

Fluorocarbon Aerosol Propellants IX: Adsorption on Activated Charcoal

KUN CHANG and WIN L. CHIOU*

Abstract □ The adsorption of three commonly used fluorocarbons, trichloromonofluoromethane, dichlorodifluoromethane, and dichlorotetrafluoroethane, on activated charcoal was studied at 25°. The adsorption *versus* pressure plots are consistent with the Brunauer, Emmett, and Teller (BET) type II and type IV isotherms, which can be explained as the condensation of the gaseous molecules in a wide range of pores in the activated charcoal. The monolayer capacity derived from the BET equation is discussed and used to estimate the volume of micropores present in the activated charcoal. Below the relative pressure of 0.01, the adsorption deviated from the BET plot. The deviation revealed that the adsorption capacity and adsorption potential at these lower pressures are greater than the extrapolated values. It is concluded that activated charcoal can be used effectively to remove propellants from the air in pollution control.

Keyphrases □ Fluorocarbon aerosol propellants—adsorption on activated charcoal, Langmuir isotherm and Brunauer, Emmett, and Teller equation compared □ Trichloromonofluoromethane—adsorption on activated charcoal, isotherms compared □ Dichlorodifluoromethane—adsorption on activated charcoal, isotherms compared □ Dichlorotetrafluoroethane—adsorption on activated charcoal, isotherms compared □ Aerosol propellants, fluorocarbon—adsorption on activated charcoal, Langmuir isotherm and Brunauer, Emmett, and Teller equation compared

Activated charcoal, also called carbon black or activated carbon, may be derived from sucrose, lactose, starch, and various industrial wastes. It has been used in medicine as an adsorbent to reduce flatulence and as an antidote in many forms of poisoning. Possible acute and chronic toxicities, especially toward the heart, due to the inhalation of a large quantity of aerosol propellants have been widely investigated recently (1–12). In this paper, the adsorption of the three most commonly used propellants, trichloromonofluoromethane, dichlorodifluoromethane, and dichlorotetrafluoroethane, on activated charcoal is investigated.

The mechanism of adsorption was explored by plotting the adsorption data according to some commonly adopted models of the adsorption isotherm. The molecular cross-sectional areas of the three fluorocarbons were estimated with the formula of Emmett and Brunauer (13). From these data, the specific area of the activated charcoal was calculated. The significance of these findings, along with the potential of using the activated charcoal as a filtering medium to remove the fluorocarbon, is discussed.

EXPERIMENTAL

Materials—Activated charcoal¹, *n*-hexane², dichlorodifluoromethane³ (bp -29.79°), dichlorotetrafluoroethane³ (bp 3.77°), and trichloromonofluoromethane³ (bp 23.82°) were used.

¹ Activated charcoal (Norit A) powder, CX655, I289, Matheson, Coleman and Bell, Norwood, Ohio.

² *n*-Hexane, 99 mole % pure, Fisher Scientific Co., Fair Lawn, N.J.

³ E. I. du Pont de Nemours and Co., Wilmington, Del.

Adsorption Studies—For the study of each fluorocarbon, 11 60-ml serum bottles were dried at 120° for 1 hr and then cooled to room temperature in a desiccator. The activated charcoal was heated at 120° for 15 hr and then cooled in the same way. About 3% of the weight was lost after heating and may be accounted for by the loss of moisture content.

One teaspoonful (approximately 2 g) of such dried activated charcoal was transferred to each tared 60-ml bottle through a powder funnel and sealed immediately with a silicone-coated rubber stopper. The weight of the activated charcoal inside the bottle was determined by weighing to the nearest 0.1 mg. These bottles were then immersed in a water bath⁴ maintained at 25 ± 0.5° to their bottle necks.

