

# Partitioning Behavior of Insecticides in Soil-Water Systems: I. Adsorbent Concentration Effects<sup>1</sup>

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## ABSTRACT

Adsorption studies were conducted to determine whether adsorbent concentration (soil-solution ratio) affected insecticide adsorption by soils and clays. Adsorption isotherms were obtained for several insecticides in Bondhead sandy loam and Ca-saturated illite suspensions using adsorbent concentrations that were varied over several orders of magnitude. There was no evidence that altering adsorbent concentration exerted any influence on partitioning of insecticides between the adsorbent and solution phases. The centrifugation process, which in effect greatly increased adsorbent concentration at the bottom of the centrifugation tube, did not change the partitioning of the insecticides between the two phases. Dieldrin (1,2,3,4,10,10-hexachloro-exo-6,7-epoxy, 4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-5,8 -dimethanophthalene), unlike the other insecticides, exhibited strong concentration-dependent adsorption by glass surfaces, which invalidated the use of the normal "blank" (no adsorbent) sample for determining the initial solute concentration. Since glass adsorption appeared quite irreversible in aqueous solution, a sequential blank/sample adsorption technique was adopted whereby the stock solution was initially equilibrated in the glass bottle, then a small aliquot was removed for analysis before adding the adsorbent for its equilibration period. This technique produced consistent adsorption data that showed no evidence of being influenced by adsorbent concentration.

**Additional Index Words:** soil-solution ratio, isotherm, adsorption, parathion, dieldrin, chlorpyrifos, fensulfthion sulfone.

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<sup>3</sup> See the Appendix for a listing of the chemical names of pesticides used in this article.

It is only recently that adsorption studies involving water-sediment (soil or clay) systems have examined the effect of changing the adsorbent concentration on partitioning of neutral organic compounds between the two phases. Adsorbent concentrations used in adsorption studies (expressed as milligrams adsorbent per liter solution) reported in the literature have ranged from approximately 10 (11) to  $1 \times 10^6$  (9). Factors involved in selecting experimental adsorption concentrations include (i) relative partitioning of compound between adsorbent and water phases, (ii) detection limits and working range of analytical methods, and (iii) concentrations at which the compound and adsorbent occur in natural aqueous environments.

Lotse et al. (10) reported that the sediment concentration ( $2 \times 10^2$  to  $5 \times 10^5$  mg L<sup>-1</sup>) as well as the lindane/sediment ratio affected lindane adsorption by several lake sediments.<sup>3</sup> They showed that relative adsorption increased with an increasing lindane/sediment ratio. Karickhoff et al. (8) reported that their isotherms for pyrene and methoxychlor on several sediments were independent of sediment concentration ( $10^3$  to  $4 \times 10^5$  mg L<sup>-1</sup>) in dilute suspensions. Koskinen and Cheng (9) found that decreasing the adsorbent concentration from  $10^6$  mg L<sup>-1</sup> (10 g/10 mL) to  $3 \times 10^5$  mg L<sup>-1</sup> (10 g/33 mL) resulted in a significant increase in 2,4,5-T adsorption, but that a further decrease in adsorbent concentration to approximately  $3 \times 10^4$  mg L<sup>-1</sup> (1g/33 mL) resulted in no further change in adsorption. Farmer and Aochi (6) found that decreasing the adsorbent concentration from  $5 \times 10^5$  to  $2 \times 10^5$  mg L<sup>-1</sup> resulted in decreased picloram adsorption.

These references, dealing primarily with adsorbent concentrations exceeding  $10^3$  mg soil L<sup>-1</sup> solution, have produced no consistent conclusions on a possible relationship between adsorbent concentration and partitioning of neutral organic compounds between sediment or soils and water.

