

The proportion of carbon-14 in the trimethyl phosphite in a mixture of 33 mmoles of trimethyl phosphite and 8.3 mmoles of methanol at equilibrium is

$$\frac{(3)(33)(100)}{(3)(33) + (8.3)} = 92.3\% \text{ of the carbon-14}$$

This calculation is based on the assumption that all the methoxyl groups in the trimethyl are equivalent and that the isotope effect is negligible. The factor of 3 is in the above equation because each molecule of trimethyl phosphite contains 3 methoxyl groups.

The results obtained indicate that exchange was 91% of the equilibrium value.

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INSECTICIDE FORMULATION

Petroleum Fractions as DDT Solvents

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The solubility of DDT in a variety of aromatic petroleum fractions used to prepare emulsifiable concentrates of pesticides has been measured. Both the low boiling, alkylbenzene-type solvents and high boiling, condensed ring aromatic solvents were investigated. These studies show that total aromatics content, molecular weight, and the structure of aromatic compounds determine solvency for DDT. The solubility of DDT decreases as the molecular weight of the alkylbenzenes increases for aromatic isomers of the same type of configuration. For the same molecular weight, the isomers with the ortho arrangement of substituted alkyl groups have the highest solvency for DDT. Naphthalenes are better solvents for DDT than alkylbenzenes. The solvency of pure aromatic compounds for DDT is best described using solubility parameter concepts. Solubility parameter, which considers the solvency effects of both solvent and DDT, qualitatively predicts DDT solubility much better than Kauri Butanol Value or Mixed Aniline Point. Solubility parameter can also be used to describe the solubility of other insecticides. However, additional development is required to make solubility parameter more of a quantitative measure and to provide means for estimating it correctly for commercial solvents.

THE USE of hydrocarbon solvents in the application of pesticides has increased greatly in the past 15 years. Solvents dissolve the pesticide along with an emulsifier to form an emulsifiable concentrate. This concentrate is mixed with water prior to application. In addition to dissolving sufficient quantities of insecticide for effective use, good solvents must also retain the insecticide in solution at low temperatures, since emulsion concentrates may be manufactured during cold weather or carried over from year to year stored in unheated warehouses. Since the solvent comes in direct contact with plants, it must be chosen so as to cause minimum plant damage. This can be accomplished by choosing a solvent with a relatively high evaporation rate so that the time of contact with the plant is minimized, or by

choosing a solvent containing hydrocarbon types that have low phytotoxic activity. The solvent should also have reasonably low odor, good color, and a flash point above 80° F. to minimize flammability (5, 7).

The type of solvent required varies with the insecticide employed. While some toxicants are soluble in practically all petroleum solvents, others such as DDT require selected solvents such as aromatics or ketones. More DDT is produced annually than any other single insecticide. This large and growing use of DDT, coupled with the difficulty of dissolving it, makes specific knowledge of the solubility characteristics of this insecticide particularly important.

There has been a great deal of interest in determining which solvents are most suitable for use in the application of

insecticides. Studies of the solubility of DDT (2, 8) in several pure chemicals and some petroleum fractions of varying aromatic content showed that nitro-cyclohexane and cyclohexanone dissolve the most DDT. Paraffinic hydrocarbon fractions are very poor solvents. Aromatic hydrocarbon fractions are intermediate. Some other ketones are only slightly better than aromatics. Examination of the data on an economic basis (dollars worth of solvent per pound of DDT dissolved) shows that aromatic petroleum fractions are the most economical solvents for DDT.

Two types of aromatic petroleum solvents are available to insecticide formulators. The low boiling or alkylbenzene type has an initial boiling point of from 260° to 325° F. and a final boiling point no greater than 450° F.

