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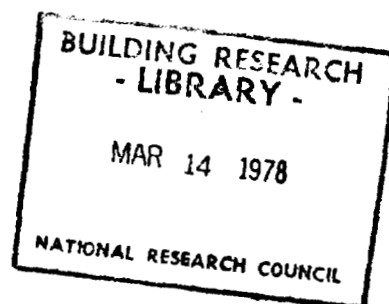
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WATER ABSORPTION IN COATINGS AT DIFFERENT
VAPOUR PRESSURES AND TEMPERATURES

by M Yaseen and H.E. Ashton

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PREFACE

Because exterior coatings are exposed to water in the form of solid, liquid or vapour, the determination of water absorption in coatings at various temperatures and relative humidities is considered important in the prediction of exterior performance. Absorption is affected by the solubility of water in a coating and by the speed with which water diffuses through a coating. Studying the changes in solubility and diffusion coefficients of coatings for water provides an understanding of how absorption is affected by coating composition and climate.

This report describes absorption studies on clear finishes intended for exterior wood. The effects of the two environmental factors on absorption, solubility coefficient and diffusion coefficient are discussed. It is shown that water absorption is affected more by the type of polar groups and their accessibility than by the type and content of oil in the coating. An increase in temperature has much less effect on absorption than increasing humidity.

Ottawa
February 1978

C.B. Crawford
Director, DBR/NRC

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Because exterior coatings are exposed to water in the form of solid, liquid or vapour, the determination of water absorption in coatings at various temperatures and relative humidities is considered important in the prediction of exterior performance. Absorption is affected by the solubility of water in a coating and by the speed with which water diffuses through a coating. Studying the changes in solubility and diffusion coefficients of coatings for water provides an understanding of how absorption is affected by coating composition and climate.

This report describes absorption studies on clear finishes intended for exterior wood. The effects of the two environmental factors on absorption, solubility coefficient and diffusion coefficient are discussed. It is shown that water absorption is affected more by the type of polar groups and their accessibility than by the type and content of oil in the coating. An increase in temperature has much less effect on absorption than increasing humidity.

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a relatively long time to reach the absorption equilibrium state. Vapours that do not interact with the coating material cause no swelling and attain equilibrium in a fairly short period; they are considered to be inert with respect to the material. As a general rule, polar materials have more affinity for polar vapours, and their absorption of non-polar vapours follows the rule applicable to inert vapours. Molecular structure also affects absorption. Loosely packed chain structures absorb more vapour than well cross-linked and packed systems (2). The degree of crystallinity of a polymer is another controlling factor (3).

Water absorption differs only in degree from that of organic solvents owing to the fact that water molecules are relatively small and strongly associated through hydrogen bond formation. Absorption of water in a polymer depends on the nature of the polar groups as well as their position in the chain. The accessibility of the polar groups, the relative strength of water-water versus water-polymer interaction and crystallinity are important factors. Polymers having well-defined crystallites have restricted accessibility to water molecules, whereas polar groups promote absorption. No simple correlation exists, however, among these factors and amount of absorption (4).

The amount of vapour sorbed as a function of relative vapour pressures at a constant temperature is represented by absorption isotherms. Absorption of vapours in polymers generally follows one of three types of absorption isotherm: in the first, absorption is strictly linear at all relative pressures; in the second, absorption continuously increases with pressure; the third type is essentially a combination, following the first type at low pressure and the second at high pressures.

Solubility Coefficient

Absorption of a mobile phase in a solid is a process of distribution and mixing associated with a change in the entropy level. It is governed by the Van der Waal's forces acting at intermolecular surfaces. Because absorption involves a change in entropy, the total free energy of the solid phase and intermolecular forces determine the extent of absorption. The absorption of a mobile phase (vapour or liquid) having a definite total free energy therefore differs from one polymer to another.

Usually, where absorption of vapour in a polymer is relatively low or the vapour pressures are not high, Henry's law is obeyed (5); at equilibrium, the concentration of the vapour absorbed in the polymer, c , is directly proportional to its partial pressure, p , that is

$$C = Sp$$

(1)

The solubility coefficient is often constant at low relative vapour pressures. When factors like concentration, time, or temperature of absorption of vapour in a polymer are increased, the process deviates from Henry's law and the value of the solubility coefficient changes accordingly. It can then be expressed in terms of the activity of the vapour

$$S_a = C/a_1 \quad (2)$$

with $a_1 \approx p/p_0$, the relative vapour pressure being an approximation of vapour activity.

Relation of Solubility and Permeability Coefficients

On differentiation with respect to x , equation (1) becomes

$$\frac{dc}{dx} = S \frac{dp}{dx} \quad (3)$$

Under conditions in which Fick's first law holds good, the flux Q of the diffusing vapour is proportional to the concentration gradient (6)

$$Q = -D \frac{dc}{dx} \quad (4)$$

where D is the diffusion coefficient. Equation (4) can be expressed as

$$Q = -DS \frac{dp}{dx} \quad (5)$$

or

$$Q \int_0^L dx = -DS \int_{p_1}^{p_2} dp \quad (6)$$

therefore

$$QL = DS (p_1 - p_2) \quad (7)$$

When rate of permeation is steady, the quantity of vapour, Q , permeating in unit time through unit area of film thickness L under a vapour pressure differential $(p_1 - p_2)$ is

$$Q = P \frac{P_1 - P_2}{L} \quad (8)$$

where P is the permeability coefficient.

$$\text{Thus} \quad P = DS \quad (9)$$

Effect of Temperature on Solubility Coefficient

In equation (9) both D and P represent movement of vapours in or through a solid, while S represents the amount of the vapour absorbed by a solid. Generally, a rise in temperature accelerates the rate of movement, so that the values of the rate-dependent constants P and D increase. Absorption, because it follows the principles applicable to solutions, is not directly affected by temperature and any increase with a rise in temperature is due to activation of absorption sites. The effect of temperature on the solubility coefficient over a small temperature change can, however, be represented by an Arrhenius-type expression

$$S = S_0 e^{(-\Delta H_s/RT)} \quad (10)$$

where S_0 is a pre-exponential function and ΔH_s is the apparent heat of solution (absorption) (7). As the process of absorption of vapour by a polymer is considered to occur in two stages - condensation of vapour, then mixing and solution in the solid phase - ΔH_s can be expressed in terms of molar heat of condensation ΔH_c and the partial molar heat of mixing ΔH_m

$$\Delta H_s = \Delta H_c + \Delta H_m \quad (11)$$

Generally, vapours with low absorption activities (ideal gases) hardly condense on the absorption sites and their ΔH_c is negligible. In such cases ΔH_s is essentially equivalent to ΔH_m , which is usually small and positive. Solubility coefficients of such vapours therefore increase slightly with temperature. On the other hand, vapours that condense easily (H_2O , NH_3 , solvents) usually have negative ΔH_s values owing to the heat of condensation. For this reason solubility coefficients of easily condensable or high absorption-activity vapours decrease with increasing temperature (8, 9).

Absorption by Coatings

Water absorption is considered to be an important property because exterior coatings remain in contact with water in the form of rain or high humidity at various temperatures. It has been observed in studies of water vapour permeation (1) that both permeation rates and permeability coefficient are affected by temperature and relative humidity as well as by the composition of the coating. The study of the effect of vapour pressure and temperature on absorption of water in organic coatings was therefore considered to be of some practical importance. This paper reports how water absorption, diffusion coefficient and solubility coefficient of coatings respond to changes in vapour pressure or temperature.

EXPERIMENTAL

Apparatus

The traditional method of measuring absorption by immersing free films of a coating in water has certain limitations and cannot be used for studying water absorption at different relative humidities and temperatures. The quartz spring balance (10) modified for use with building materials (11) does not have these limitations and has been used in this and previous work (1, 12).

Materials

Twelve paraphenyl-phenolic resin varnishes and 10 alkyds upon which permeability measurements had been made (1) were used in this work. Their formulations are summarized in Table I.

Procedure

The specific gravities of the dried films were determined in accordance with ASTM Method D1963, using Hubbard-type pycnometers (Table I).

Four pieces (each about 30 by 70 mm) of a sample were placed on a triangular platinum wire loop, allowing free access of vapour to all surfaces. The loop was then suspended from a spring in a glass tube. Four such tubes were fixed on each of two absorption units. The test samples were evacuated to constant weight, then subjected to several cycles of absorption at 99 per cent RH and desorption at 0 per cent RH. This operation has been found necessary for removing traces of solvent trapped in the dried film (12).