Recently O'Connor and Connolly (11), DiToro et al. (5), and Horzempa and DiToro (7) described experiments in which, at low adsorbent concentrations (10-1000 mg L<sup>-1</sup>), the relative adsorption of organochlorine insecticides and polychlorinated biphenyls apparently increased by orders of magnitude as a result of comparable decreases in the sediment (or clay) concentration. DiToro and Horzempa (4) have also reported that when a portion of the supernatant solution of hexachlorobiphenyl (HCBP) in equilibrium with lake sediment, was removed and the remaining solution used to resuspend the sediment (with no new solution addition), there appeared to be a significant increase in HCBP solution concentration. They attributed this increase to HCBP desorption in response to the increased sediment concentration following the resuspension step.

The authors concluded that these results were important to understanding the adsorption/desorption status of these compounds in river or lake systems. They hypothesized that as dilute sediment suspensions containing adsorbed pesticide settle to the river bottom, the "sediment concentration" would increase, thereby lessening its ability to retain the pesticide, resulting in a partial desorption. Conversely, if the pesticide-loaded sediments were resuspended by stream currents, the "sediment concentration" would decrease, thereby increasing their ability to re-adsorb more pesticide. They suggested that this process could significantly influence the manner in which pollutants are flushed from river systems.

The implications of these proposals, if proven correct, could be far-reaching. For example, adsorption isotherms could not be directly compared unless they had similar adsorbent concentrations, thereby making comparisons among many published isotherms difficult, if not impossible. Traditionally, the centrifuge has been used to separate the aqueous and adsorbent phases in adsorption experiments. This research casts doubts on the validity of this technique, since, according to their hypothesis, the sediment concentration would increase tremendously as it was thrown to the bottom of the centrifuge tube where a partial desorption would supposedly occur, destroying the equilibrium attained before centrifugation.

The purpose of this report is to further investigate the effect of adsorbent concentration upon the adsorption of several insecticides in aqueous suspensions of an agricultural sandy loam and a Ca-saturated illite clay and to discuss these findings in relation to these recent new hypotheses.

## MATERIALS AND METHODS

The chemical names of substances referred to in the text are given in the Appendix. A soil, Bondhead sandy loam (3.9% organic matter), the characteristics of which have been reported previously (3) and a Ca-saturated Morris illite (< 2- $\mu$ m fraction) were used as adsorbents. After Ca-saturation, the illite was freeze-dried. Both adsorbents were passed through a 40-mesh sieve. Fensulfothion sulfone (FSO<sub>2</sub>) was re-crystallized from methanol at -20°C. Parathion was of 98.8% purity, dieldrin purity exceeded 99%, and chlorpyrifos purity was 94%.

Batch-type adsorption experiments were used to generate adsorption data, as previously reported (2, 3). Adsorption blanks were unnecessary for parathion and FSO<sub>2</sub> (unpublished data, this laboratory), but were necessary for the dieldrin experiment to correct for glass adsorption, as will be detailed later in this report. The range of adsorbent concentrations examined varied with the particular adsorption system, depending on the nature of the compound and adsorbent, as well as on the analytical working range of the gas-liquid chromatograph (GLC) (Table 1). All adsorption points were done in triplicate at 20  $\pm$  1.5°C. Thirty-milliliter adsorption volumes were used for the organophosphorus insecticides, and 50-mL volumes were used in the dieldrin studies.

Other batch-type adsorption experiments (to investigate the effect of equilibrium solution volume-reduction on partitioning) involving the adsorption of parathion and chlorpyrifos by Bondhead sandy loam, and Ca-saturated illite, were done in 150-mL Corex<sup>®</sup> glass centrifuge tubes (0.5 g adsorbent per 50 mL for chlorpyrifos, 1.0 g adsorbent per 50 mL for parathion). After the equilibration period (wrist-action shaker for at least 16 h), the suspension was left to settle (Bondhead), or was centrifuged at 1500 x g for 10 min (Ca-illite) to separate the phases. A 40-mL aliquot was removed and centrifuged at 43 500 x g for 10 min prior to GLC analysis. The remaining 20-mL aliquot in the Corex<sup>®</sup> tubes was used to resuspend the adsorbent. The samples were shaken for 24 h followed by separation of the phases, as before, and GLC analysis of the supernatant. Additional experiments were conducted in which all the samples were centrifuged in the Corex<sup>®</sup> tubes at 600 x g for 0.5 h, following the first equilibration period. After the primary separation, the 40-mL aliquots, which were removed from the tubes, were again centrifuged at 43,500 x g prior to GLC analysis. This same separation procedure was followed after the resuspension-reequilibration period with the remaining 20-mL aliquot.