Table I. Properties and Composition of Insecticide Solvents

Properties	Solvent	Solvent			
	Xylene	A	B	C	D
Specific gravity 60/60	0.876	0.864	0.877	0.871	0.878
Gravity, °API	30.1	32.2	29.8	31.0	29.7
Kauri Butanol Value	100	95	91	92	90
Mixed Aniline Point, °C.	10.4	14.2	11.9	12.8	16.1
Distillation, ASTM °F.					
IBP	281	265	313	325	326
5%	281	269	322	329	329
10%	282	271	324	331	331
50%	283	277	327	334	335
90%	284	284	334	344	355
95%	285	288	341	352	386
FBP	287	311	410	356	390
Flash, TCC, °F.	81	81	113	112	112
Color, ASTM	1.25	0	0.5	1	1
Sulfur, p.p.m.	3	13	8	13	4
Bromine No.	0.1	0.1	3.8	0.1	0.1
Surface tension, dynes per cm.	28.2	27.8	28.8	28.4	28.9
Composition, Wt. %					
Toluene		21.2			0.1
<i>o</i> -Xylene	18.0	1.1	5.0	4.6	2.6
<i>m</i> -Xylene	47.1	56.0	0.1	0.1	
<i>p</i> -Xylene	11.1	13.0	0.1	0.1	
Ethylbenzene	23.3	8.4	0.1	0.1	
<i>n</i> -Propylbenzene			10.3	5.8	9.1
<i>i</i> -Propylbenzene		0.1	1.5	2.6	3.2
1-Methyl-2-ethylbenzene			2.0	5.3	7.2
1-Methyl-3-ethylbenzene	0.1		16.1	15.2	25.1
1-Methyl-4-ethylbenzene			6.3	7.2	
1,2,3-Trimethylbenzene			14.7	6.7	5.2
1,2,4-Trimethylbenzene	0.1		25.1	29.0	22.7
1,3,5-Trimethylbenzene			3.0	6.4	9.0
C ₁₀ alkylbenzenes			13.8	11.8	9.4
C ₁₁ aromatics			1.7	2.3	7.7
Total aromatics	99.7	99.8	99.8	96.4	98.3

The high boiling type has an initial boiling point which is higher than 325° F. and a final boiling point that can be as high as 650° F. Although not always the case, most high boiling solvents contain significant amounts of condensed ring aromatics (naphthalenes). The low boiling solvents have a faster evaporation rate and are less phytotoxic because they are in contact with the plants for a shorter period of time. However, they are usually more costly. Specially selected petroleum fractions have been shown to be excellent solvents (9) with low phytotoxicity and have been used for many years.

However, these solvents have varied widely in their solvency for DDT, and the reasons for these differences have not been understood. Aside from many studies of methyl-substituted naphthalenes (3, 6, 10, 14) which showed them to be excellent solvents for DDT, there has been very little work comparing the solubility of DDT in the other aromatic hydrocarbons found in petroleum fractions. In addition, Kauri Butanol Value and Mixed Aniline Point have not proved useful in explaining some of the differences which have been observed.

This paper discusses the results of an investigation of the solubility of DDT in various aromatic solvents to explain

some of the differences which exist between commercially available insecticide solvents. The data are examined within the framework of a more recent solvency concept (solubility parameter) to relate the observed differences in solvency to the characteristics of the solvents and DDT.

Experimental Procedure

Since it is difficult to obtain most of the components of insecticide solvents in pure form, the contributions of the aromatic components to DDT solubility were investigated using commercially available solvents of varying known compositions. Typical inspections and composition analyses of the low boiling products are shown in Table I. Analysis of the individual aromatics was done by gas chromatographic or mass spectrometer techniques. Similar data for the high boiling solvents are shown in Table II. In this case, component analyses were obtained by separating the solvent into its aromatic and saturate fractions with silica gel. Composition data for the aromatic fractions were then obtained using mass spectrometer techniques.