Dichlorodifluoromethane and dichlorotetrafluoroethane were transferred to the bottles by purging a preregulated aerosol propellant flow over the charcoal powder with no observable disturbance of the powder. The time period used for such purging process varied from 2 to 45 min. In the case of trichloromonofluoromethane, a precooled syringe was used to transfer the various amounts into each bottle. This transfer was followed by capping (aluminum caps) and releasing the excess pressure in the bottles properly over a short period.

After the transfer of each fluorocarbon, the bottles were weighed again to obtain the net weights of the fluorocarbon, which were in the range of approximately 0.1–1 g. When the process of releasing the excess pressure was carried out properly, a subsequent puncture, made a few hours later, in the cap with a syringe needle (27G) for several seconds resulted in no significant change in weight. If the punctures were made for longer than several seconds, they resulted in increased weights due to the adsorption of moisture from the air.

These bottles of the fluorocarbon and charcoal were then left to establish equilibrium in the constant-temperature water bath overnight (16–20 hr). Finally, the equilibrium concentration in the headspace of each bottle was analyzed by GC. The GC analysis was similar to those reported previously (12, 14, 15). However, the peak height-enhancing effect due to the presence of solvent was corrected for the detection of fluorocarbon in *n*-hexane. Preliminary experiments found that equilibration of the adsorption process could be accomplished within 7 hr and that the loss of propellants in highly concentrated bottles was negligible within a day.

THEORETICAL

Adsorption Isotherms—Both the Langmuir adsorption isotherm (16) and the Brunauer, Emmett, and Teller (BET) equation (17) have commonly been used to describe the phenomenon of adsorption. The former model is also called the monolayer adsorption isotherm. Its rearranged equation (18) can be written as shown here:

$$\frac{PX_s}{X} = \frac{P}{C_m} + \frac{1}{BC_m} \quad (\text{Eq. 1})$$

where P is the equilibrium pressure of the gaseous adsorbate, X_s is the weight of the solid adsorbent, X is the weight of a gas or vapor adsorbed, C_m is a constant called the monolayer capacity or the maximum adsorption capacity, and B is a constant.

In this study, the experimental procedure used differed from the conventional method (19) in measuring the value of P . Here the equilibrium pressure was substituted by the equilibrium partial pressure, which was calculated from the equilibrium concentration as discussed later. For each P value, the weight of a fluorocarbon adsorbed was calculated according to:

⁴ Versa-bath, Fisher.

Table I—Some Physical Properties and Constants of Fluorocarbons

	Trichloro- mono- fluoro- methane	Dichloro- difluoro- methane	Dichloro- tetra- fluoro- ethane
Molecular weight ^a	137.37	120.92	170.93
Boiling point ^a , °K	296.9	243.3	269.3
Density in liquid state ^a at 25° (Q_l), g/ml	1.476	1.311	1.456
Density of saturated vapor pressure ^a at boiling point (Q_b), mg/ml	5.86	6.33	7.83
Saturated vapor pressure ^a at 25° (P_0), atm	1.003	6.38	2.13
Compressibility ^b at 1 atm and boiling point (Z_0)	0.962	0.957	0.988
Density ^c at 25° and 1 atm (Q_l), mg/ml	5.84	5.17	7.28
Molecular cross-sectional area ^d (A_m), Å ²	31.4	31.2	36.7

^aSee Ref. 20. ^bCalculated from Q_b according to Eq. 5. ^cCalculated with Eq. 5. ^dCalculated with Eq. 6.

$$X = W - Q \left(V - \frac{W_c}{d} \right) \left(1 - \frac{Q_a}{Q_l} \right) \quad (\text{Eq. 2})$$

where W is the weight gained by the serum bottle after the fluorocarbon is introduced and equilibrated with the activated charcoal; Q is the headspace equilibrium concentration (weight per unit volume) of the fluorocarbon over the activated charcoal; V is the volume of the serum bottle; W_c is the weight of the activated charcoal; d is the density of the activated charcoal; Q_a is the air density in the laboratory, which was approximately 1.19 mg/ml at 25° and 1 atm (20); and Q_l is the density of the fluorocarbon at 25° and 1 atm (Table I).