All analyses were performed by GLC using triplicate injections. All samples were injected as aqueous methanol mixtures with standards of the same solvent composition. Both dieldrin and parathion were analyzed on a 60 cm by 2 mm i.d. Pyrex<sup>®</sup> glass column packed with 6% XE-60 Chromosorb W, 100/120 mesh (AW-DMCS) using an electron capture detector. Fensulfothion sulfone was analyzed on a 46 cm by 2 mm i.d. column packed with 2% OV-275, modified with 0.1% H<sub>3</sub>PO<sub>4</sub>, on Chromosorb<sup>®</sup>W-HP, 100/120 mesh, using an alkali flame ionization detector. Chlorpyrifos was analyzed on a 46 cm by 2 mm i.d. column packed with 10% QF 1 on Chromosorb<sup>®</sup>W-HP, 100/120 mesh (AW-DMCS), using an alkali flame ionization detector.

## RESULTS

Both "adsorbent concentration," expressed in mg L<sup>-1</sup> and "soil/water ratio" are terms that can be used interchangeably. Since adsorbent concentrations are reported as a single number, whereas soil/water ratios are shown as ratios (i.e., 1/33), "adsorbent concentration" lends itself better to graphical representation and will be used throughout this report. The adsorption data were plotted using the modified Freundlich isotherm (1) to make comparisons of adsorption at several equilibrium mole fraction concentrations.

$$S = K_{MF} Z^N \quad [1] \quad \text{or in the log transformation form} \quad \log S = \log K_{MF} + N \log Z, \quad [2]$$

where

S = moles insecticide adsorbed/grams adsorbent

Z = equilibrium mole fraction insecticide concentration (molar insecticide concentration/ molar water concentration in dilute solution)

N = Freundlich slope

K<sub>MF</sub> = regression constant with no physical meaning, since it would be evaluated at Z = 1.0 (pure insecticide, no solvent in solution)

**Table 1. Adsorption isotherm constants, adsorbent concentrations, and calculated adsorbed concentrations for the various insecticide-adsorbent systems.**

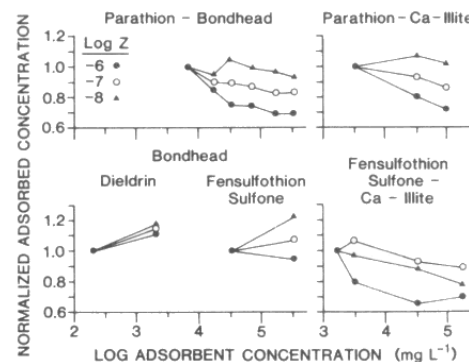
System	Adsorbent conc.		K <sub>MF</sub>	N	S (mol adsorbed g <sup>-1</sup> )		
	mg L <sup>-1</sup>	g mL <sup>-1</sup>			mol g <sup>-1</sup>	log Z = -6	log Z = -7
					x 10 <sup>-6</sup>	x 10 <sup>-7</sup>	x 10 <sup>-8</sup>
Parathion-Bondhead	6.667 E03	0.2/30	0.372	0.899	1.509	1.907	2.408
	1.667 E04	0.5/30	0.233	0.876	1.295	1.724	2.295
	3.333 E04	1.0/30	0.105	0.827	1.141	1.698	2.528
	6.667 E04	2.0/30	0.125	0.840	1.145	1.655	2.394
	1.667 E05	5.0/30	0.091	0.823	1.049	1.578	2.373
	3.333 E05	10/30	0.086	0.819	1.044	1.582	2.398
	Variable	Variable	0.320	0.894	1.374	1.751	2.232
Parathion-Ca-illite	3.333 E03	0.1/30	9.377	1.041	5.309	4.832	4.398
	3.333 E04	1.0/30	3.011	0.978	4.224	4.470	4.729
	1.000 E05	3.0/30	2.367	0.965	3.821	4.139	4.483
FSO <sub>2</sub> -Bondhead	3.333 E04	1.0/30	0.046	0.856	0.336	0.468	0.652
	1.667 E05	5.0/30	0.020	0.801	0.318	0.502	0.793
FSO <sub>2</sub> -Ca-illite	1.667 E03	0.05/30	7.784	1.014	6.424	6.222	6.026
	3.333 E03	0.1/30	15.84	1.054	7.492	6.613	5.838
	3.333 E04	1.0/30	10.65	1.038	6.323	5.796	5.314
	1.667 E05	0.5/30	18.41	1.074	6.601	5.564	4.689
Dieldrin-Bondhead	2.000 E02	0.01/50	0.185	0.786	3.576	5.858	9.595
	2.000 E03	0.1/50	0.177	0.775	3.979	6.684	11.123