The amount of water absorbed in the free film of a coating under the condition of equilibrium was calculated as the per cent by weight of water absorbed at a given relative vapour pressure (relative humidity). The solubility coefficient denotes the amount of water (g) absorbed in unit volume of the coating (cm^3) when the vapour pressure is 1 mm of mercury.

RESULTS AND DISCUSSION

The coatings under study contain a fairly high proportion of either a drying or a semi-drying oil. As some partially reacted oil or other active ingredients are present, the coatings develop relatively greater affinity for water, especially in humid environments, and may exhibit some hydrophilic characteristics. In such cases the increase in water absorption and the dimensional changes in a coating depend mainly on the relative vapour pressure (humidity) and the nature and position of polar groups in the structure.

Water Absorption and Solubility Coefficient

Phenolics: The amount of water absorbed and the resulting solubility coefficients are shown in Tables II to IV. As illustrated in Figure 1, water absorption by these coatings is an approximately linear function of relative vapour pressure in accordance with Henry's Law up to about 60 to 70 per cent RH. The solubility coefficients shown in Figure 2 deviate from being parallel to the RH axis at higher relative humidities. This deviation is believed to be the result of hydration of some polar groups present in the coating, illustrating the concentration dependence of absorption in phenolics.

Examination of the results indicates that the higher oil content phenolics absorb relatively more water. The effect of relative humidity on their solubility coefficients is also greater at high relative vapour pressure than for the lower oil content phenolics (Figure 3). Because of greater cross-linking with the resin, tung phenolics absorb less water than their counterparts based on other oils, although at 58.3 per cent oil content the differences between tung and linseed are not significant. Consequently, their solubility coefficients are affected less by the high activity of water. Differences in water absorption values or solubility coefficients with respect to oil contents and oil types are, however, not great. By contrast, oil content or oil type markedly affected the rate of water vapour permeation and the tensile properties of these phenolics (1, 13).

Alkyds: As stated, absorption depends on the chemical configuration of the constituents and their position in the molecular structure of the coating material. As a product of oil, phthalic anhydride, polyol and other ingredients, a conventional alkyd has relatively more active areas to absorb water than has a phenolic. The values given in Table V show that at 50 per cent RH most alkyds absorb twice as much water as do phenolics, and that above 90 per cent RH the ratio becomes almost 3. This indicates that partially reacted ingredients in these alkyds retain some of their polar groups, causing alkyd coatings to exhibit hydrophilic characteristics in a humid environment.

The solubility coefficients of alkyds (Table VI), unlike those of phenolics, show a regular increase in value with increasing relative humidity, the relation being essentially linear for most of the alkyds studied (Figure 4). The extent of the deviation of the plots from the

RH axis indicates the degree of hydration of polar groups that may cause swelling and dimensional changes in the coating. One interesting feature is that the plots indicate that orthophthalic alkyds are more hydrophilic than isophthalic alkyds, although the oil contents of the latter are higher. As both types are commercial products and all of their constituents are not known, this feature can be correlated at present only with the phthalic isomer used in the formulation.

Water absorption in alkyds 912, 913 and 914 decreases with oil content, but this relation does not hold good for other orthophthalic alkyds or for isophthalic alkyds; in other words, oil content may not be the major factor responsible for water absorption in these alkyds. Apart from oil content, water absorption in alkyds is probably affected mainly by polyol content and the extent of the reaction.

Plots in Figure 5 of solubility coefficients for some alkyds and phenolics illustrate the differences in water absorption characteristics of these coatings. Oil content in soya phenolics 1022 and 1023 or in alkyds E4 and E6 does not cause much difference in the solubility coefficients of materials of the same type, but there is a large difference between the two types of coating. Although linseed phenolic 1021 (Figure 3) and alkyd 1055 (Figure 5) have similar oil contents, they show a relatively large difference in their solubility coefficients. These observations indicate that water absorption in coating materials depends more on the nature of the polar groups and their accessibility to water than on the type and content of oils in the coatings.

Influence of Water Absorption on Permeability and Diffusion Coefficients

In the process of permeation, vapour at the high pressure side is absorbed, then diffuses to the low pressure side where it is desorbed. Permeation, which describes the continuous flow of vapour from high to low pressure, is therefore directly proportional to the rate of diffusion, which maintains the concentration of the permeant in the coating at the absorption equilibrium level. The period required to establish absorption equilibrium within the system depends on the rate of diffusion of the condensed vapour through the absorbing sites in the coating and on the affinity between the mobile and solid phases. Once the absorption equilibrium of the mobile phase in the coating has been attained, permeation is a steady-state flow process. This indicates that the time for the steady state of permeation is equivalent to the time required for the system to attain absorption equilibrium while temperature and vapour pressure are constant.

The water retained in the coating under the condition of absorption equilibrium acts as a plasticizer for the movement of segments of the polymer molecules. This is the reason why, in cases where relatively more water is absorbed at high relative pressures (because of some physical interaction between water and the polar groups), the permeability coefficient of the coating for water vapour increases with a rise in relative humidity. In other words, the permeability coefficient of a coating is partly controlled by the coefficient of diffusion and partly by the amount of mobile phase retained in the coating at absorption equilibrium.

In previous work (1) it was shown that the permeability coefficients of phenolics are only slightly affected by increasing relative humidity while those of alkyds are moderately affected. The theoretical values of water diffusion coefficients of 20-gallon phenolics were calculated from the known values of their solubility and permeability coefficients at 73°F (22.8°C) and different relative humidities (Table VII). The plots of diffusion coefficients as a function of relative humidity are straight lines with a slight inclination towards the RH axis (Figure 6). With alkyds, permeability and absorption determinations were made at only one relative humidity, at the same temperature. In the other cases, although the humidities were the same at each level, temperature varied somewhat for the two determinations. The temperatures were comparable enough, however, to permit approximate calculation of the alkyd diffusion coefficients, which were found to behave in a similar manner to those of phenolics. This feature indicates the small effect of relative humidity on the values of D and suggests that the increase in permeability coefficients can be attributed to an increase in solubility coefficients at high relative humidities.

Effect of Temperature on Water Absorption

Absorption of water takes place in two stages: condensation of vapour on the surface, and its distribution (mixing) to the active sites within the coating until it attains a state of absorption equilibrium. This shows that absorption is mainly governed by heat of condensation and by the activities of the mobile and solid phases, and that it is independent of rate because it is expressed as absorption at equilibrium. Change in temperature does activate absorption sites, but it is not so significant as for rate dependent phenomena. Although the activity of the vapour condensed in the coating increases with a rise in temperature, the amount absorbed in a coating under equilibrium at a particular relative pressure does not change much with temperature.

The per cent water absorbed by four 20-gallon phenolics at four different temperatures (Table VIII) shows a limited linear increase with temperature. This indicates that the effect of temperature on absorption is directly proportional to the extent of activation of the groups responsible for absorption and on their physical interaction with water molecules. Observations of the relation between temperature and water absorption for alkyds (Table IX) show that alkyds have relatively more polar groups than phenolics and are affected more by temperature. The difference between the extent of activation of the groups can be estimated in Figure 7 from the ratio between the slopes of the plots for water absorption versus temperature for phenolics and alkyds - about 1:1.7. This ratio could also be used as an approximate measure of the activity of polar groups in the alkyds and phenolics studied here with respect to water molecules.

The fairly high level of water absorption and the relatively large differences from one type of coating to another show that absorbed water is in the form of condensed vapour or liquid. If water were present only as vapour, the amount would not be sufficient to distinguish between

coatings. There is, therefore, a physical mixture of two phases, and the affinity of water molecules for the active groups in the coating and the level of their physical interaction can be considered mainly responsible for the effect of temperature on absorption. If there are no strong physical interaction forces between water molecules and the chemical groups in the coating, the thermodynamics of water absorption at low relative humidities can be described by theories applicable to solutions.

Effect of Temperature on Water Solubility, Permeability, and Diffusion Coefficients of a Coating

The solubility coefficient is directly proportional to the capacity of a coating to retain a certain amount of water in a condition of absorption equilibrium, whereas the diffusion and permeability coefficients depend on the structural configuration of the coating and the migration of the mobile phase through it. With condensable vapours the heat of solution, ΔH_s (coming mostly from the heat of condensation, ΔH_c , equation (11)), is usually negative. The temperature dependence of the solubility coefficient of a coating for such vapour is therefore a function of the degree of condensability of the vapour. Because water is a fairly condensable vapour, there is a significant decrease in the water solubility coefficients of coating materials with an increase in the temperature of the environment. Figure 8 shows that the solubility coefficients decrease sharply with increasing temperature, although the per cent water absorbed by phenolics and alkyds increases slightly with temperature.

