STUDY OF PERFORMANCE OF AIR FILTERS IN PUBLIC SHELTERS

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ABSTRACT

This study was initiated to assess the performance of public shelter's filtering system. Tests were carried out on the adsorption efficiency of the shelter's activated carbon beds of various weights and depths, and different granule sizes, viz. 3.775, 3.383, 3.25, and 2.975 mm. The adsorbate employed was carbon tetrachloride vapor at a rate of 1.2 L/min and a concentration of 98 mg/L. Flame ionization detector was installed on-line to monitor the concentration variation continually. The results showed that the breakthrough time increases with decreasing granule size, and increasing bed weight (or depth).

A main conclusion of this work is that the shelter's filtering system operates satisfactorily, this was indicated by the bed depth required for 1% saturation of the carbon bed. This depth was calculated using different methods: LUB method, Wheeler's equation and scale-up method, giving bed depths of 0.317, 0.31, and 0.332 m respectively, as compared with the actual bed depth of 0.35 m.

INTRODUCTION

The initial development of high-efficiency air filters was largely associated with health protection. Respirators, incorporating filters to remove suspended particles from inhaled air, have been in use for many years. A considerable amount of the development of these filters was associated with military requirements to protect against airborne particles. High-efficiency filters have been used in exhaust air lines to prevent the release of radioactive and other potentially harmful particles to the environment.

In the adsorption process, many adsorbents may be employed, the adsorbents most commonly used are: activated clays, bauxite, alumina, bone char, decolorizing carbons, gas adsorbent, carbon, molecular-screening, activated carbon, synthetic polymeric adsorbents, silica gel, and molecular sieves [1].

Activated carbon is an optimum material for a wide range of applications, since it can be prepared in a variety of structures with regard to pore volume and pore size [2]. There is a widespread use of carbon in air filters as an adsorbent for gas, odor, and aerosol removal.

Granular-activated carbon, which has been used and has become contaminated, can often be treated to return to its original condition. Regeneration can be achieved by either (i) steam stripping, (ii) heating coils, (iii) vacuum, (iv) hot gas stripping, (v) oxidation of pollutant, and (vi) displacement (preferential adsorption)[3].

Kinetics of gas adsorption

Mathematical equations and kinetic processes of gaseous adsorbate removal has been made by Wheeler [4]. The final form of the equation suggested by Wheeler is:

$$t_b = \frac{\omega_e}{C_o Q}\left[W - \frac{\rho_B Q \ln(C_o / C_X)}{K_V} \right] \quad (1)$$

The height of the adsorbent bed (Z), may be calculated using the following equation:

$$Z = LUB + Z_S \quad (2)$$

Where,

$$LUB = \frac{Za}{t_S}(t_S - t_b) \quad (3)$$

and

$$Z_S = \frac{G_S (Y_o - Y_o^*) t_b}{\rho_b (X_t - X_o)} \quad (4)$$

The symbols are given in the nomenclature and the use and explanation of the above equation are given later.

This investigation was initiated to access the performance of the carbon bed absorbers and the aerosol filters installed in the public shelters, where an experimental rig was setup for this purpose.

EXPERIMENTAL WORK

Chemicals used

The chemicals used were Nitrogen (99.99%) purity, hydrogen from hydrogen generator (Chrompack 7525), carbon tetrachloride (AR grade) and activated carbon absorbent (obtained from one of the shelters). The specification of these materials may be found elsewhere [5,6,7].

Description of Equipment

The vapor adsorption test apparatus had three functional sections, one for vapor generation, another for vapor adsorption by the carbon and the third for the detection of vapor penetration by the carbon bed. A diagram of experimental apparatus is shown in figure (1). Full details of the experimental setup is given in reference (7).

Experimental Procedure

Nitrogen gas supplied from a cylinder was dried by passage through silica-gel column. This dry nitrogen gas was then split into two parts, one sweeping across a liquid layer of carbon tetrachloride and becoming saturated with adsorbate vapor, and the second part meeting the nitrogen-adsorbate vapor stream in the diluting vessel for the purpose of adjusting the vapor feed concentration.

Samples of N_2-CCl_4 vapor were analyzed until the desired vapor concentration was obtained. The activated carbon was oven dried at 100°C for 24 hrs and stored in a desiccator until used. Three different bed weights for each granule size, were exposed to the established vapor concentration drawn into the carbon bed at a volumetric flow rate of 1.2 L/min.

The exit stream from the bed was monitored continually by passage into a gas sampling valve. The breakthrough time (t_b) was the time in second when exit stream vapor concentration was 1% of the inlet concentration (C_X/C_o=0.01).

The last was completed when the area trace on the chart of the recorder indicated that the full inlet concentration was penetrating the carbon bed.