Solubility was measured by preparing 100-ml. solutions containing 20, 25, 30, and 35 wt. % technical grade DDT

Table II. Properties and Composition of Insecticide Solvents

Physical Properties	Solvent				
	E	F	G	H	I
Specific gravity 60/60	0.935	0.932	0.916	0.893	0.892
Gravity, °API	19.9	20.3	23.0	27.0	27.2
Kauri Butanol Value	103	105	83	88	90
Mixed Aniline Point, °C.	24.2	32.4	25.2	20.0	18.3
Distillation, ASTM °F.					
IBP	372	403	337	372	364
5%	410	453	368	376	369
10%	421	454	380	377	372
50%	468	485	428	383	379
90%	500	524	438	397	393
95%	505	536	497	408	401
FBP	519	546	516	478	416
Flash, TCC, °F.	150	175	150	153	151
Color, ASTM	1.25	1	1	1.5	1
Sulfur, Wt. %	0.09	0.66	0.01	0.002	0.0006
Bromine No.	8.2	18.6	9.6	8.9	0.2
Surface tension, dynes per cm.	31.4		30.3		29.6
Composition, Wt. %					
Alkylbenzenes	23.5	18.0	46.4	85.4	71.0
Tetralin and indanes	11.4	13.4	13.2	8.1	18.9
Indenes	4.5	4.0	4.0		
Naphthalenes	46.2	38.9	25.1	4.0	4.3
Acenaphthenes	1.7	4.2			
Acenaphthalenes		1.4	0.6		
Tricyclic aromatics	0.3	0.2	0.3		
Total aromatics	87.6	80.1	89.6	97.5	94.2

(99+% *p*, *p'*-dichlorodiphenyltrichloroethane). Three solutions at each concentration level were prepared by dissolving the specified amount of DDT in the solvents at 100° F. in 4-oz. tall form oil bottles. The containers were corked, and a sample of each was placed in one of three constant temperature baths—0°, 40°, and 78° F. Each solution was seeded with "one" crystal of DDT 24 hours after preparation, with care not to agitate the solutions. The solutions were left in the constant temperature baths for an additional 6 days with no agitation. The quantity of crystals present after the 24-hour and 7-day periods was appraised visually and rated on a number scale discussed in Tables III and IV. Observations at the two time intervals provided a measure of storage stability of the solutions as well as initial DDT solubility.

This technique has been utilized in earlier work (9). In both this work and the previous studies, the procedure gave reproducible results. No attempt was made to evaluate the effect of container shape and size or the degree of crystal compaction. Precipitated crystal size appeared to be the same with all solvents.

The results of the solubility measurements are shown in Tables III and IV for the low boiling (alkylbenzene) and high boiling (condensed ring) solvents, respectively. Table III also includes solubility data for the pure xylene isomers and ethyl benzene. These were used to evaluate the solvency of DDT in a

Table III. DDT Solubility—Low Boiling Solvents

Time, Days	DDT, Wt. %	Temp., °F.			Temp., °F.			Temp., °F.			Temp., °F.						
		0	40	78	0	40	78	0	40	78	0	40	78				
		<i>o</i> -Xylene			<i>m</i> -Xylene			<i>p</i> -Xylene			Ethylbenzene			Solvent Xylene			
1	25	1 ^a	1	1	2	1	1	3	1	1	2	1	1	1	1	1	1
1	30	1	1	1	3	1	1	5	1	1	5	1	1	3	1	1	1
1	35	3	1	1	5	1	1	5	1	1	5	1	1	5	1	1	1
7	25	1	1	1	2	1	1	3	1	1	3	1	1	2	1	1	1
7	30	3	1	1	5	1	1	5	1	1	5	1	1	5	1	1	1
7	35	4	2	1	5	1	1	5	3	1	5	4	1	5	3	1	1
DDT solvency rating		0.85			0.60			0.50			0.50						
		A			B			C			D						
1	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	30	3	1	1	3	1	1	4	1	1	5	1	1	5	1	1	1
1	35	5	1	1	5	3	1	5	3	1	5	3	1	5	3	1	1
7	20	2	1	1	1	1	1	2	1	1	2	1	1	2	1	1	1
7	25	3	1	1	3	1	1	4	1	1	4	1	1	4	1	1	1
7	30	5	1	1	5	3	1	5	3	1	5	3	1	5	3	1	1
7	35	5	3	1	5	4	1	5	4	1	5	4	1	5	4	1	1
DDT solvency rating		0.60			0.55			0.50			0.50						

^a 1 = no crystals, 2 = 1 to 10 crystals, 3 = slight precipitate on bottom and sides, 4 = moderate precipitate, clear liquid visible at top, and 5 = thick but not solid.