The factor Q_a/Q_l introduced in Eq. 2 was used to correct the weight of fluorocarbon in the headspace by subtracting the weight of air displaced from the bottle. The density of the activated charcoal was estimated by weighing the activated charcoal before and after it was immersed in a full bottle of deionized water. The density obtained was about 1.7 g/ml. With this information, the left-hand side term of Eq. 1 can be plotted with respect to P . A straight line can be expected to form for this type of adsorption isotherm, and the monolayer capacity can be calculated from the inverse of its slope.

The BET model is an extension of the Langmuir monolayer adsorption concept to a multilayer one. Theoretically, if an infinite number of adsorbed layers are allowed to form, the BET equation (18) can be written as:

$$\frac{X_s P}{X(P_0 - P)} = \frac{(C - 1)P}{C_m C P_0} + \frac{1}{C_m C} \quad (\text{Eq. 3})$$

where X_s , X , and P are defined in the same way as in Eq. 1; P_0 is the saturated vapor pressure of the fluorocarbon at 25° (21) (Table I); C is a BET constant; and C_m is the BET monolayer capacity which is not the maximum adsorption capacity.

The plotting of the left-hand side term versus the relative pressure (P/P_0) should yield a straight line according to Eq. 3, where the values of the slope and the intersection can be used to calculate the BET constants C and C_m .

It is understood that both Eqs. 1 and 3 are special cases of a generalized equation called the modified BET equation (18). If the number of layers allowed to be adsorbed on the solid adsorbent is limited, then the generalized equation is expected to fit better the adsorption isotherm. However, due to the mathematical complexity involved in the generalized equation, this procedure is generally replaced by attempting to fit Eq. 3 because the generalized equation can be approximated by Eq. 3 at low relative pressures, so at least a portion of the curve is expected to be straight.

Estimation of Equilibrium Partial Pressure—The deviation of the fluorocarbon gas from the ideal gas behavior can be measured by a compressibility factor, Z , defined in the following equation (22):

$$PV = ZnRT \quad (\text{Eq. 4})$$

When Z is equal to 1, Eq. 4 is simply reduced to the ideal gas equation for n moles of gas. The Z values calculated for the fluorocarbons according to Eq. 4 based on the literature data (21) of vapor density at the boiling point and 1 atm, called Z_0 , are given in Table I. These Z_0 values are at most about 4% smaller than 1. Under moderate pressures, the compressibility factor is known to be proportional to the gas temperature and inversely proportional to its pressure (22).

In this adsorption study, the equilibrium partial pressures were much less than 1 atm and the temperature was higher than any of the boiling points of the three fluorocarbons. Therefore, the Z values for the fluorocarbons under the present experimental conditions are expected to be larger than Z_0 but smaller than 1. In reality, air was also present in the serum bottles to make the total pressure near 1 atm. Thus, a good approximation for the estimation of the equilibrium partial pressure of the fluorocarbon in the headspace would be:

$$P = \frac{Z_0 Q_l R T}{M} \quad (\text{Eq. 5})$$

where M is the molecular weight of the fluorocarbon.

Molecular Cross-Sectional Area of Adsorbate (A_m) and Specific Surface of Adsorbent (S)—Emmett and Brunauer (23) proposed the following equation to estimate A_m for an ordinary adsorbate in the liquid form:

$$A_m \text{ (cm}^2\text{)} = 1.091 \left(\frac{M}{Q_l N} \right)^{2/3} \quad (\text{Eq. 6})$$

where M is the same as in Eq. 5, Q_l is the density of the fluorocarbon in liquid form at 25°, and N is Avogadro's number (6.02×10^{23}). Thus, the specific surface area of activated charcoal, defined as the total surface area per gram of adsorbent, can be estimated by:

$$S = \frac{A_m C_m N}{M} \quad (\text{Eq. 7})$$

RESULTS AND DISCUSSION

Some physical constants (21) and properties of the three fluorocarbons required for the analysis are listed in Table I. The adsorption (X/X_s) versus the relative pressure (P/P_0) was plotted for the three fluorocarbons (Fig. 1). The adsorption values, which may be called the adsorption capacities, for each fluorocarbon at $P = 0.5$ atm are indicated on each curve in Fig. 1. These values are 0.310, 0.351, and 0.450 for dichlorodifluoromethane, dichlorotetrafluoroethane, and trichloromonofluoromethane, respectively. The rank order of these adsorption capacities is in the same order as their