Vapour condensed at the surface has a tendency to move into the coating under a pressure differential. As diffusion and permeation are rate dependent phenomena, the vapour needs energy in addition to that of the heat of solution for its movement through the coating. This energy is principally supplied by the thermal movement of the molecules and this is increased by a rise in the temperature of the system. Diffusion and permeation, being thermally activated processes, are therefore considerably influenced by changes in temperature.

The values presented in Table X for phenolics and in Table XI for alkyds show the effect of temperature on permeation and diffusion coefficients, with the latter illustrated in Figure 9. As with humidity, the permeability coefficients of phenolics do not change markedly with temperature, but those of alkyds are more affected. The diffusion coefficients of both increase rapidly because permeation and diffusion are rate dependent; and because the solubility coefficient is rate independent, it decreases with increasing temperature.

For a particular class of coating, permeability coefficients are affected by oil content or type in the coating, but within each class the solubility coefficients are approximately the same; e.g., 893 versus 1022 for phenolics (Tables VIII and X) and E4 versus 1056 for alkyds (Tables IX and XI). The diffusion coefficient does not appear to be related to the class of coating because soya iso-alkyd E6 has a much lower diffusion coefficient than the corresponding soya phenolic 1022.

CONCLUSIONS

The amount of water absorbed by phenolic varnishes increases linearly up to 60 per cent RH; below this value their solubility coefficients are relatively unaffected by relative humidity. Although those containing slower drying oils or more oil absorb more water, especially at higher relative humidities, than the short oil tung and linseed varnishes, the differences are not so great as for permeation rates. The same is true when solubility coefficients are compared with permeability coefficients. These results show that phenolic varnishes contain only a relatively small proportion of polar groups attractive to water. Increasing oil content has little effect on polar group concentration, but it does reduce the compactness and rigidity of the film structure, thereby increasing permeation.

Alkyds, on the other hand, absorb twice as much water as phenolics at 50 per cent RH and their solubility coefficients are markedly affected by relative humidity. This is considered to be evidence of the hydration of polar groups in the alkyd molecule. It is known that all the carboxyl and hydroxyl groups are not reacted during alkyd preparation for fear of gelling the alkyd through too much cross-linking. The reason that water absorption is not always directly related to phthalic or oil content is that some alkyds contain a greater amount of excess polyol, which would have a greater effect on absorption.

Diffusion coefficients of both phenolics and alkyds are not affected by relative humidity. Consequently, change in permeability coefficients with relative humidity is due to an increase in the solubility coefficients. Higher solubility leads to greater absorption of water, which acts as a plasticizer and promotes permeation.

An increase in temperature has much less effect on water absorption than an increase in relative humidity. The size of the temperature effect shows that the increase in absorption is the result of temperature activation of absorption sites. The rate of change for alkyds is about 1.7 times that for phenolics.

Conversely, diffusion coefficients increase markedly with temperature but appear to be unrelated to class of coating. Owing to the negative heat of solution of condensable vapours, the solubility coefficients of coatings for water decrease with increasing temperature. The permeability coefficient, P , the product of D and S , therefore increases less than D .

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TABLE I

COMPOSITION OF CLEAR FINISHES

Para-Phenylphenolic Varnishes

NRP Formula No.	Oil Content			Composition of Volatile Content Per Cent		Varnish Properties		Density of Dry Film
	Type	Approx Length	Per Cent of Solids	Aromatic Solvent	Mineral Spirits	Per Cent Solids	G - H Viscosity	g/ml
1020	Tung	15	58.3	85.3	14.7	51	A-B	1.166
893	Tung	20	66.7	33.3	66.7	50	C	1.140
894	Tung	30	75	10.0	90.0	50	D	1.124
901	Tung	40	80	-	100.0	50	B-C	1.106
1021	Linseed	15	58.3	49.4	50.6	49.5	D	1.166
902	Linseed	20	66.7	30.6	69.4	51	B-C	1.138
903	Linseed	30	75	20.2	79.8	49.5	D	1.127
905	Linseed	40	80	10.0	90.0	50	C-D	1.119
1022	Soya	20	66.7	28.6	71.4	50	B	1.131
1023	Soya	40	80	34.7	65.3	50	C-D	1.087
1024	DH Castor	20	66.7	33.3	66.7	50	C	1.132
1025	DH Castor	40	80	2.6	97.4	49	E	1.109
Alkyds								

NRP Formula No.	Oil Content		Per Cent Phthalic Content		Solution Characteristics		Density of Dry Film
	Type	Per Cent of Solids	Isomer	Per Cent of Solids	Per Cent Solids	G - H Viscosity	g/ml
912	Soya	59.4*	Ortho	25	50	A-B	1.112
913	Soya	62.5*	Ortho	24	50	A-B	1.107
914	Soya	56 *	Ortho	30	50	D-F	1.120
915	Soya	48 *	Ortho	35	42	E	1.184
916	Soya	39.6*	Ortho	39	40	G-H	1.202
1055**	Linseed	54	Ortho	35	50	A-B	1.130
1056**	Soya	56.5	Ortho	31	50	A-B	1.120
E4	Soya	75	Iso	18	50	C-D	1.060
E5	Soya	72	Iso	20	50	C-D	1.080
E6	Soya	67	Iso	28	50	C-D	1.092

* Per cent oil content calculated from reported fatty acid content.
Other commercial alkyds are the reported oil content.

** Prepared in laboratory.

WATER ABSORPTION OF 20-GAL PHENOLICS AT DIFFERENT RELATIVE HUMIDITIES
(Absorption in per cent by weight)

Relative Humidity at 20.1°C	Relative Humidity at 22.8°C				Relative Humidity at 25.1°C			
	893 Tung	902 Linseed	1022 Soya	1024 DH Castor	893 Tung	902 Linseed	1022 Soya	1024 DH Castor
21.3	0.184	0.192	0.190	0.192	0.218	0.233	0.229	0.236
35.3	.305	.327	.324	.322				
47.5	.409	.440	.442	.424				
59.6	.502	.556	.585	.556	50	.448	.480	.483
70	.596	.666	.677	.673	57.5	.501	.537	.539
76	.673	.748	.764	.741	70	.616	.680	.683
80.6	.716	.792	.814	.790	80	.734	.795	.812
89.3	.853	.909	.928	.949				
					90	.860	.925	.940
97.5	.971	1.048	1.050	1.087	97	.950	1.040	1.051

TABLE III

WATER ABSORPTION OF PHENOLICS AT DIFFERENT RELATIVE HUMIDITIES

Relative Humidity at 20.3°C	15 Gal			30 Gal			Relative Humidity at 20.4°C	40 Gal				
	1020 Tung	1021 Linseed	894 Tung	903 Linseed	901 Tung	905 Linseed		1023 Soya	1025 DH Castor			
25.7	0.214	0.195	0.227	0.235	25.3	0.241	0.253	0.252	0.236			
50.9	.424	.387	.451	.486	48.9	.475	.491	.458	.457			
70.1	.585	.561	.656	.703	67.4	.680	.743	.671	.678			
81.1	.694	.650	.804	.850	81.8	.908	.954	.888	.894			
					87.6	.972	1.086	1.041	1.010			
88.3	.755	.728	.909	1.006	94	1.071	1.211	1.164	1.112			
95.2	.811	.785	.961	1.109	97	1.144	1.276	1.277	1.191			
97.5	.871	.863	1.015	1.173								

TABLE IV

EFFECT OF RELATIVE HUMIDITY
ON SOLUBILITY COEFFICIENT OF PHENOLIC VARNISHES

Solubility Coefficient $\times 10^4$ g/cm³/mm Hg*

Oil Length					20 gal				
Relative Humidity at 20.1°C	893 Tung	902 Linseed	1022 Soya	1024 DH Castor	Relative Humidity at 22.8°C	893 Tung	902 Linseed	1022 Soya	1024 DH Castor
21.3	5.59	5.82	5.72	5.79	25.1	4.75	5.08	4.95	5.12
35.3	5.59	5.98	5.88	5.85					
47.5	5.56	5.98	5.96	5.77	50	4.90	5.25	5.09	5.25
					57.5	4.77	5.10	4.98	5.09
59.6	5.45	6.02	6.29	5.99	70	4.82	5.32	5.19	5.31
70	5.51	6.13	6.20	6.17					
76	5.72	6.35	6.45	6.26	80	5.03	5.44	5.46	5.52
80.6	5.75	6.34	6.47	6.29					
80.3	6.17	6.57	6.66	6.82	89.9	5.24	5.62	5.57	5.68
					97	5.37	5.78	5.83	5.90
97.5	6.43	6.93	6.90	7.15					
Relative Humidity at 20.3°C					Relative Humidity at 20.4°C				
15 gal					40 gal				
1020 Tung	1021 Linseed	894 Tung	903 Linseed		901 Tung	905 Linseed	1023 Soya	1025 DH Castor	
25.7	5.41	4.96	5.56	5.77	25.3	5.86	6.22	6.07	5.76
50.9	5.40	4.97	5.58	6.03	48.9	5.98	6.26	5.71	5.77
70.1	5.41	5.22	5.89	6.33	67.4	6.21	6.86	6.07	6.20
81.1	5.55	5.85	6.24	6.62	81.8	6.84	7.26	6.60	6.74
					87.6	6.82	7.72	7.23	7.11
88.3	5.55	5.39	6.47	7.19	94	7	8.02	7.49	7.30
95.2	5.53	5.39	6.35	7.35	97	7.26	8.19	8.01	7.58
97.5	5.80	5.77	6.55	7.59					