The granular carbon was weighted before being dumped, thus providing a direct weight method for calculating the saturation capacity of the carbon for the vapor. After the traced areas on the chart were converted to vapor quantities, a plot was made of the ratios of exit concentration, C_X, to the inlet concentration, C_o, against the sampling time (t) for each specified run.

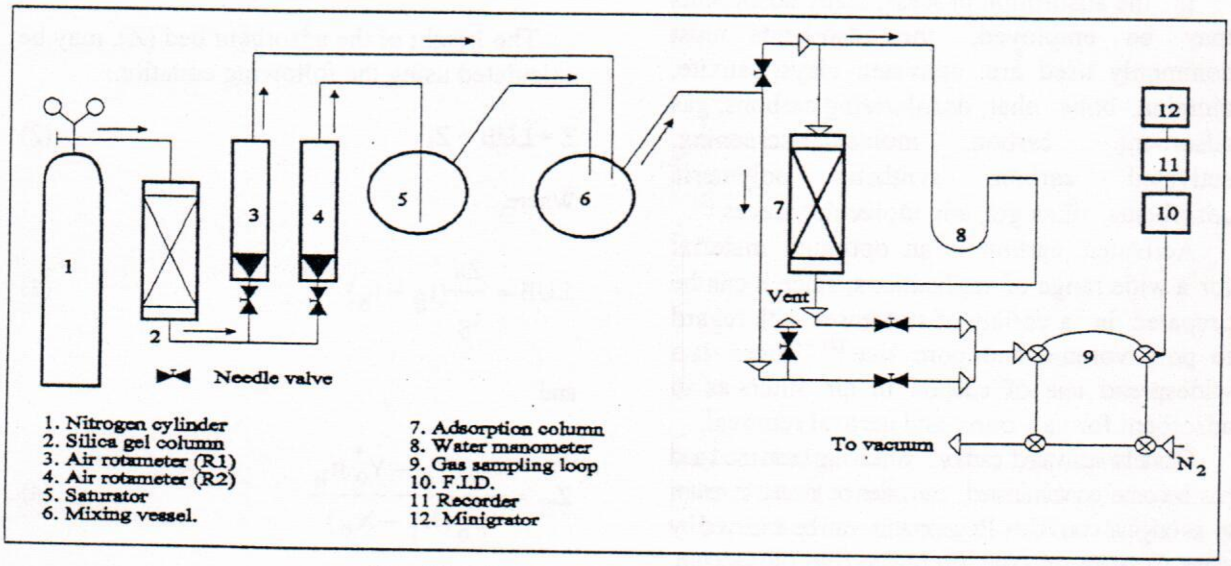

Fig. (1) Diagram of adsorption apparatus

RESULTS AND DISCUSSION

(1) Isothermal Experimental Data

The efficiency of granular carbon bed may be measured by defining a breakthrough time taken, which is the time taken before $C_x/C_o=0.01$, where C_x and C_o are the concentration of vapor in the effluent and the influent respectively. In this work a continuous record of C_X/C_o with time, from a value of zero to unity, has been kept. All of the adsorption isotherms have been constructed by drawing smooth curves through the experimentally determined points and the graphic origin. Adsorption isotherms were sigmoid shaped curves differing in the slopes of convex, straight, and concave segments of the curves. The plots of C_x/C_o vs. t for the specified runs at a temperature of (40°C) were obtained experimentally and shown in figures (2), (3),(4) and (5).

It can be concluded from these figures that the breakthrough time (t_b) and the time for complete saturation of the bed i.e. saturation capacity increases with increasing bed height (or weight) and decreasing granular size.

It was also observed during the study that aging the carbon and increasing its moisture content reduced the saturation capacity [7,8,9].

And by plotting t_b vs. bed weight (W) in accordance with wheeler's equation gives straight lines were the kinetic saturation capacity (ω_e) is obtained as the slope and the first order adsorption rate constant (k_v) as the intercept with x-axis. Both ω_e and K_v were found to increase with decreasing granular size [7,10].