Table IV. DDT Solubility—High Boiling Solvents

Time, Days	DDT, Wt. %	Temp., °F.			Temp., °F.			Temp., °F.			Temp., °F.			Temp., °F.			
		0	40	78	0	40	78	0	40	78	0	40	78	0	40	78	
1	20	1 ^a	1	1							1	1	1	1	1	1	1
1	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	30	1	1	1	2	1	1	1	1	1	4	1	1	5	2	1	1
1	35	3	1	1				5	4	1	5	4	1	5	4	1	1
7	20	1	1	1							3	1	1	2	1	1	1
7	25	2	2	1	2	1	1	2	2	1	4	2	1	5	2	1	1
7	30	3	3	1	4	4	1	5	4	1	5	3	1	5	3	1	1
7	35	4	4	1				5	5	2	5	5	1	5	5	1	1
DDT solvency rating		0.65			0.60			0.55			0.50			0.45			

^a Same as in Table III.

series of pure alkylbenzenes to examine the effect of molecular structure.

To facilitate comparisons and to provide a simpler means of correlation, a single value, solvency rating, calculated from these data was devised to characterize DDT solubility. Briefly, the numbers resulting from DDT solubility observations at 25 and 30 wt. % DDT, at three temperatures and for both the 1- and 7-day observations, are added. The ratio of a perfect score, 12, to the sum of the solubility observations is defined as solvency rating. It ranges from 0.2 to 1. The larger the number, the higher the solubility of DDT in the solvent. Solvency rating calculated in this manner is reproducible to ±0.05. Consequently, all calculated values are rounded to the nearest 0.05. It should be remembered that such a number combines temperature effects and storage stability into a single value.

Discussion

Effect of Composition. LOW BOILING SOLVENTS. The lowest boiling petroleum fraction which is used as an in-

secticide solvent is xylene. This is because safety and ICC regulations dictate a solvent with a flash point of 80° F. or higher. Commercial xylene is a mixture of the ortho, meta, and para isomers of xylene and ethyl benzene. Since work with resin solutions in the author's laboratories had shown that alkyl benzenes of the same molecular weight have markedly different solvency characteristics (13), an investigation of the solubility of DDT in the isomers of xylene and ethyl benzene was undertaken. The results are shown in Table III. *o*-Xylene is significantly the best solvent for DDT. This particular solvent xylene which contains 18 wt. % of the ortho isomer is about equivalent in solvency to pure *m*-xylene and significantly better than *p*-xylene or ethyl benzene. Marked differences in solvency among C₈ alkylbenzenes have also been observed when these solvents are used to dissolve coating resins (13). However, in this case *o*-xylene has the poorest solvency (produces highest viscosity solutions) for coating resins, a directly opposite effect from the data presented for DDT.

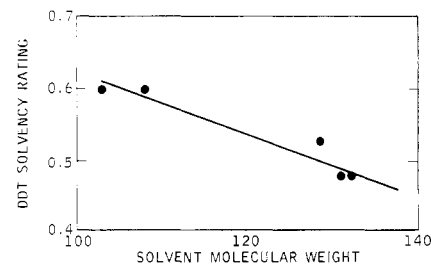


Figure 1. Effect of solvent molecular weight on DDT solvency (low boiling solvents)

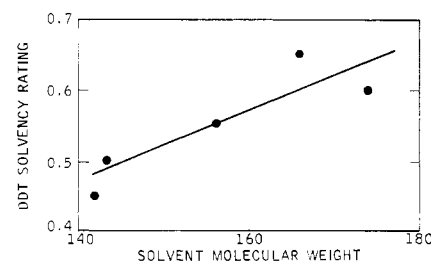


Figure 2. Effect of solvent molecular weight on DDT solvency (high boiling solvents)