* Vapour pressure

TABLE V

EFFECT OF RELATIVE HUMIDITY ON WATER ABSORPTION OF ALKYDS AT 20.0°C (68°F)

Relative Humidity %	Water Absorption - Per Cent									
	Orthophthalic						Commercial Isophthalic Soya Alkyds			
	Commercial Soya Alkyds			Lab prepd						
	912	913	914	915	916		1055 Linseed	1056 Soya	E4	E5 E6
50.2	1.159	1.200	1.121	1.181	1.079		1.141	1.044	1.090	1.151 1.021
60	1.499	1.640	1.441	1.532	1.460		1.540	1.384	1.401	1.481 1.320
69.7	1.861	2.121	1.800	1.901	1.881		1.999	1.763	1.741	1.841 1.640
80	2.291	2.641	2.219	2.316	2.340		2.480	2.203	2.125	2.243 2.001
90	2.770	3.218	2.659	2.811	2.799		2.991	2.653	2.564	2.722 2.400
97.5	3.170	3.745	3.039	3.220	3.159		3.360	3.005	2.923	3.101 2.701

TABLE VI

EFFECT OF RELATIVE HUMIDITY ON SOLUBILITY COEFFICIENT
OF ALKYDS FOR WATER AT 20.0°C (68°F)

Relative Humidity %	Solubility Coefficient - $S \times 10^4$ g/cm ³ /mm Hg									
	Orthophthalic						Isophthalic Commercial Soya Alkyds			
	Commercial Soya Alkyds						Lab Prepd			
	912	913	914	915	916		1055 Linseed	1056 Soya	E4	E5 E6
50.2	14.65	15.09	14.26	15.89	14.74		14.65	13.28	13.12	14.13 12.67
60	15.85	17.26	15.34	17.24	16.68		16.54	14.74	14.12	15.21 13.71
69.7	16.94	19.22	16.50	18.42	18.50		18.49	16.16	15.11	16.28 14.66
80	18.18	20.87	17.74	19.57	19.64		20.00	17.62	16.08	17.29 15.59
90	19.52	22.57	18.87	21.09	21.32		21.41	18.83	17.23	18.63 16.61
97.5	20.62	24.24	19.90	22.30	22.20		22.21	19.68	18.12	19.59 17.25

TABLE VII

EFFECT OF RELATIVE HUMIDITY ON DIFFUSION COEFFICIENT OF PHENOLICS
CALCULATED FROM KNOWN VALUES OF P AND S AT 22.8°C (73°F)

Relative Humidity %	Permeability Coefficient* $P \times 10^{12}$ g/cm/s/mm Hg				Diffusion Coefficient $P/S^{**} = D \times 10^9$ cm ² /s			
	893	902	1022	1024	893	902	1022	1024
50	4.53	5.07	7.48	6.23	9.25	9.66	14.70	11.87
57.5	4.61	5.08	7.49	6.31	9.67	9.96	15.04	12.40
70	4.53	5.11	7.62	6.27	9.40	9.61	14.68	11.81
80	4.52	5.14	7.86	6.37	9.00	9.45	14.40	11.54
87	4.65	5.17	8.16	6.52	9.00	9.30	14.76	11.62
97	4.84	5.58	8.30	6.75	9.01	9.65	14.24	11.44

* from Table 10 of Report 430

** from Table IV

TABLE VIII

EFFECT OF TEMPERATURE ON WATER ABSORPTION AND
SOLUBILITY COEFFICIENT OF PHENOLICS AT 50 PER CENT RH

Temperature °F (°C)	Water Absorption - Per Cent				Solubility Coefficient $S \times 10^4$ g/cm ³ /mm Hg			
	893	902	1022	1024	893	902	1022	1024
53 (11.7)	0.412	0.449	0.447	0.440	9.15	9.95	9.85	9.70
63 (17.2)	.426	.467	.461	.452	6.61	7.23	7.10	6.96
73 (22.8)	.448	.480	.468	.483	4.90	5.25	5.09	5.25
83 (28.3)	.452	.492	.491	.500	3.57	3.88	3.84	3.91

TABLE IX

EFFECT OF TEMPERATURE ON WATER ABSORPTION
AND SOLUBILITY COEFFICIENT OF ALKYDS AT 50 PER CENT RH

Temperature °F (°C)	Water Absorption - Per Cent				Solubility Coefficient - $S \times 10^4$ g/cm ³ /mm Hg			
	E4	E5	E6	1056	E4	E5	E6	1056
53 (11.7)	1.058	1.119	0.991	1.013	21.84	23.53	21.07	22.09
63 (17.2)	1.073	1.132	1.006	1.029	15.47	16.64	14.94	15.68
73 (22.8)	1.100	1.156	1.031	1.056	11.20	12.00	10.81	11.36
83 (28.3)	1.123	1.181	1.057	1.080	8.23	8.82	7.99	8.37

TABLE X

EFFECT OF TEMPERATURE ON DIFFUSION COEFFICIENT OF PHENOLICS
CALCULATED FROM KNOWN VALUES OF P AND S AT 50 PER CENT RH

Temperature °F (°C)	Permeability Coefficient $P \times 10^{12}$ g/cm/s/mm Hg				Diffusion Coefficient $P/S = D \times 10^9$ cm/s			
	893	902	1022	1024	893	902	1022	1024
63 (17.2)	3.88	3.93	5.88	4.80	5.87	5.44	8.28	6.90
73 (22.8)	4.53	5.07	7.48	6.23	9.25	9.66	14.70	11.87
83 (28.3)	4.73	5.42	8.87	6.82	13.25	13.97	23.10	17.44

TABLE XI

EFFECT OF TEMPERATURE ON DIFFUSION COEFFICIENT OF ALKYDS
CALCULATED FROM KNOWN VALUES OF P AND S AT 50 PER CENT RH

Temperature °F (°C)	Permeability Coefficient $P \times 10^{12}$ g/cm/s/mm Hg				Diffusion Coefficient $P/S = D \times 10^9$ cm ² /s			
	E4	E5	E6	1056	E4	E5	E6	1056
63 (17.2)	11.15	9.05	7.10	6.20	7.21	5.44	4.75	3.95
73 (22.8)	12.64	10.49	8.54	7.23	11.29	8.74	7.90	6.36
83 (28.3)	14.55	12.29	10.36	8.38	17.68	13.93	12.97	10.01