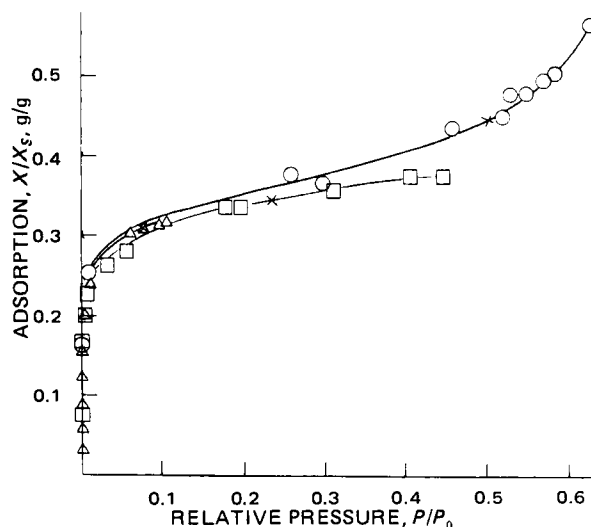


Figure 1—Adsorption isotherms of three fluorocarbon aerosol propellants at 25°. Key: O, trichloromonofluoromethane; Δ, dichlorodifluoromethane; and □, dichlorotetrafluoroethane; X, $P = 0.5$ atm.

Table II—Adsorption and Related Values at Low Relative Pressures

Fluorocarbon	Q, mg/ml	P, atm	X/X _s , g/g	P/P ₀	PX _s /X, atm
Trichloromonofluoromethane	3.17 × 10 ⁻³	5.44 × 10 ⁻⁴	0.1634	5.44 × 10 ⁻⁴	3.33 × 10 ⁻³
	5.36 × 10 ⁻²	9.19 × 10 ⁻³	0.2543	9.18 × 10 ⁻³	3.62 × 10 ⁻²
Dichlorotetrafluoroethane	6.77 × 10 ⁻⁴	9.57 × 10 ⁻⁵	0.0721	4.50 × 10 ⁻⁵	1.33 × 10 ⁻³
	1.20 × 10 ⁻²	1.69 × 10 ⁻³	0.1658	7.96 × 10 ⁻⁴	1.02 × 10 ⁻²
	6.14 × 10 ⁻²	8.71 × 10 ⁻³	0.1999	4.09 × 10 ⁻³	4.34 × 10 ⁻²
Dichlorodifluoromethane	0.107	1.51 × 10 ⁻²	0.2290	7.09 × 10 ⁻³	6.60 × 10 ⁻²
	8.13 × 10 ⁻⁴	1.57 × 10 ⁻⁴	0.0302	2.46 × 10 ⁻⁵	5.21 × 10 ⁻³
	2.47 × 10 ⁻³	4.78 × 10 ⁻⁴	0.0554	7.49 × 10 ⁻⁵	8.64 × 10 ⁻³
	8.24 × 10 ⁻³	1.59 × 10 ⁻³	0.0884	2.49 × 10 ⁻⁴	1.80 × 10 ⁻²
	2.33 × 10 ⁻²	4.51 × 10 ⁻³	0.1219	7.07 × 10 ⁻⁴	3.70 × 10 ⁻²
	3.94 × 10 ⁻²	7.63 × 10 ⁻³	0.1546	1.20 × 10 ⁻³	4.91 × 10 ⁻²
	0.210	4.06 × 10 ⁻²	0.201	6.36 × 10 ⁻³	0.202

partition coefficients between *n*-hexane and air, which were determined in this laboratory to be 27, 60, and 213, respectively. Such correlation is in agreement with the predominantly lipophilic character of the adsorption surface existing in activated charcoal. For relative pressures below 0.01, the adsorption values along with some other functions are listed in Table II.

