C. P., BLANKENSHIP D. W., *The removal of mercury (II) from dilute aqueous solution by activated carbon*, Water Res., Vol. 18 (1) (1984), pp. 37-46.
- [15] FREUNDLICH H., *Colloid and Capillary Chemistry*, Methuen and Co., Ltd., London 1926.
- [16] CHIN-PAO HUANG M., OSTOVIC F. B., *Removal of cadmium (II) by activated carbon adsorption*, Journal of Environmental Engineering Division, Vol. 104 (1978), EE5.
- [17] LANGMUIR I., *The adsorption of gases on plane surfaces of glass, mica and platinum*, J. Amer. Chem. Soc., 40, 1361 (1918).
- [18] BRUNAUER S., EMMETT P. H., TELLER E., *Adsorption of gases in multimolecular layers*, J. Amer. Chem. Soc., 60, 309 (1938).
- [19] GARRISON W. E., GRATTEAU J. C., HANSES B. E., LUTHY R. F., *Gravity carbon filtration to meet reuse requirements*, Journal of the Environmental Engineering Division, Vol. 104, EE6, pp. 1165-1174, Dec., 1978.
- [20] Environmental Protection Agency, *Trace of Heavy Metals in Water Removal Processes and Monitoring*, prepared for Princeton Univer., Publication PB-235-398, Nov., 1973.
- [21] CRITTENDEN J. C., WEBER W. J., Jr., *Model for design of multicomponent adsorption systems*, Journal of the Environmental Engineering Division, Vol. 104 (1978), EE6, pp. 1195.
- [22] CHIN R. I., TAKAMATSU L., *Carbon contact-filtration: how it works*, Water & Sewage Works, August 1974.

USUWANIE KADMU I OŁOWIU Z ROZTWORÓW WODNYCH PRZEZ ZASTOSOWANIE WĘGLA AKTYWNEGO

W roztworach wodnych badano adsorpcję kadmu i ołowiu na granulowanym i sproszkowanym węglu aktywnym. Roztwory te sztucznie zanieczyszczano kadmem i ołowiem w stężeniu 1 mg każdego pierwiastka na 1 dm³ wody. Adsorpcję prowadzono w systemie okresowym i ciągłym. W systemie okresowym określano czas potrzebny do utrzymania równowagi, po którym otrzymywano izotermę adsorpcyjną. Gdy używano sproszkowanego węgla, stwierdzono zgodność otrzymanych wyników z wynikami obliczonymi na podstawie równania Freundlicha, tzn. wartość $1/n$ dla kadmu wynosiła 2,12, a dla ołowiu 2,096. Odpowiadające im stałe K wynosiły $4,2 \cdot 10^{-2}$ i $76,0 \cdot 10^{-2}$. Aby zawartość pozostałego w roztworze kadmu i ołowiu zmniejszyć do stężenia 0,01 mg/dm³, potrzeba odpowiednio 26,98 i 2,86 mg sproszkowanego węgla aktywnego. Podobny eksperyment w systemie okresowym został przeprowadzony dla węgla granulowanego. Gdy węgiel granulowany zastosowano w systemie ciągłym, obserwowano adsorpcję przy dwu różnych czasach kontaktowania, 10 i 20 min. Okazało się, że zwiększenie czasu z 10 do 20 min powodowało zwiększoną adsorpcję metali. Otrzymane wyniki wskazują, że punkt przebiecia zarówno dla kadmu jak i ołowiu jest odwrotnością ich adsorpcji, o czym świadczą wartości stałych K .

УДАЛЕНИЕ КАДМИЯ И СВИНЦА ИЗ ВОДНЫХ РАСТВОРОВ ПОСРЕДСТВОМ ПРИМЕНЕНИЯ АКТИВНОГО УГЛЯ

В водных растворах исследована адсорбция кадмия и свинца на гранулированном и порошкообразном активном угле. Эти растворы искусственно загрязняли кадмием и свинцом концентраций 1 мг каждого элемента на 1 dm³ воды. Адсорбцию вели временной и непрерывной системами. Во временной системе определяли время, нужное для удержания равновесия, после которого получали адсорбционную изотерму. Когда употребляли порошкообразный уголь, установили соотношение полученных результатов с результатами, рассчитанными на базе уравнения Фройдлица, значит, значение $1/n$ для кадмия составляло 2,12, а для свинца 2,096. Отвечающие им постоянные K составляли $4,2 \cdot 10^{-2}$ и $76,0 \cdot 10^{-2}$. Чтобы содержание оставшегося в растворе кадмия и свинца уменьшить до концентрации 0,01 мг/дм³, требует соответственно 26,98 и 2,86 мг порошкообразного активного угля.

Похожий эксперимент во временной системе был проведен для гранулированного угля. Когда гранулированный уголь применили в непрерывной системе, наблюдали адсорбцию при двух разных временах контактирования, 10 и 20 мин. Оказалось, что увеличение времени с 10 до 20 мин вызывало повышенную адсорбцию металлов. Полученные результаты показывают, что точка пробоя как для кадмия, так и для свинца является обратной величиной их адсорбции, о чем свидетельствуют значения постоянных K .