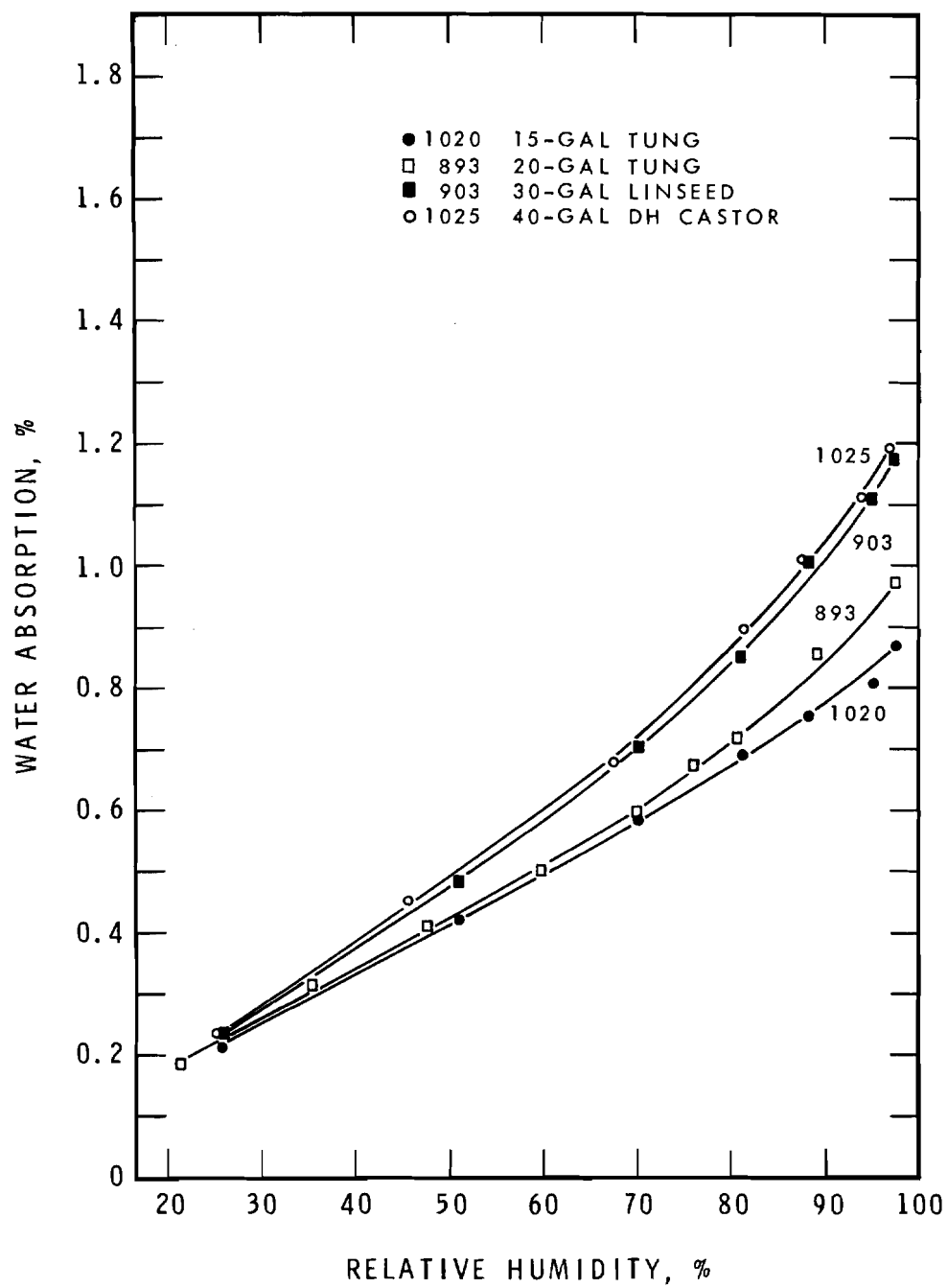


FIGURE 1
RELATIVE HUMIDITY VS WATER ABSORPTION
FOR PHENOLICS

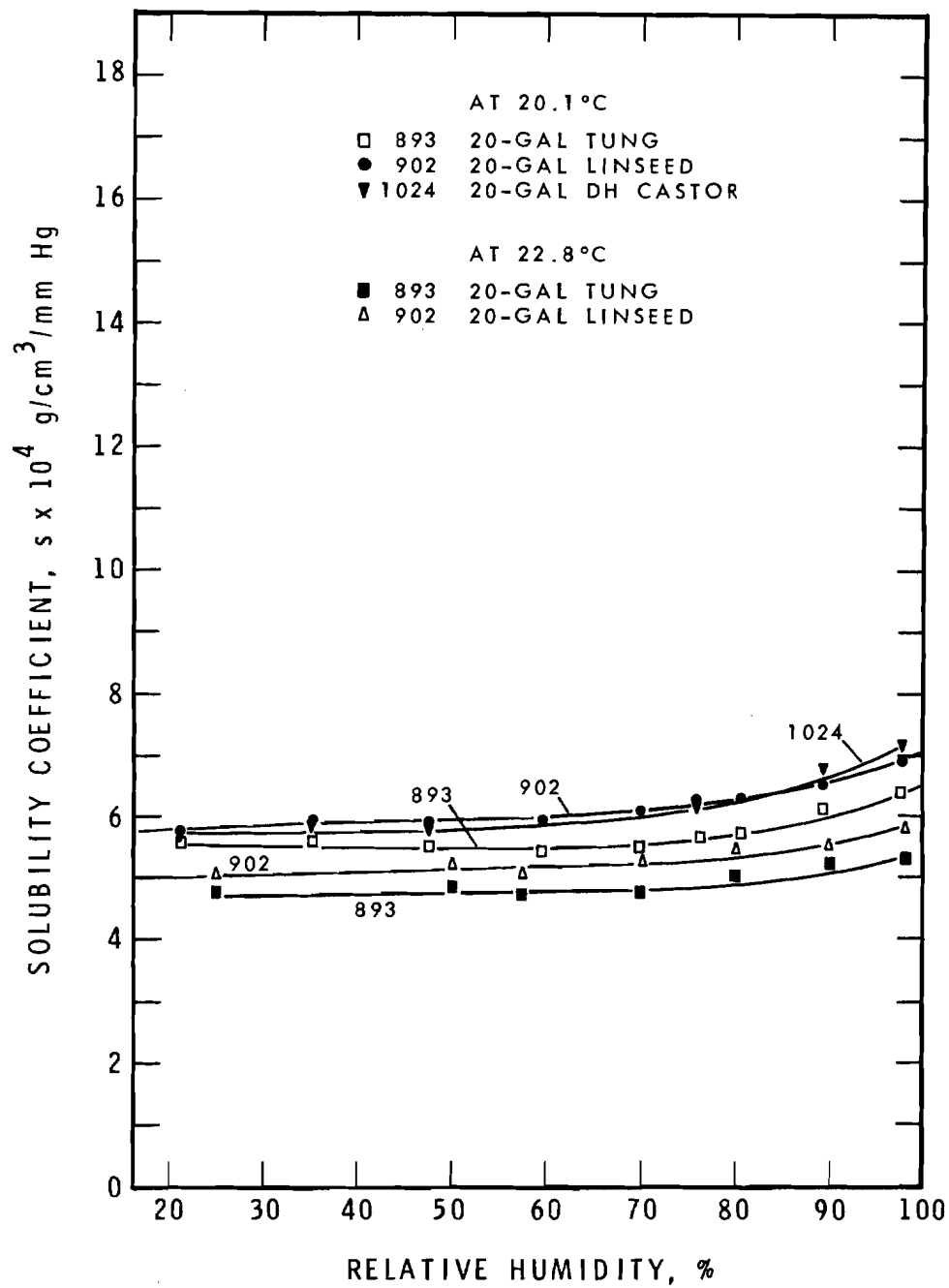


FIGURE 2

RELATIVE HUMIDITY VS SOLUBILITY COEFFICIENT
FOR 20-GAL PHENOLICS

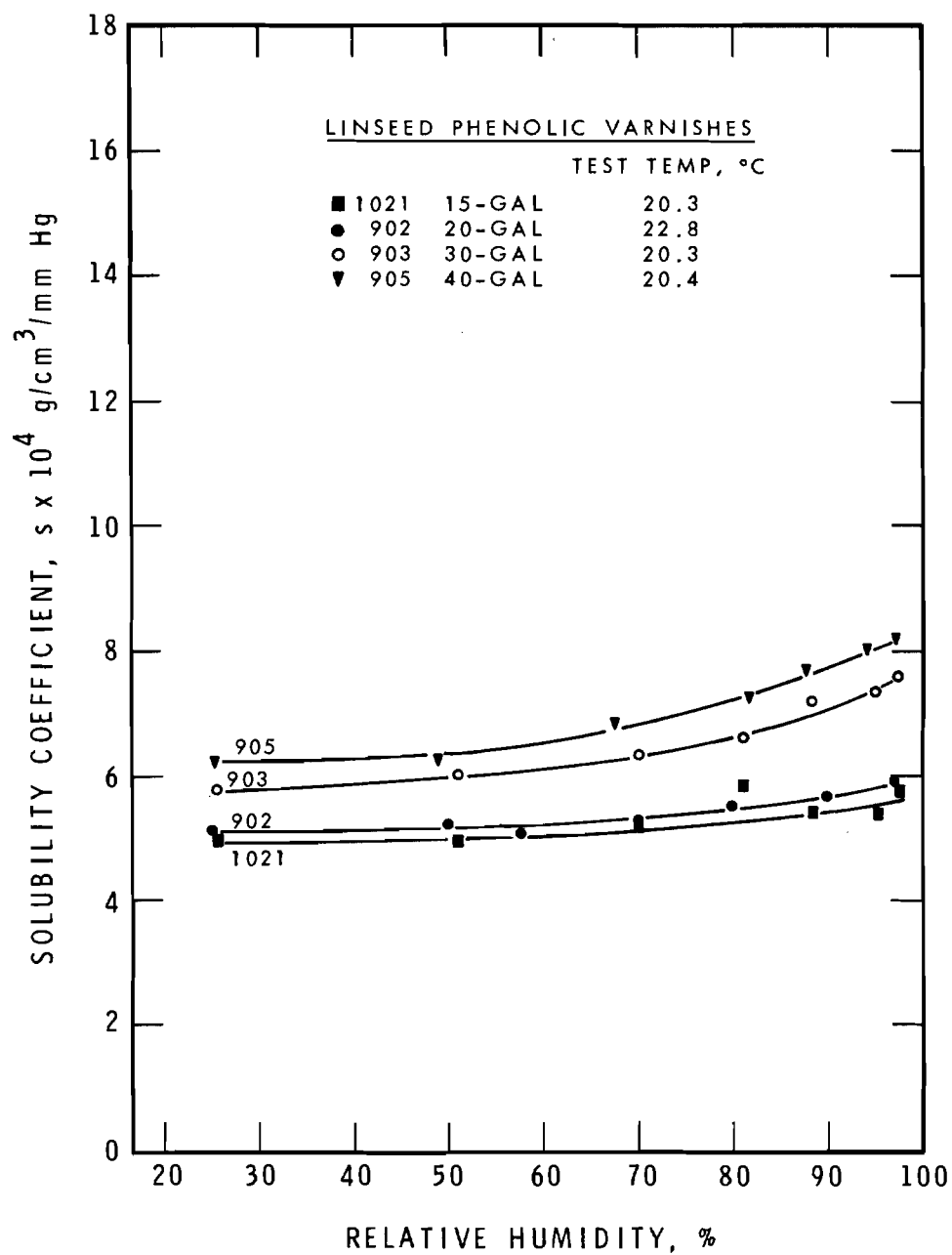