In attempting to investigate the mechanism of adsorption, the Langmuir adsorption isotherm was tested. This involved the plotting of PX_s/X versus P for the three fluorocarbons (Figs. 2-4). Between the relative pressures of about 0.01-0.3, the mechanism of adsorption apparently can be assumed to be of the monolayer type. For dichlorodifluoromethane, the highest relative pressure used in this experiment was only 0.105. Therefore, the extension of such a linear region to about 0.3 is only speculated. The limitation of the present experimental method confined this adsorption study to lower relative pressures for dichlorodifluoromethane due to its high saturated vapor pressure.

However, from the deviation observed in the Langmuir linear plots for dichlorotetrafluoroethane and trichloromonofluoromethane, one cannot explain the adsorption mechanism for these two propellants simply by the monolayer adsorption kinetics. To appreciate the nature of such deviation, it should be recalled that the slope of the Langmuir plot is equal to the reciprocal of the monolayer capacity. If the Langmuir plot is a curve, then the value of C_m is not a constant. In Figs. 3 and 4, the curves at the higher sides of their equilibrium partial pressures would yield higher C_m values. This phenomenon can be imagined as if more adsorption sites are created as more adsorption sites are occupied. Thus, the monolayer capacities evaluated from Figs. 2-4 do not represent their maximum adsorption capacities.

The failure to obtain a meaningful monolayer adsorption capacity from the Langmuir plot prompted the analysis of adsorption through the BET equation. The plots based on the BET equation are shown in Fig. 5; all three plots have a common linear range ex-

tending from the relative pressure of around 0.01 to about 0.25. Such a small linear section has been quite common in plotting the BET equation (18). Therefore, the mechanism of adsorption for these fluorocarbons on activated charcoal can be more satisfactorily described by the generalized BET model in which the possible number of adsorbed layers is greater than 1.

Based on this discussion and the characteristics of the adsorption isotherm shown in Fig. 1, these adsorption isotherms can be designated as the type II or type IV isotherm according to the BET classification (18). Under the same classification, the Langmuir adsorption isotherm belongs to the type I isotherm. Although the type I isotherm also follows the Langmuir equation, it is not restricted to the monolayer adsorption mechanism. The condensation of gas in the micropores of an adsorbent can also result in the type I isotherm (18).

The type IV isotherms are generally associated with the porous solid possessing a transitional range of pores (between micropores and macropores), *i.e.*, having diameters ranging from tens to hundreds of Angstrom units. The presence of micropores along with the transitional pores still leads to the type IV isotherm (18). Similarly, the general shape of the type II isotherm can also be found if the adsorbent is partially macroporous and partially microporous. In both cases, the effect of micropores can be felt at a lower range of relative pressures. That is, this branch of adsorption isotherm can be approximated by the type I isotherm if the amount of micropores present is quite large compared with the transitional pores or macropores. Apparently, such is the case with the present study. Therefore, the activated charcoal used in this analysis can be described as a porous solid possessing a wide range of pores including the smallest micropores, the transitional pores, and, possibly, the macropores.