Comparisons of the isotherms derived using different adsorbent concentrations (made by comparing values of S at a single value for Z) were made using Eq. [2] and the regression constants (Table 1). The S values are tabulated in Table 1

for the respective log Z values of - 6.0, - 7.0, and - 8.0. In order to show, in one graph, the relationship of S to log adsorbent concentration for all three levels of log Z (each different by one order of magnitude) (Fig. 1), the S values were normalized to the S values at the lowest adsorbent concentration for each level of log Z (i.e., for the parathion-Bondhead system at log Z = - 6, all values were divided by 1.509 E-06, from Table 1).

In most cases, log Z values of - 6.0 would be at or slightly above the maximum equilibrium concentrations obtained in the experiments, while log Z values of - 8.0 would be at or slightly below the minimum concentrations. Generally, log Z values between - 7.0 and - 8.0 would be in the region where the conventional Freundlich K values (at equilibrium concentration,  $C_e = 1.0$ ) would be calculated. Small differences in the Freundlich slope (N) are responsible for the divergent nature of the lines in Fig. 1.

The re-suspension experiments (Table 2, 40 mL supernatant solution removed, adsorbent re-suspended in remaining 20 mL) did not produce significant increases in equilibrium concentrations similar to those reported in the literature (4). There were no concentration changes for either insecticide in Ca-illite suspensions, but there was a consistent decrease in both Bondhead suspensions. Adsorption vs. time studies with the Chlorpyrifos-Bondhead system indicated that there was a further 15% adsorption during the second 24-h equilibrium period, which would account for a portion of the concentration decrease (perhaps due to a secondary slow adsorption process by soil organic matter). The re-suspension adsorption experiments using the Bondhead soil were duplicated such that the suspensions in one set of samples were allowed to separate out by gravity, while the other set (Table 2) was separated by direct centrifugation at 6000 x g in the Corex® tubes. Both types of supernatant samples were re-centrifuged at 43,500 x g to remove any remaining adsorbent traces prior to analysis. There were no differences in equilibrium concentrations between the two techniques, leading to the conclusion that centrifugation did not affect results of adsorption experiments. In a future report, we will deal with the possible effects of centrifugation on desorption processes.



**Fig. 1. Effect of adsorbent concentration on insecticide adsorption by Bondhead sandy loam and Ca-illite.**

## DISCUSSION

The adsorbent concentration experiments demonstrated that there were not any great changes in insecticide adsorption over adsorbent concentration ranges of about two orders of magnitude. The maximum decrease in adsorption (relative to the lowest adsorbent concentration) was about 36% in the FSO<sub>2</sub>-Ca-illite system, while the maximum adsorption increase of 22% was noted in the FSO<sub>2</sub>-Bondhead system. Both of these extremes were obtained at mole fraction values of 10<sup>-6</sup>, which were at or slightly above the upper extremities of the data. More realistic comparisons (similar to those made using the conventional Freundlich K) should be made in the area between the log Z = - 7 and - 8 lines. Using these two lines for comparison, there is no distinct tendency for adsorption to increase or decrease with increasing adsorbent concentrations.