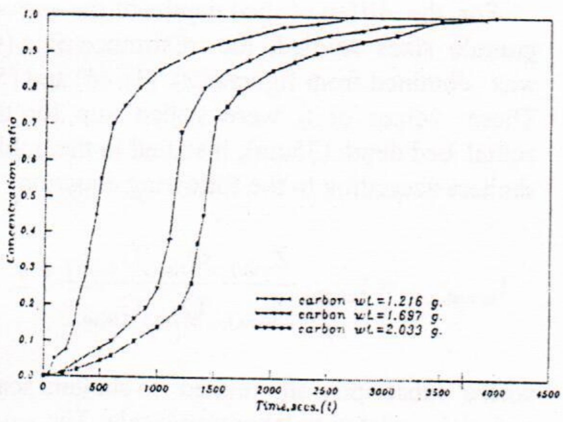

Fig. (2) CCl_4 penetration curves for various weight carbon beds all granule size carbon: 1.2 L/min flow rate

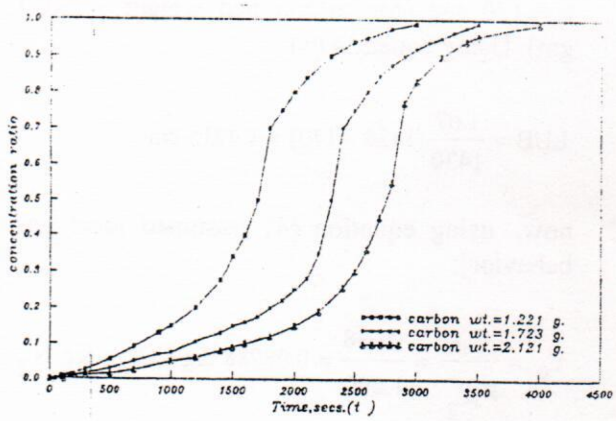

Fig. (4) CCl_4 penetration curves for various weight carbon beds: 3.25 mm diam. Granules: 1.2 L/min flow rate

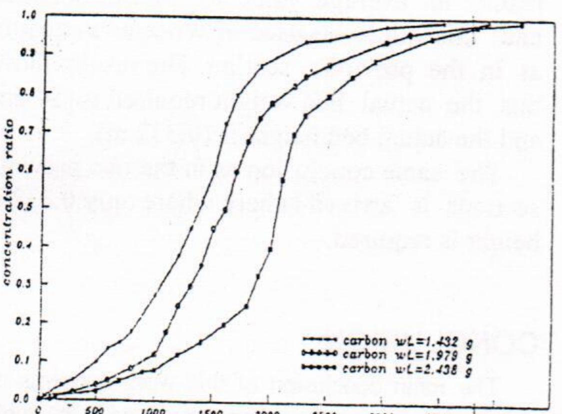

Fig. (3) CCl_4 penetration curves for various weight carbon beds: 3.775 mm diam. Granules: 1.2 L/min flow rate

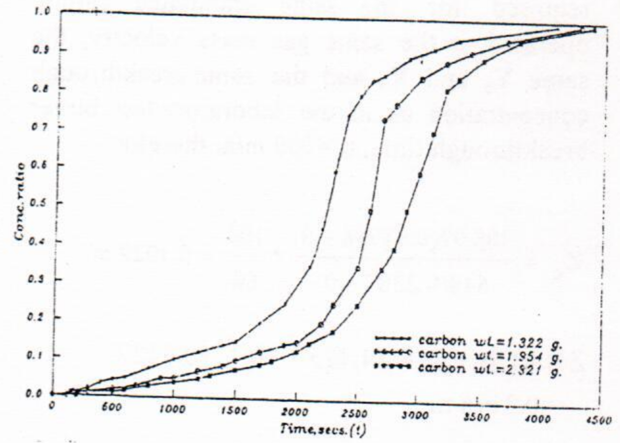

Fig. (5) CCl_4 penetration curves for various weight carbon beds: 2.975 mm diam. Granules: 1.2 L/min flow rate

(2) Assessment of the Performance of Activated Carbon Filter Bed Studied

The performance of the carbon beds employed may be assessed by determining the height of bed required to give a breakthrough time of 100 min. (Designer specification).

(i) Analysis according to LUB method

Data from laboratory test using shelter's granulated carbon: Bed depth =1.67 cm (0.0167 m), initial CCl_4 concentration in carbon (X_o) = 0, bulk density of bed (ρ_B) = 640 kg/m^3, temperature = 40°C, gas pressure = 101.325 KN/m^2, nitrogen flow rate (G_S) = 1.2 L/min (or 308.97 Kg/m^2.hr), initial CCl_4 concentration in gas (C_o) = 0.098 gm/L, from the breakthrough time curve, the value of t_S = 1430 sec. and t_b = 170 sec (for carbon bed weight = 2.033 gm). Using equation (3)

$$LUB = \frac{1.67}{1430}(1430 - 170) = 1.4715 \text{ cm}$$

now, using equation (4) [assumed ideal gas behavior]:

$$Y_o = \frac{C_o}{\rho_{N_2}} = \frac{0.098}{1.090} = 0.08988 \text{ Kg } CCl_4 / \text{Kg } N_2$$

and $X_{1=}X_o^*$ = the saturation adsorption capacity of carbon (ω_m) =0.2387 KgCCl$_4$/kg carbon.