The adsorption below the relative pressure of 0.01 is generally inexplicable by the Langmuir or BET method (18). To describe the adsorption phenomenon in this pressure region for the present study, it is convenient to call temporarily the expression $X/(QX_s)$ as the adsorption potential or simply as A . The physical meaning of A is the volume of adsorbate (X/Q) in concentration Q that can be condensed on a unit weight of adsorbent at the equilibrium concentration Q . At low relative pressures ($P/P_0 < 0.01$), the left-hand sides of both Eqs. 1 and 3 are inversely proportional to A as a good approximation. Therefore, both Eqs. 1 and 3 can be approximated

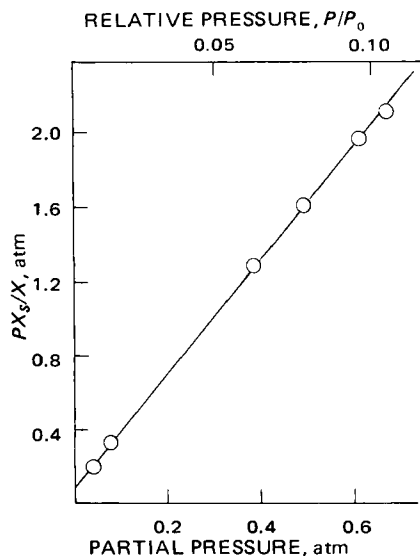


Figure 2—Langmuir adsorption plot for dichlorodifluoromethane at 25°.

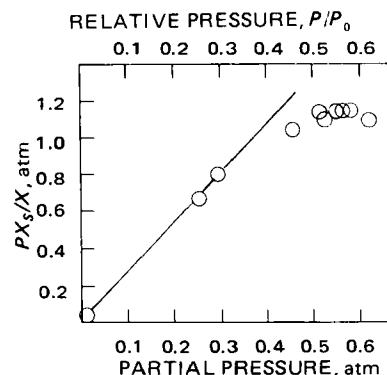


Figure 3—Langmuir adsorption plot for trichloromonofluoromethane at 25°.

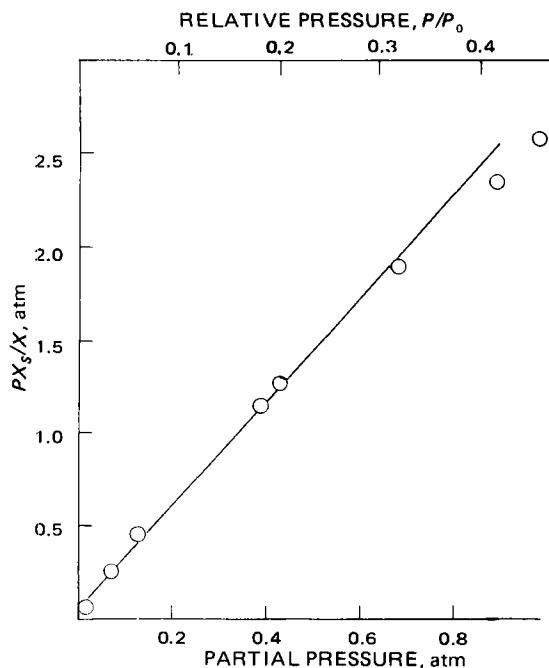


Figure 4—Langmuir adsorption plot for dichlorotetrafluoroethane at 25°.

by:

$$\frac{k}{A} = mP + d \quad \text{for } P/P_0 < 0.01 \quad (\text{Eq. 8})$$

where k , m , and d are constants, and k/A is equal to PX_s/X .

The plotting of k/A versus P is essentially the Langmuir plot at low relative pressures. The data points required for the plot are shown in Table II. If such plots are made, it can be observed that the reciprocal of the adsorption potential does not increase linearly with the equilibrium pressure. On the contrary, it rises very sharply near the origin ($P \rightarrow 0$) and the slope of the curve decreases as P increases. In other words, both the adsorption potential and the adsorption capacity are greater near the origin than the prediction from either Eq. 1 or 3. A typical plot is shown in Fig. 6.