FIGURE 3

RELATIVE HUMIDITY VS SOLUBILITY COEFFICIENT
FOR 15- TO 40-GAL PHENOLICS

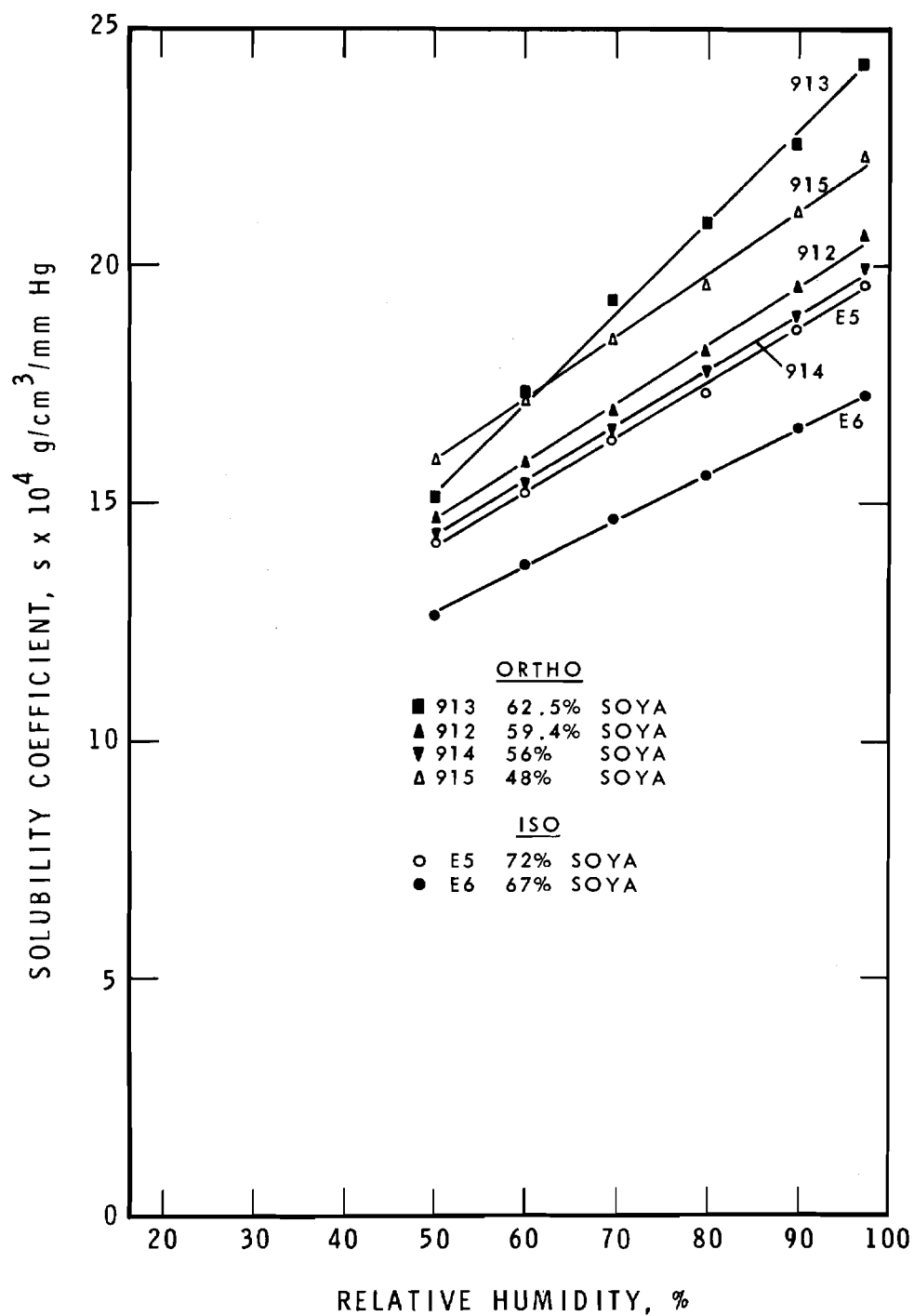


FIGURE 4
RELATIVE HUMIDITY VS SOLUBILITY COEFFICIENT
FOR ALKYDS

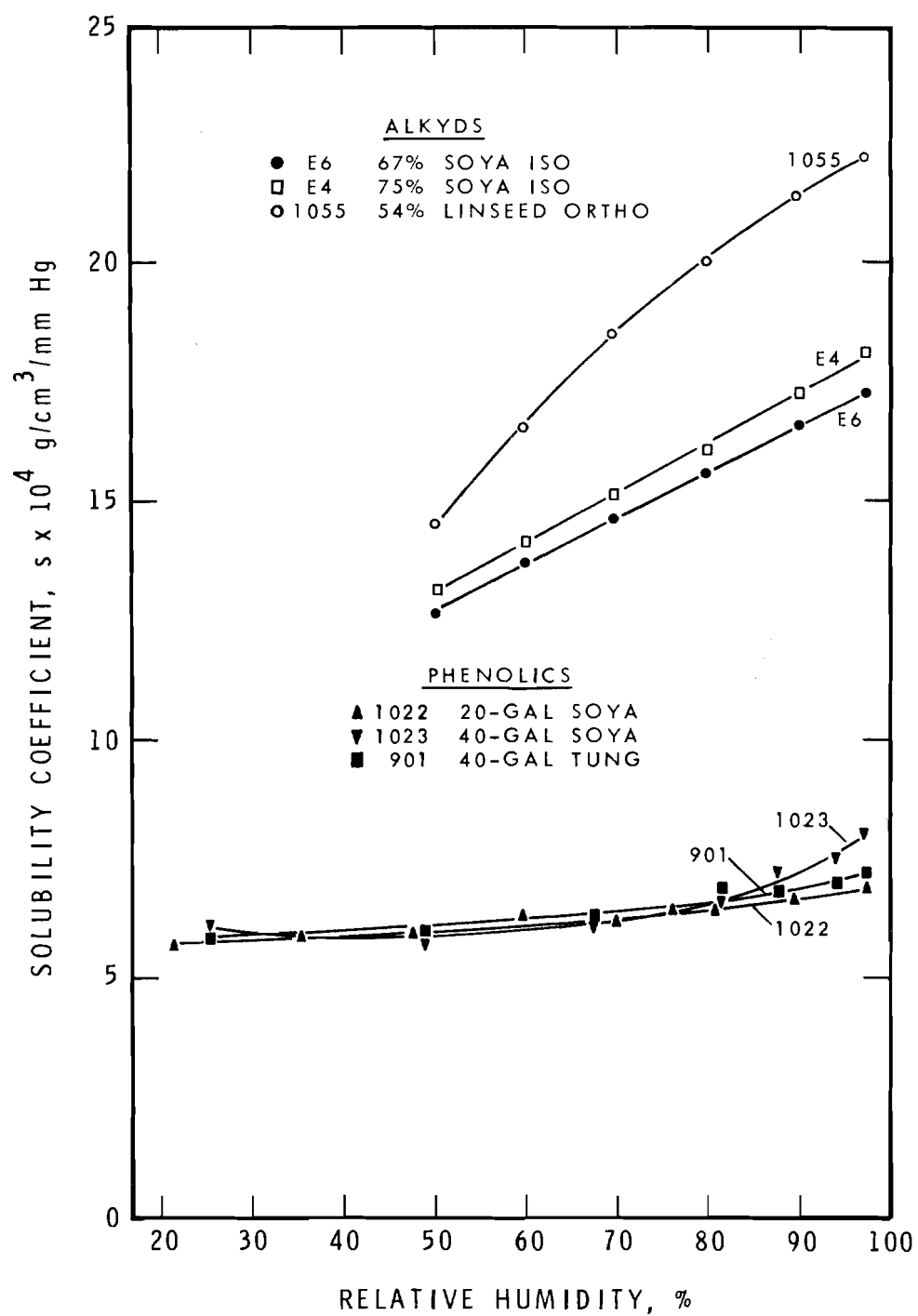


FIGURE 5