An additional adsorption isotherm was constructed for the parathion-Bondhead system where the adsorbent concentration was varied (using five different weights ranging from 0.5 to 15 g per 30 mL) in order to achieve a range of  $C_e$  values comparable to the other isotherms (Table 1, variable adsorbent concentration). It is interesting to note that the slope of this isotherm falls within the range of the others in the same system. Had the partitioning been increasing significantly with decreasing adsorbent concentration, then the isotherm slope would have been somewhat greater than any of the others, since the higher  $C_e$  values were attained using the lowest adsorbent concentrations.

These data do emphasize the necessity of (i) determining entire isotherms rather than single equilibrium adsorption points, and (ii) comparing these isotherms at more than one solution concentration in order to obtain a balanced view of relative adsorption behavior. Relatively small changes in isotherm slope can produce rather large changes in relative adsorption when being compared over several orders of magnitude, as is shown here.

With many of the more soluble organophosphorus compounds (i.e., parathion, FSO<sub>2</sub>), which have lower soil partitioning coefficients relative to organochlorine insecticides, we have found minimal losses from "blank" insecticide solutions that have been put through the same procedures as their respective sample solutions (unpublished data, this laboratory).

**Table 2. Effect of volume removal/ resuspension on adsorption of parathion and chlorpyrifos by Bondhead sandy loam and Ca-illite suspensions.**

Adsorption system	1st Equilibration		After volume removal	
	Adsorbent conc.	$C_e$	Adsorbent conc.	$C_e$
	mg L <sup>-1</sup>	µg mL <sup>-1</sup>	mg L <sup>-1</sup>	µg mL <sup>-1</sup>
Parathion-Bondhead	1.667 E04	3.16	5.00 E04	2.85
Parathion-Ca-illite	1.667 E04	1.22	5.00 E04	1.22
Chlorpyrifos-Bondhead	8.333 E03	0.112	2.50 E04	0.078
Chlorpyrifos-Ca-illite	8.333 E03	0.123	2.50 E04	0.123

However, such is not the case with dieldrin, where glass adsorption in the blank solutions ranged up to 17% of the initial concentrations. Dieldrin adsorption isotherms derived without properly compensating for this loss produced erroneously large adsorbed-concentration values. However, when using the proper "operational" blank correction for dieldrin, in the 10 mg per

50 mL system, the blank concentrations were consistently less than their respective sample equilibrium concentrations. We found that dieldrin adsorbed strongly on glass surfaces with the adsorption isotherm taking the form

$$X_g = K_g C_s \quad [3]$$

where

$X_g$  = dieldrin removed from solution (glass adsorption + other losses)  $K_g$  = constant ranging from 5 to 20  
 $N_g$  = constant ranging from 0.85 to 1.3  $C_s$  = dieldrin concentration in solution ( $\mu\text{g mL}^{-1}$ )

The amount of glass adsorption of dieldrin was a function of the solution concentration (showing no sign of reaching a maximum within the data range). Since the "blank" solution (no adsorbent) had a greater concentration ( $C_o$ ) than its respective sample solution,  $C_e$ , its dieldrin depletion was also proportionally greater, rendering it useless as a true correction factor.

An attempt was made to use Eq. [3] as a corrective equation substituting  $C_e$  for  $C_s$  and using the  $X_g$  value derived to reduce the "analytical" concentration (of the original stock solution) before being introduced to the "blank" bottles. However, this produced erratic results. It is believed that there was considerable variation in dieldrin adsorption among the various pieces of glassware used, which also accounted for the large range in regression constants ( $K_g$ ,  $N_g$ ) in Eq. [3].