The monolayer capacities for the activated charcoal calculated from Fig. 5 vary only slightly with the fluorocarbons. The adsorbed weight of trichloromonofluoromethane or dichlorodifluoromethane by each gram of activated charcoal is about 0.292 g, and that of dichlorotetrafluoroethane is 0.278 g. The maximum adsorption capacity cannot be estimated for the type II or type IV isotherm without having the adsorption data near the relative pressure of 1. Therefore, the most that can be said here is that the maximum ad-

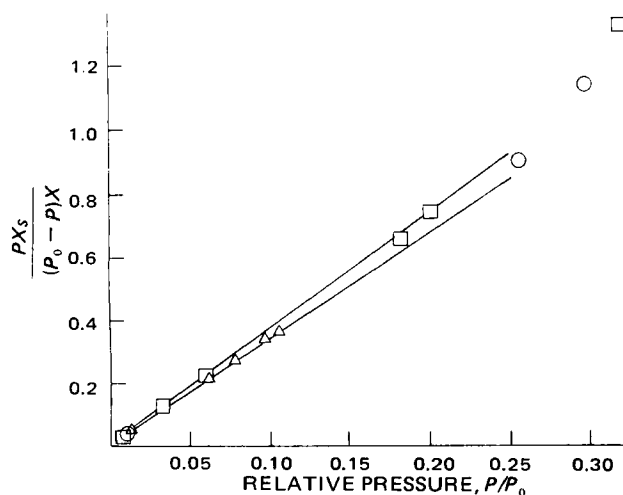


Figure 5—BET adsorption plots for three fluorocarbon aerosol propellants at 25°. Key: O, trichloromonofluoromethane; Δ, dichlorodifluoromethane; and □, dichlorotetrafluoroethane.

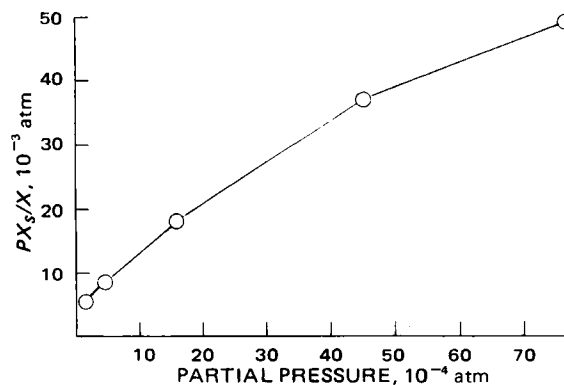


Figure 6—Langmuir adsorption plot for dichlorodifluoromethane at relatively lower partial pressures.

sorption capacity must be considerably larger than the largest adsorption values in Fig. 1.

The estimated molecular cross-sectional areas (A_m) for the three fluorocarbons were calculated according to Eq. 6 (Table I). These values were used to calculate the specific surface area of activated charcoal using Eq. 7. The specific areas so calculated were 454, 402, and 359 m^2/g for dichlorodifluoromethane, trichloromonofluoromethane, and dichlorotetrafluoroethane, respectively. These values are in the same range as reported for sugar charcoal, *i.e.*, between 100 and 1000 m^2/g (19). However, the rather large variation occurring in this study suggests that the monolayer capacity may in fact represent the micropore capacity. Thus, by assuming that the mechanism of micropore condensation predominates over the monolayer adsorption at low pressures, the micropore volume may be estimated using the values of the liquid densities of fluorocarbons at 25° given in Table I, which leads to 0.223, 0.198, and 0.191 ml/g for the same order of fluorocarbons just mentioned. The somewhat larger value derived for dichlorodifluoromethane is not unusual because the micropore volume available for smaller molecules has been found to be larger (18).

In the preliminary trials of the adsorption study, 5-ml serum bottles were used. The equilibrium state of adsorption and desorption was found to establish almost immediately after the propellant was introduced over the activated charcoal. However, due to experimental difficulty in handling small quantities of activated charcoal in small bottles, the 60-ml serum bottles were used instead. Then the equilibrium was found to establish rather slowly, as mentioned before, although at least 90% of the propellant was estimated to be adsorbed in a few minutes. Thus, the rate of equilibration appeared to be dependent mainly on the rate of diffusion in both the headspace and the interspace of the adsorbent particles.