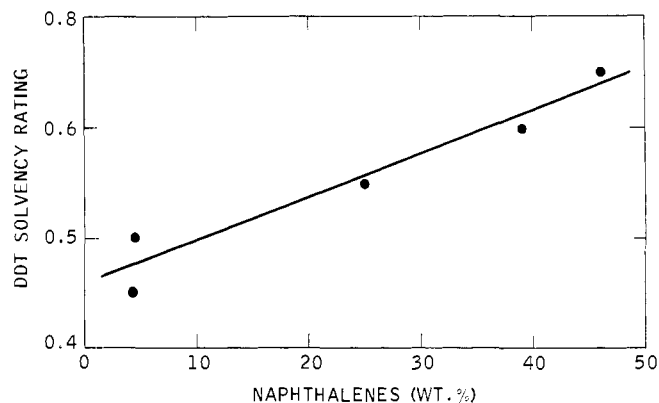


Figure 3. Effect of naphthalene content on DDT solvency (high boiling solvents)

The solvency rating of solvent xylene for DDT is simply additive from the solvency rating of the isomers and their concentrations in solvent xylene. The calculated solvency rating is 0.60, the same as the measured rating.

The solvency of the commercial low boiling solvents for DDT is plotted as a function of solvent molecular weight in Figure 1. These data show that the solubility of DDT in the alkylbenzene solvents varies inversely with solvent molecular weight.

Table I shows that solvent A contains more toluene and less *o*-xylene than solvent xylene. On the basis of molecular weight alone, pure toluene should dissolve more DDT than any of the xylene isomers. While the solvency of toluene was not measured and the literature values are diverse, it was calculated by difference from solvency ratings of the xylene isomers and solvent A to be 0.75. Thus, *o*-xylene with a solvent rating of 0.85 is the best solvent of all the alkylbenzenes investigated. The reasons for this will be discussed in a later section.

Solvent B will dissolve less DDT than solvent xylene or solvent A because of its higher molecular weight. However, it will dissolve significantly more DDT than solvents C and D even though its

molecular weight is only slightly lower. While Table I shows several compositional differences among the three solvents, only the higher concentration of 1,2,3-trimethylbenzene distinguishes solvent B from solvents C and D taken together. The higher solvency of solvent B is probably due then to its higher 1,2,3-trimethylbenzene content. This effect coupled with the good solvency of *o*-xylene suggests that methylbenzenes with the substituted methyl groups arranged adjacently are the best solvents of this class for DDT. This is certainly true for the groups studied in this work and may extend to other alkylbenzenes as well.

HIGH BOILING SOLVENTS. The data in Table IV show that solvent E is the best DDT solvent of all high boiling and low boiling commercial solvents tested. The solvency of the high boiling solvents is plotted as a function of solvent molecular weight and naphthalene concentration in Figures 2 and 3, respectively. DDT solvency increases linearly as molecular weight or concentration of naphthalenes increases. The correlation is much better with naphthalene concentration. Even though molecular weight and naphthalene concentration are not independent, naphthalene concentration seems to be

the more important variable. This result is in line with the findings of previous investigators. Because of the analytical difficulties involved, solvency caused by the individual naphthalenes cannot be separated. Based on the work of others, methyl naphthalenes are presumably the best DDT solvents. In addition to good solvency for DDT, methyl naphthalenes also reportedly exhibit insecticidal activity (17).

Characterization of Solvency. Kauri Butanol Value and Mixed Aniline Point have been used as measures of solvency for a number of years. Figures 4 and 5 show the solvency ratings for all of the commercial solvents evaluated as a function of Mixed Aniline Point and Kauri Butanol Value. These figures show some relationship between DDT solubility and Kauri Butanol Value. In general, higher KB values correlate with better solvency for DDT. However, there seems to be no trend with Mixed Aniline Point. Neither can be used with any degree of reliability.