COMPARISON OF SOLUBILITY COEFFICIENTS FOR
ALKYDS AND PHENOLICS

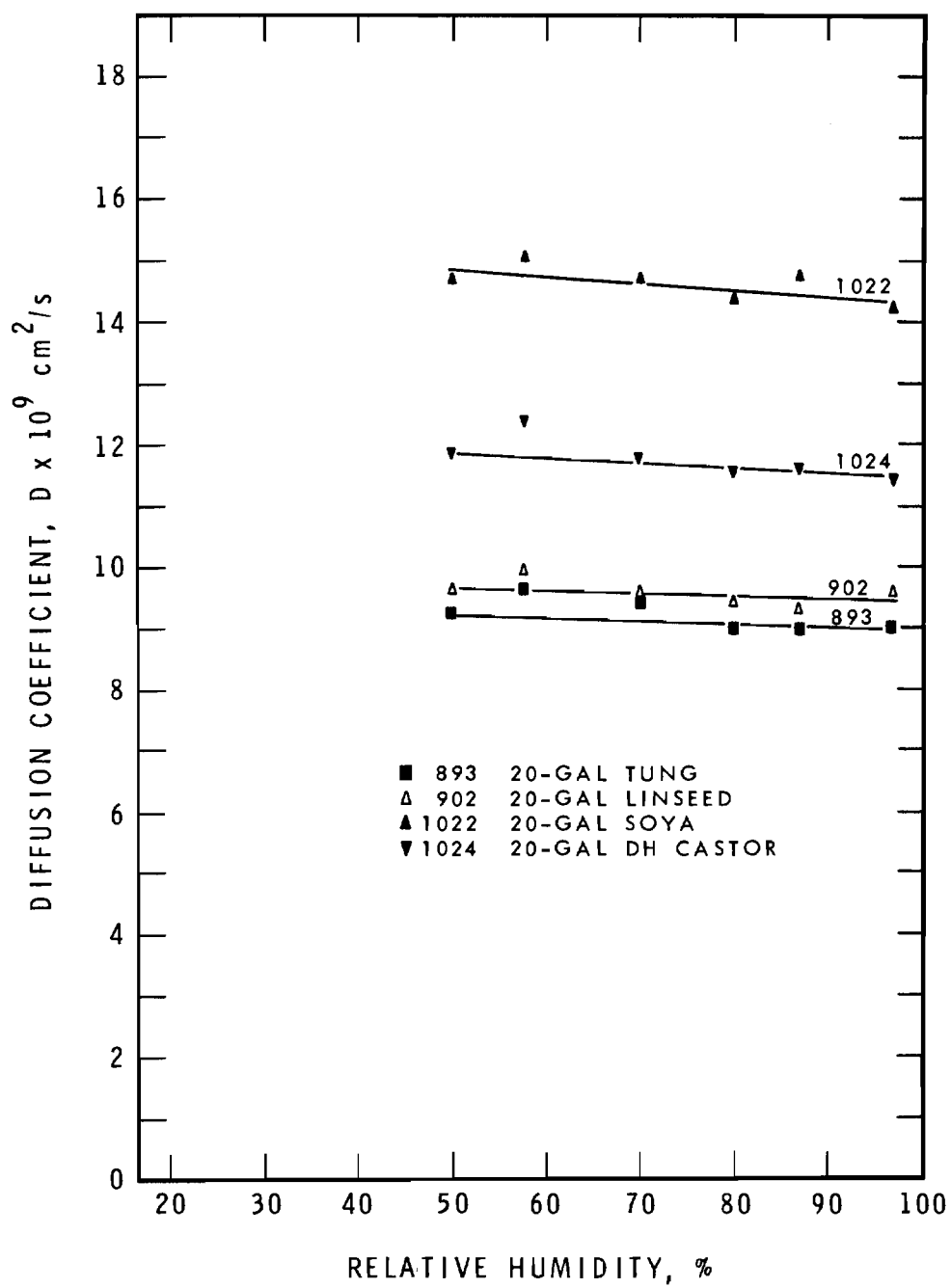


FIGURE 6
RELATIVE HUMIDITY VS DIFFUSION COEFFICIENT
FOR 20-GAL PHENOLICS AT 73°F

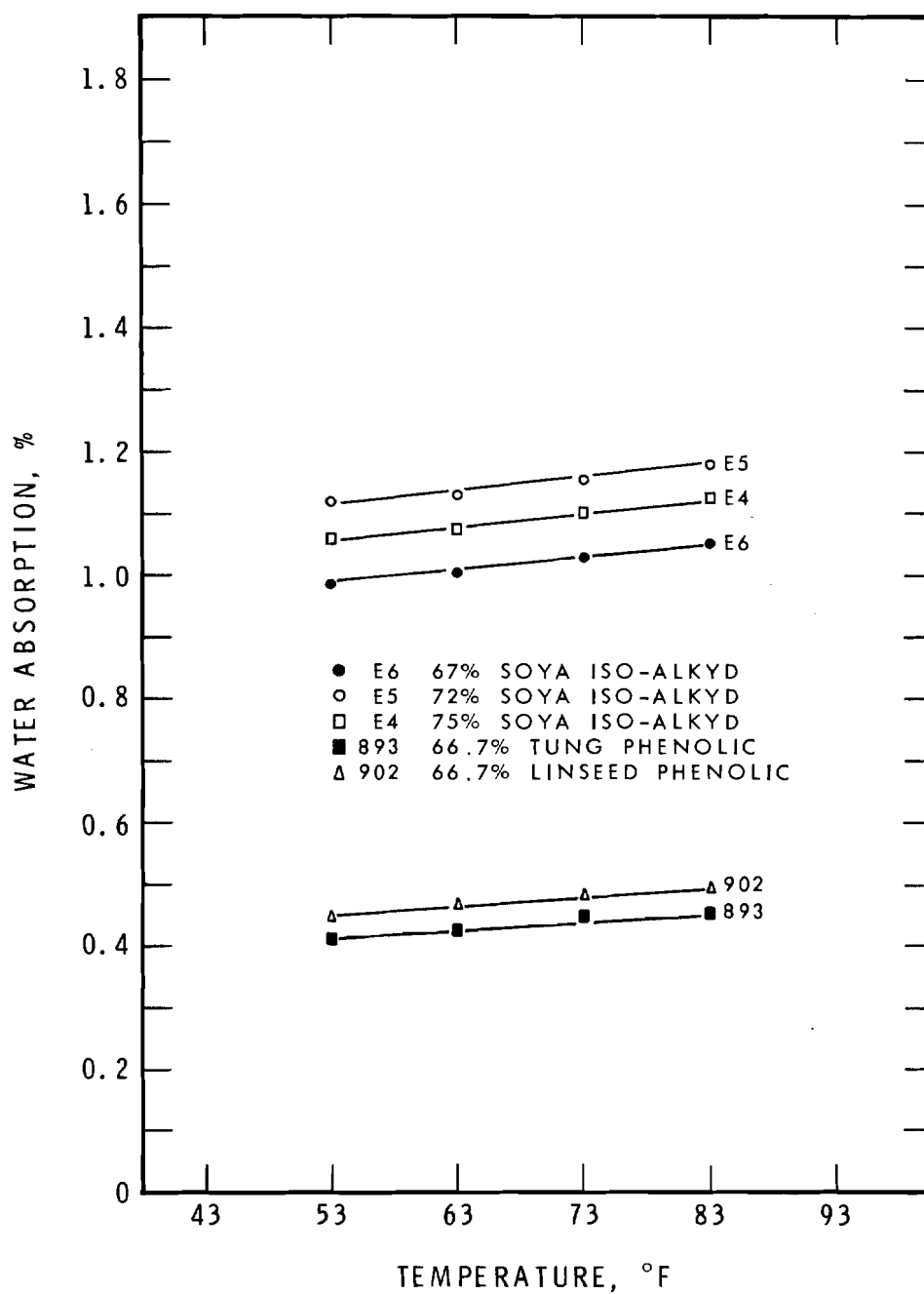


FIGURE 7