It is desired to estimate the depth of bed required for the same granulated carbon operated at the same gas mass velocity, the same Y_o and X_o and the same breakthrough concentration as in the laboratory test, butter breakthrough time, t_b=100 min, therefor

$$Z_S = \frac{308.97(0.08988 - 0)}{640(0.2387 - 0)} * \frac{100}{60} = 0.3029 \text{ m}$$

$$Z = LUB + Z_s = 14.715 * 10^{-3} + 0.3029$$
$$= 0.3176 \text{ m}$$

This value of Z compares favorably with the actual bed height. i.e., the present filter performance is excellent since the test shows that only 0.317m are required while its actual height is 0.35 m, at 40°C.

(ii) Analysis according to Wheeler's equation for all granule size

Substituting numerial values for ω_e, C_o, Q, ρ_B, K_v and C_o/C_x equation (1) simplifies to the following form:

$t_b = 121.78W - 76.2011$

Now, if t_b = 100 min. = 6000 sec, then:

$6000 = 121.7857W - 76.2011$

W = 49.892gm =0.31m at 40°C

The same conclusion as in the previous section is arrived at where only 0.31m height is required while the available height of bed is 0.35m.

(iii) Analysis according to scale-up of resistance time

For the different bed depths of the various granule sizes studied, the resistance time (t_b) was obtained from figures (2), (3), (4) and (5). These values of t_b were scaled –up for the actual bed depth (35cm), installed in the public shelters according to the following equation:

$$t_{b(scal-up)} = t_{b(lab.)} \frac{Z_{(sh.)}}{Z_{(lab.)}} \frac{Q_{(lab.)} C_{o(lab.)}}{Q_{(sh.)} C_{o(sh).}} * 2$$

where subscripts, sh. related to shelters scale and, lab. related to laboratory scale. The value of t_b was multiplied by (2) to convert to the corresponding chloropicrin breakthrough time. The results are given in table (1). From these results an average value of (t_b was obtained, and this value was used in Wheeler's equation as in the previous section. The results shows that the actual bed weight required is (54 gm) and the actual bed height is (0.332 m).

The same conclusion as in the two previous sections is arrived at here where only 0.332 m height is required.

CONCLUSION

The main conclusion of this work concerns the efficiency of the carbon beds employed in the public shelters. The results showed that these beds (average granular size: 3.383 mm) are still very efficient, since the heights required for t_b = 100 min (manufacturer specification) were 0.31 m according to Wheelers equation and 0.317 m according to LUB method. While the actual height of the carbon beds is 0.35 m.

Table (1) Scaled-up breakthrough time values for different bed heights and granular size

All granule size avg. diam. = 3.383 mm		Granule of avg. diam. = 3.775 mm		Granule of avg. diam. = 3.25 mm		Granule of avg. diam. = 2.975 mm	
Z (cm)	t_b (min)	Z (cm)	t_b (min)	Z (cm)	t_b (min)	Z (cm)	t_b (min)
0.75	103.90	0.90	75.25	0.76	120.60	0.75	188.78
1.05	117.60	1.24	88.52	1.07	128.22	1.12	179.83
1.50	103.60	1.56	93.93	1.32	135.12	1.33	178.67

SYMBOLS

C	Vapor concentration at any time	$Kg\ m^{-3}$
C_b	Breakthrough concentration	$Kg\ m^{-3}$
C_o	Inlet concentration	$Kg\ m^{-3}$
X_X	Vapor concentration at a point x in the bed	$Kg\ m^{-3}$
G_S	Mass velocity of unabsorbed gas based on container cross section	$Kg.m^{-2}.s^{-1}$
K_V	Adsorption rate constant	min^{-1}
LUB	Length of unused portion of fixed bed	m
T	Time	s
t_b	Breakthrough time	s
t_S	Time of idealized breakthrough	s
W	Adsorbent bed weight	g
X_o	Initial adsorbate concentration in adsorbent	$Kg\ CCl_4/Kg$ carbon
X_t	Saturation adsorbate concentration in adsorbent	$Kg\ CCl_4/Kg$ carbon
Y_o	Initial solute concentration in solvent gas	$Kg\ CCl_4/Kg\ N_2$
Y_o^*	Solute concentration in equilibrium with X_o	$KgCCl_4/Kg\ N_2$
Z	Height of adsorbent column	m
Za	Bed depth	m
Z_s	Length of bed in equilibrium with feed	m

Creak Letters

ρ_B	Adsorbent bulk density	$Kg\ m^{-3}$
ω_e	Kinetic adsorption capacity	$Kg\ Cl_4/Kg$ carbon

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