Table V shows DDT solvency ratings and physical characteristics which have been used to estimate solvency for some pure solvents. For the data shown, the solubility of DDT in low boiling solvents is directly proportional to Kauri Butanol Value. The higher solubility of DDT in *o*-xylene than toluene or the other xylene isomers correlates with Kauri Butanol Value. Mixed Aniline Point does not predict *o*-xylene to be a better solvent for DDT.

Another measure of solvency, solubility parameter, has been used with some success to predict the solvency of a variety of solvents for resins (4, 7). Solubility parameter is an attempt to measure the cohesive forces between molecules of solvent and solute. Both solvent and solute have a solubility parameter value, and the smaller the difference between them the better the solvency of the solvent for that particular solute. Hildebrand and Scott (7) give the complete relationship as

$$\ln X_2 = \ln a_2^s - \frac{V_2 \phi_1^2 (\delta_2 - \delta_1)^2}{RT}$$

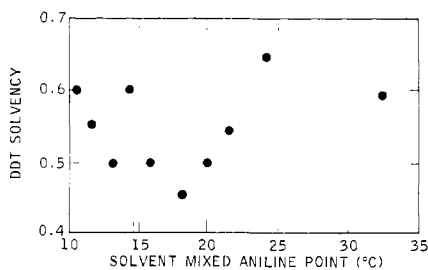


Figure 4. Relationship between solvent Aniline Point and DDT solvency

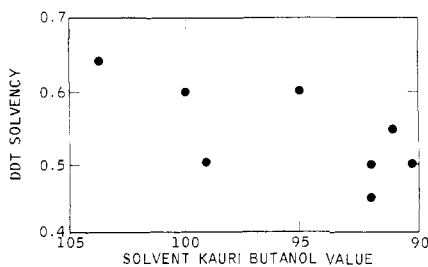


Figure 5. Relationship between solvent Kauri Butanol value and DDT solvency

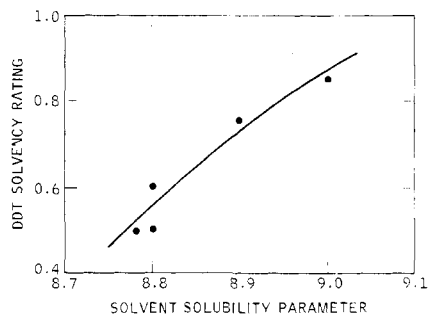


Figure 6. DDT solvency as a function of solubility parameter for toluene and xylenes

Table V. DDT Solvency Ratings and Physical Characteristics of Pure Solvents

Solvent	DDT Solvency Rating	Kauri Butanol Value	Mixed Aniline Point	Solvability Parameter
Toluene	0.75	105	8.9	8.9
<i>o</i> -Xylene	0.85	105.9	10.0	9.0
<i>m</i> -Xylene	0.60	96.9	10.3	8.8
<i>p</i> -Xylene	0.50	92.6	11.0	8.8
Ethylbenzene	0.50	94.8	11.1	8.8
1,2,3-Trimethylbenzene	...	104.6	...	9.1
1,2,4-Trimethylbenzene	...	97	...	8.9
1,3,5-Trimethylbenzene	...	86	...	8.8
Naphthalenes	9.8-10.7
Cyclohexanone	9.9

where

- X_2 = mole fraction of solute in saturated solution,
- a_2^s = activity of solute (in pure state),
- V_2 = molal volume of solute, cc.,
- ϕ_1 = volume fraction of solvent,
- δ_1, δ_2 = solubility parameters of solvent (1) and solute (2),
- R = gas constant,
- T = temperature, °K.

The total forces between molecules of a solvent or solute can include forces other than those represented by the van der Waal's forces of molecular attraction, such as those caused by hydrogen bonding or polarity. Since solubility parameter is a measure only of the molecular forces, it is a simplification on nature and it suffers from an inability to account for the polarity of the highly chlorine-substituted DDT. The solubility parameter of DDT calculated from its structural formula is 10.7. However, the best known solvent for DDT is cyclohexanone, with a solubility parameter of 9.9. Since cyclohexanone is highly polar, this discrepancy is not surprising, illustrating a current deficiency of solubility parameter. To be consistent with other data presented later, the solubility parameter of DDT will be considered to be 10.7.