Further glass adsorption studies revealed that very little dieldrin was desorbed by water once it was adsorbed by glass (confirmed by acetone extraction of glass surfaces). Five concentrations of dieldrin (65 mL volume) ranging from 0.02 to 0.136  $\mu\text{g mL}^{-1}$  were tumbled in glass bottles for 24 h, 15 mL was removed for analysis, and a 50-mL aliquot for distilled water was added to the bottles. After a second 24-h period, the solutions were analyzed. Less than 3% of the dieldrin desorbed from the glass into the diluted solution phase. Since desorption was minimal, an alternate adsorption technique was used where the blanks and samples were sequentially equilibrated in the same adsorption bottle (similar to the glass desorption experiment). Triplicate 65-mL aliquots of five dieldrin concentrations were shaken for 24 h, 15-mL aliquots were removed for "blank" analyses, and appropriate amounts of soil (10 or 100 mg) were weighed into each sample bottle, followed by a second 24-h equilibration period. The technique therefore compensated for individual variations in the glass adsorption providing more consistent results. Using this technique (Fig. 1), dieldrin adsorption was actually somewhat less at the lower adsorbent concentration, although these differences may not be of significance. Using such small quantities (10 mg) of natural soil adsorbent tend to exaggerate any small heterogeneities in the adsorbent itself, as well as emphasizing relative errors in measuring the small difference between two similar values,  $C_o$  and  $C_e$ .

These results for dieldrin adsorption are in sharp contrast to those reported by O'Connor and Connolly (11), who found that dieldrin adsorption (partition coefficient) increased at almost the same rate that adsorbent concentration decreased (log partition coefficient vs. log sediment concentration produced almost a  $-45^\circ$  slope). At a  $-45^\circ$  slope, the increase in partition coefficient would have completely offset the decrease in adsorbent concentration, meaning that a 10 mg  $\text{mL}^{-1}$  suspension of montmorillonite would have removed the same amount of dieldrin as a 100 mg  $\text{mL}^{-1}$  or a 10,000 mg  $\text{mL}^{-1}$  suspension. These results seem consistent with the occurrence of a secondary source of dieldrin loss, independent of the adsorbent (i.e., glass), which, while constant in the various systems, would gradually become the dominant portion of the total dieldrin removal as the adsorbent concentration decreased. The "adsorbed dieldrin" concentration (actually dieldrin loss from solution) would exhibit an inverse linear relationship with the adsorbent concentration, since the adsorbent weight was the divisor in the "adsorbed dieldrin" concentration value. Unfortunately, no experimental details of adsorption techniques were provided in this study (11) to substantiate this hypothesis.

Heptachlor was originally selected as the test compound whose adsorption behavior was to have been compared with the adsorption data of O'Connor and Connolly (11). However, the heptachlor disappearance rate (volatility, degradation) was large enough to cause substantial errors in concentration measurements at low adsorbent concentrations, which in turn would have resulted in inflated adsorbed concentration values.

The well-detailed study of Lotse et al. (10) demonstrated an interesting relationship between lindane/sediment ratio and the Freundlich adsorption K value. They reported that as the lindane loading of the sediment increased, the relative adsorption (K) also increased and the Freundlich slope decreased. These results seem somewhat incongruous with the notion of adsorption-site energies, with the most energetic sites being occupied first. These data would imply that adsorption energies were actually increasing with increasing loading levels of lindane.

Their thorough experimental documentation made it possible to recalculate their adsorption data, keeping the adsorbent concentration, rather than the lindane/sediment ratio, constant for each isotherm. When the recalculated K values were plotted vs. adsorbent concentration (Fig. 2), a minimum in the K value occurred at a sediment concentration of 2000 mg  $\text{L}^{-1}$ , with the K value increasing dramatically at lower sediment concentrations. The numbers written above the line indicate the approximate percent removal of lindane for each isotherm. It is estimated that at the lowest adsorbent concentration of 100 mg  $\text{L}^{-1}$  (4 mg per 40 mL), where there was just 5% removal, only a small increase in equilibrium concentration in the order of 0.01  $\mu\text{g mL}^{-1}$  (based on a calculated  $C_e$  value of 0.096  $\text{mL}^{-1}$ ) would have been sufficient to have reduced the K value to the 0.3 value found at 2000 mg  $\text{L}^{-1}$  sediment concentration. Similarly, as the percent removal increased above 50%, at higher sediment concentrations the K value appeared to increase again. It may well be possible that a considerable amount of the variation in K values with changing adsorbent concentration may be ascribed to relative errors associated with measuring a small difference between two large concentrations ( $C_o$ ,  $C_e$ ) at low adsorbent concentrations, or to accurately measuring the small concentration ( $C_e$ ) at very high adsorbent concentrations.