TEMPERATURE VS WATER ABSORPTION FOR
PHENOLICS AND ALKYDS AT 50% RH

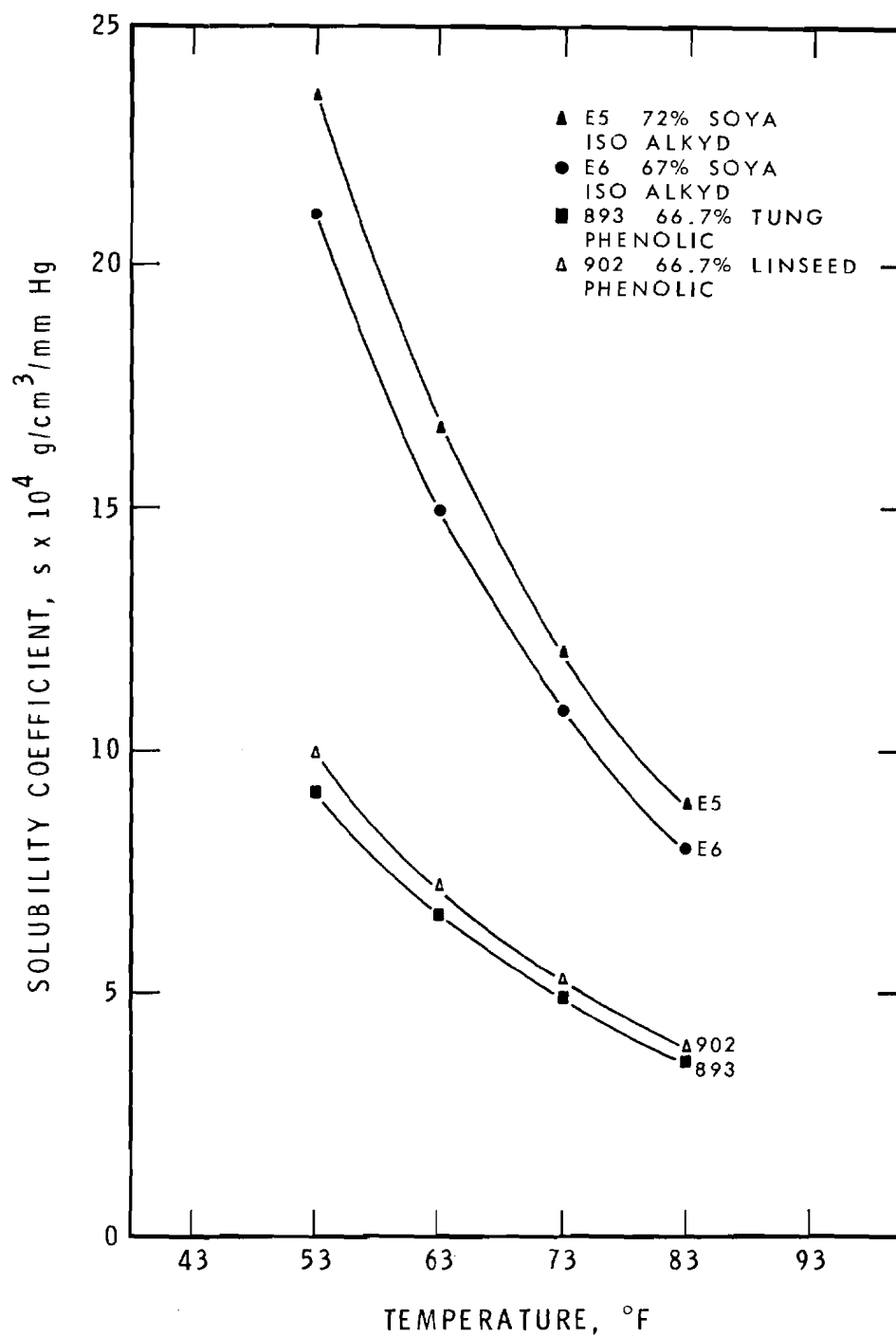


FIGURE 8

TEMPERATURE VS SOLUBILITY COEFFICIENT
AT 50% RH

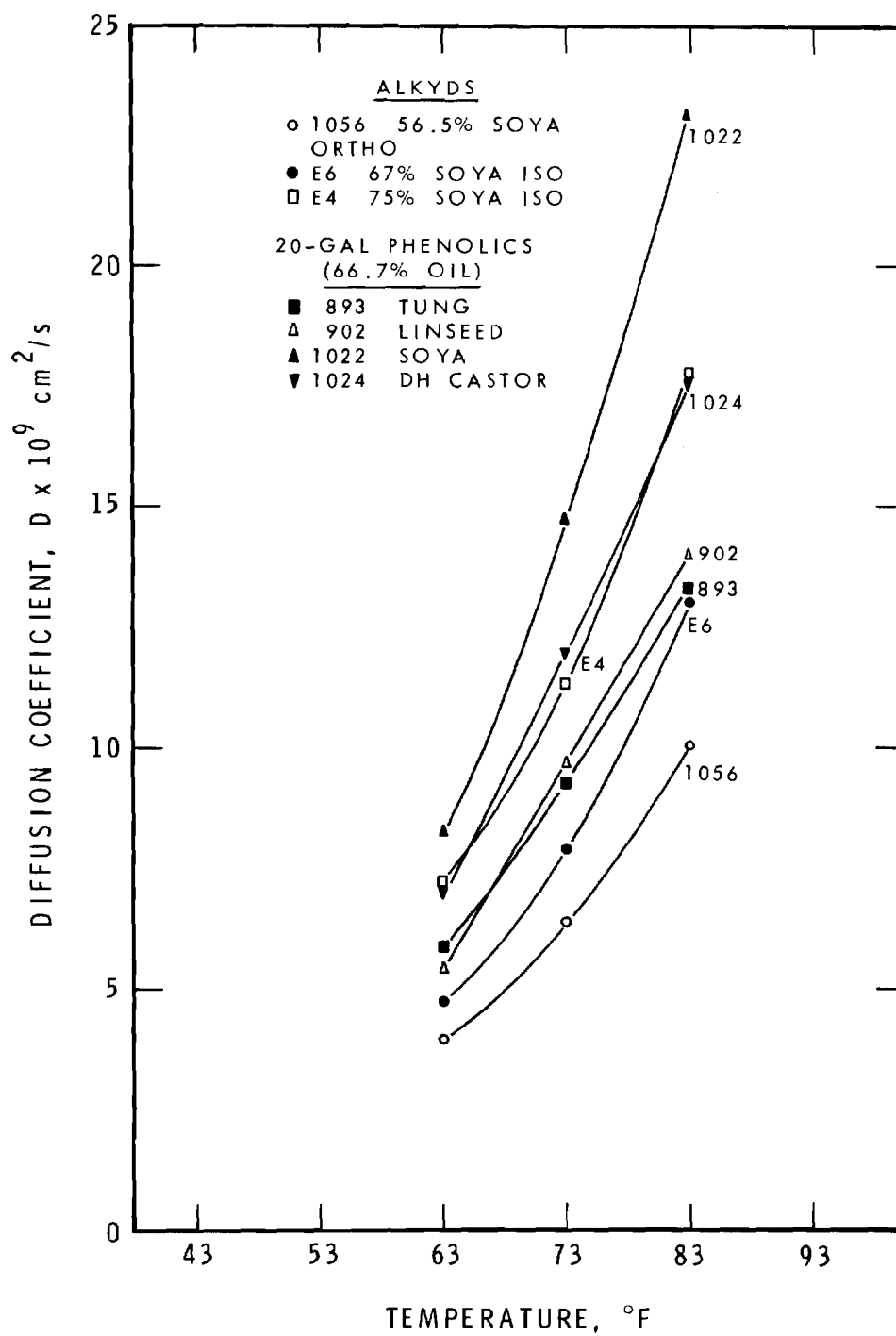


FIGURE 9
TEMPERATURE VS DIFFUSION COEFFICIENT
AT 50% RH