Figure 6 is a plot of DDT solvency rating of these solvents as a function of solubility parameter. This figure shows that as the solubility parameter of the solvent increases toward that of DDT (10.7), the solubility of DDT increases. From Table V, the solubility parameter of 1,2,3-trimethylbenzene is closer to that of DDT than the other trimethylbenzene isomers. Solubility parameter concepts are consistent with the earlier conclusion that adjacent substitution of methyl groups on the benzene nucleus results in higher solvency than intermittent substitution. The solubility parameter of 1,2,3-trimethylbenzene is

higher than *o*-xylene. This suggests that 1,2,3-trimethylbenzene is probably a better solvent for DDT than *o*-xylene. These data also show that naphthalenes are better solvents for DDT than alkylbenzenes because the difference between the solubility parameters of alkylbenzenes and DDT is greater than the difference between naphthalenes and DDT.

To show the application of solubility parameter concepts to other toxicants, Figure 7 shows the relationship between the solubility of other insecticides and their solubility parameters for the two types of aromatic solvents. Solubility data were taken from published trade literature (7), and solubility parameters were calculated from the structural formulas of the insecticides (4). Unfortunately, it is difficult to calculate the solubility parameters of aromatic solvents. Either surface tension or heat of vaporization measurements coupled with molecular weight is required to calculate solubility parameter. These are difficult to obtain accurately for mixtures of aromatic hydrocarbons. However, the solubility parameters of aromatic solvents are known to be in the range of 8.5 to 10.

Figure 7 shows that insecticides with solubility parameters which are further away from the solubility parameter range of the aromatic solvents are less soluble. The data show that the rate of change of solubility is less with the low boiling solvents. Except in the case of lindane, with its high solubility parameter, the high boiling solvents have higher insecticide solvency. As can be seen from Hildebrand's equation, quoted earlier, the lines in Figure 7 are actually portions of parabola-like curves. The curve for high boiling solvent would peak at approximately 10 solubility parameter and 7 pounds of solvent per gallon of solute. The curve for low boiling solvent will peak at about 9 solubility parameter

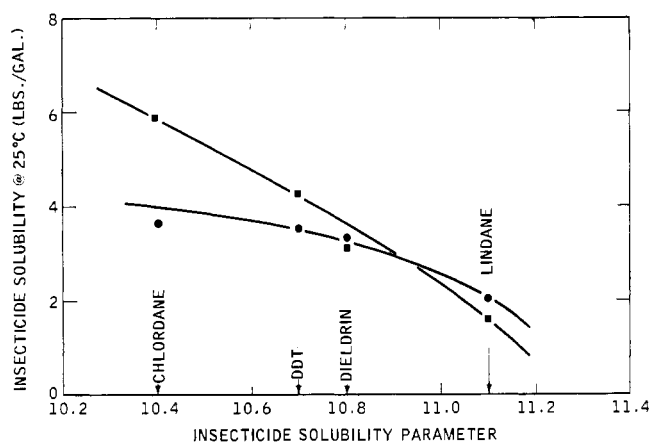


Figure 7. Relationship between insecticide solubility and solvent-insecticide solubility parameter

■, High boiling solvents; ●, low boiling solvents

at the same concentration as the high boiling solvent. Thus, the high boiling solvent curve is steep, due to its proximity to the peak, while the low boiling solvent curve is more gradual. Thus, solubility parameter explains the previously unaccounted for higher solubility of lindane in light alkylbenzenes than in naphthalenes. This reversal of the effect noted in this paper and observed by the industry for DDT is because of the widely different solubility parameters of lindane and DDT.

This effect cannot be explained through Kauri Butanol or Mixed Aniline Point values. These measures include only the properties of the solvent and do not take the solubility characteristics of different solutes into effect. Both solvent and solute properties must be included to predict solvency adequately. Since solute purity can also affect solubility, purity is a significant solute property to be considered.