Voice et al. (12) have recently reported that solids concentration seemed to significantly affect the adsorption of several hydrophobic pollutants by Lake Michigan sediments. However, they concluded that "the solids effect appears to result from

the presence of microparticles contributed by the solids and not removed from suspension in the separation procedures." In conclusion, these studies have demonstrated several important points regarding adsorption studies.

1. For those compounds (such as dieldrin) exhibiting strong tendencies to adsorb to glassware, the conventional adsorption blank, used in the batch-type adsorption isotherm, is inadequate to properly compensate for glass adsorption. Adsorbate removal by glass from the blank solution exceeds that from the respective sample because of its higher equilibrium concentration in the blank.

2. For maximum precision in adsorption experiments, it is preferable to adjust the adsorbent concentration so that the percent removed is in the 20 to 80% range. Outside this range, relative measurement errors can become a dominant factor. Systematic minor losses, such as glassware adsorption, may become a dominant factor at low adsorbent concentrations unless special steps are taken, such as the sequential blank/sample procedure outlined earlier.

3. Adsorbent concentration (soil/water ratio) does not appear to significantly affect the partitioning of these pesticides in sediment-water systems, over a fairly wide range of values. Reported solids effects on partitioning may be ascribed to incomplete phase separation during centrifugation or to accumulative relative errors in measuring concentrations as discussed above.

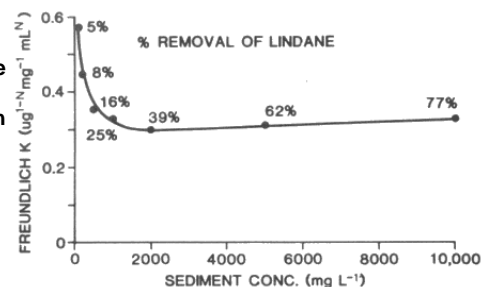
4. The centrifugation process does not appear to change the partitioning of pesticides between the adsorbent and water phases.

## APPENDIX

### Nomenclature of Pesticides Mentioned in Text, Tables, and Figures

<u>Common Name</u>	<u>Chemical Name</u>	<u>Common Name</u>	<u>Chemical Name</u>
Chlorpyrifos	O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate	Lindane	$\alpha$ -1,2,3,4,5,6-hexachlorocyclohexane
Dieldrin	1,2,3,4,10,10-hexachloro-exo-6,7-epoxyl, 4, 4a,5,6,7, 8, 8a-octahydro-1,4-endo, exo-5, 8-dimethanophthalene	Methoxychlor	1,1'-(2,2,2-trichloroethylidene) bis(4-methoxybenzene)
Fensulfothion sulfone	O, O-diethyl O-[p-(methylsulfonyl)phenyl] phosphorothioate	Parathion	O, O-diethyl O-p-nitrophenyl-phosphorothioate
Heptachlor	1,4,5,6,7,8,8-heptachloro-3 $\alpha$ ,4,6, 7 $\alpha$ -tetrahydro-4,7-methanoindene	Picloram	4-amino-3,5,6-trichloropicolinic acid
Hexachlorobiphenyl	2,4,5,2'5'-hexachlorobiphenyl	2,4,5-T	2,4,5-trichlorophenoxyacetic acid

**Fig. 2. The apparent effect of sediment concentration on Freundlich K values for lindane adsorption (recalculated data of Lotse et al., 1968). Numbers above line indicate approximate percent lindane removal for each isotherm.**



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