In conclusion, the adsorption of the three fluorocarbons on activated charcoal at 25° can be described by the BET type II or type IV isotherm. The adsorption mechanism can be assumed as primarily through the condensation of fluorocarbon gas in the pores of activated charcoal. The deviation of the adsorption isotherms at low relative pressures was in favor of adsorption, which is an advantage in using this adsorbent as a filtering medium to remove aerosol propellants from air.

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Fluorocarbon Aerosol Propellants X: Pharmacokinetics of Dichlorotetrafluoroethane in Dogs

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Abstract □ An intravenous dosage form of dichlorotetrafluoroethane, a common fluorocarbon aerosol propellant, was formulated in polyethylene glycol 400 for single dosing to unanesthetized dogs. A three-compartment open model was proposed for the disposition of this compound in dogs, with average half-lives of 1.3, 9.6, and 50.8 min for the three disposition phases. An analysis of tissue compartment distribution following a single dose showed that it took about 2 hr to achieve pseudo-distribution equilibration, following which more than 90% of the propellant remaining in the body was retained in the tissue compartments. Pulmonary clearance and volumes of distribution were calculated considering the first-pass effect through the lungs. The volume of distribution was approximately 10 times the body weight in terms of blood concentration, and about 84% of the propellant was cleared from the blood passing through the lungs in each cycle.

Keyphrases □ Fluorocarbon aerosol propellants—dichlorotetrafluoroethane, tissue compartment, distribution analysis, three-compartment open model, dogs □ Dichlorotetrafluoroethane—tissue compartment distribution analysis, three-compartment open model, dogs □ Aerosol propellants, fluorocarbon—dichlorotetrafluoroethane, tissue compartment distribution analysis, three-compartment open model, dogs □ Pharmacokinetics—dichlorotetrafluoroethane, tissue compartment distribution analysis, three-compartment open model, dogs

The wide use of fluorocarbon aerosol propellants in various household, cosmetic, and medicinal pressurized packages has recently prompted extensive studies on their possible adverse effects. These include effects on the cardiovascular system (1-4), enzyme activities (5), mutation (6), and ozone concentrations in the stratosphere (7). Arguments that have often been presented in favor of the low systemic toxicity of fluorocarbons is that these compounds are not absorbed to any significant extent when inhaled from commercial aerosol products and that the small frac-

tion absorbed is eliminated rapidly from the body, decreasing the possibility of any toxic reaction (8-10).

Unfortunately, the conclusions drawn from most previous studies were not based on sound pharmacokinetic principles and do not reflect the true disposition pattern of these compounds (4, 11).

The objectives of this study were to demonstrate that dichlorotetrafluoroethane, one of the most commonly used fluorocarbon propellants, has a longer biological half-life than previously thought and undergoes extensive distribution in the body, an observation that might have an important bearing on its toxicity profile.

EXPERIMENTAL

Materials—A medical-grade silicone tubing¹ [0.3 cm (0.125 in.) i.d.] was used with 18-20-gauge cannulas² for venous cannulation. The infusion of the solution was performed using a constant-rate infusion pump³.

Intravenous Dosage Form—Sterile solutions of dichlorotetrafluoroethane⁴ were prepared by purging the fluorocarbon, which exists in gaseous form at room temperature, through a needle inserted deep into the sealed serum bottle containing a known volume of polyethylene glycol 400⁵. The gas was allowed to escape the bottle through a 27-gauge needle inserted just below the surface of the stopper. After purging for 15 min, the needles were removed and the solution was set aside for at least 30 min. Then the rubber stopper was pierced with another 27-gauge needle to release any excessive pressure.

¹ Dow Corning Corp., Midland, Mich.

² Medicut, Aloe Medical, St. Louis, Mo.

³ Harvard Apparatus Co., Millis, Mass.

⁴ Supplied by E. I. du Pont de Nemours & Co., Wilmington, Del.

⁵ Union Carbide Chemical Co., New York, N.Y.