Before the forces between molecules of solvents and solute can be used to characterize solvency, solubility parameter must be extended to include all forces between molecules. When the polarity of solvent and solute and hydrogen bonding forces can be accounted for in some manner, then molecular forces can quantitatively predict the solubility of insecticides in any solvent. Solubility parameter, as it now stands, performs this function admirably on a qualitative basis. Neither Kauri Butanol Value nor Mixed Aniline Point does even this well.

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INSECT RESISTANCE TO INSECTICIDES

The Enzymatic Degradation of Parathion in Organophosphate-Susceptible and -Resistant Houseflies

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The metabolic fate of parathion and diazinon, in one susceptible and two organophosphate-resistant strains of houseflies, was studied by chromatography and radioisotope techniques. The main interstrain difference resulted from the superior ability of the resistant strains to degrade parathion to diethyl phosphorothionate. The enzyme involved in the degradation process in the strains S and Ka was purified about 30 times by acetone powder formation, DEAE-fractionation, and ethanol precipitation. The partially purified enzyme preparations obtained from all three strains hydrolyzed parathion and diazinon to diethyl phosphorothionate, but their activity in hydrolyzing paraoxon was relatively low. The importance of these interstrain differences in relation to organophosphate resistance is discussed.

STUDIES on insecticide resistance during the past decade have elucidated several mechanisms of resistance in many insect species (3). Biochemical aspects of organophosphate-resistance (OP-resistance) were first studied in the housefly (*Musca domestica*) by March (14), who found the malathion-resistant Stauffer strain to degrade malaaxon in vitro more rapidly than the susceptible individuals. Similarly, Oppenoorth and van Asperen (27) showed the importance of biochemical degradation of paraoxon, diazinon, and malaaxon by demonstrating that, at relatively low concentrations, the speed of disappearance of these toxic phosphates was much faster in homogenates of resistant strains than that in the susceptible strain. They employed a fly head cholinesterase bioassay technique. These authors had already shown by genetic and other means that OP-resistance was very often associated with an abnormally low level of alioesterase activity in the housefly (7). They concluded that the mutant gene which caused the lower alioesterase level

was also responsible for the organophosphate-breakdown enzymes, and that, in fact, the alioesterase became modified to a phosphatase (27, 22).

Meanwhile, Matsumura and Brown (16) studied a malathion-resistant strain of *Culex tarsalis*, which showed no cross-resistance to any organophosphorus compounds other than malathion and its analogs (e.g., malaaxon), and found that it showed a high carboxyesterase activity against malathion. The carboxyesterase found in the resistant strain resembled the carboxyesterase of the susceptible strain in its function and properties, but it was more abundant, so that the resistant mosquitoes had the advantage of hydrolyzing malathion much faster than the susceptible ones (17).

While the balance of evidence at present favors the view that the biochemical mechanisms of resistance, e.g., the elimination of the toxicants by acquired enzymes, is the most effective mechanism of OP-resistance in many insect species, the mechanism in certain instances may be complex. For instance, in the housefly, interstrain differences—i.e., the resistant strain *vs.* the susceptible strain—were also found in the

rate of cuticular absorption (13) and behavioristic avoidance (8).

Extensive studies made by Mengle and Casida (19), and Krueger *et al.* (13), did not reveal important interstrain differences in vivo in the rate of insecticide breakdown, cuticular penetration, phosphorothionate oxidation, or disappearance rate of the actual toxicant phosphate. The main difference which appeared to be related to resistance was in the rate of cholinesterase inhibition which was modified by a "factor" in the thorax and/or abdomen. Since no one has found any indication that the cholinesterase of the resistant housefly is different from the susceptible one in any respect, the "factor" causing the difference in the inhibition rate must be sought elsewhere.

So far, the metabolic fate of these insecticides in housefly strains has been studied mainly in vivo, where a possible difference in the detoxication activity at the vital site of the insects may not always be apparent. Moreover, no attempt has been made to compare the qualitative aspects of organophosphate metabolism in resistant and susceptible houseflies. In the present study, an

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