

APPENDIX B

Use and Replaceability of PCBs

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APPENDIX B

Use and Replaceability of PCBs

I. DIELECTRIC FLUIDS

Dielectric (electrically insulating) liquids are important to the electrical industry for filling agents or impregnants in transformers, capacitors, and other devices. Besides their electrical functions, the liquids may also be used for cooling and arc quenching functions. Detailed discussions of dielectric fluid applications are available (1-4).

A. CAPACITORS

Generally, industrially important capacitors use liquid impregnated cellulose paper as a dielectric. The required properties of the liquid are:

1. Non-flammability (important for preventing fires, particularly in indoor use).
2. Dielectric constant matching that of paper. A good match reduces electric field inhomogeneities, increases dielectric strength and lifetime, and allows decrease in capacitor size.
3. Low dissipation factor (reduces energy loss and destructive heating in a capacitor).
4. High dielectric strength (prevents breakdown and allows decrease in capacitor size).
5. High chemical stability (increases capacitor lifetime and stabilizes its performance).
6. Low vapor pressure (increases physical stability).
7. Inert decomposition products in an electric arc (prevents explosion or corrosion following breakdown).
8. Low toxicity of the material and its decomposition products.
9. Low cost.

1. Advantages and Disadvantages of PCB in Capacitors

The PCB capacitor liquids, commonly called askarels, are mixtures of chlorinated biphenyls and chlorinated benzenes. Several standard mixtures are specified by ASTM (5). The askarel capacitor liquids and their decomposition products are non-flammable. Thus their use in capacitors greatly reduces fire and explosion hazards. This characteristic permits economies where safety codes require fireproof enclosures for capacitors containing flammable liquids.

The dielectric constant of the askarels is high compared to other common dielectric liquids. Doubling the dielectric constant of the dielectric allows a reduction by half in the area of the capacitor electrodes, and a significant saving in the cost of construction and installation. The dielectric constant of askarels closely matches that of the capacitor paper.

TABLE 1

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TYPICAL PROPERTIES OF LIQUIDS												
	Uninhib- ited trans- oil	Mineral Oil				Polybutenes		Alkyls				
		Capac- itor oil	Pipe cable oil	Heavy cable oil	Pipe cable liquid	Paper impregnant	Capac- itor liquid					
Specific gravity, SUS 25°C												
37.8°C	58.2*	103*	763*	2365*	1,200*	8,000	300,000*	50-42	41-51	32-42	18-230	100-250
99-100°C		10*	60*	101*	63*	176*	2,200*	30-31	31-32	31-33	26-27	31-33
Viscosity, cs, 25°C												
37.8°C	9.79	21						4.6	6.9	17.2	45.3	46.4
99-100°C		3.5	10	21				1.8	1.8	2.5	3.2	6.1*
Flashpoint open cup, °C	146*	154.4*	196.1*	243.3*	154*	160*	252*	146.1*	143.3*	162.2*	152.8*	150*
Flashpoint closed cup, °C	6*	6	0*	0*	0.01*	0.01*	0.01*	0.010 max	0.010 max	0.010 max	0.010 max	0.010 max
Pour point, °C	-45.6	-45.6*	-26.1*	-17.8*	-14*	-23*	1.7	1.1	-35.5	-19.9	-7.9	10.9
Specific gravity, 15.6°C	0.898*	0.907*	0.928*	0.926*	0.862*	0.870*	0.905*					
25°C								1.18	1.26	1.38	1.45	1.54
Coef. of expansion, cc/cc/°C	0.00063				0.00078	0.00076		0.00071	0.00073	0.00069	0.00070	0.00066
Thermal conduct., liquid, cal/sec (cm) (°C/cm)	0.00031*	0.00031*	0.00030*	0.00030*								
(BTU/hr (ft) (°F))	0.076*	0.076*	0.072*	0.072*		0.062*	0.062*	0.067	0.063	0.058	0.057	0.054
Boiling point at 760 mm, °C								275.0	290.0	325.0	340.0	365.0
Volatility, weight loss												
Dielectric strength, kv/1" (0.254 cm)	32.5*	>30*	>30*	>30*	>35*	>35*	>35*	>35	>35	>35	>35	35
Dielectric constant, 60 Hz												
10 ³ Hz, 25°C								4.5	5.7	5.8	5.6	5.0
10 ³ Hz					2.14*	2.16*	2.22*					
Dissipation factor, 60 Hz	0.001*	0.001*	0.001*	0.001*	0.0005*	0.0005*	0.0005*					
10 ³ Hz, 100°C								0.001	0.001	0.001	0.001	0.001
10 ³ Hz												
Volume resistivity, ohm cm					>1x10 ¹⁰ **	>1x10 ¹⁰ **	>1x10 ¹⁰ **	>5x10 ¹⁰ **	>5x10 ¹⁰ **	>5x10 ¹⁰ **	>5x10 ¹⁰ **	>5x10 ¹⁰ **

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Table 2

Physical and Other Properties of Lubricating Oils, Engine Oils, and Hydraulic Fluids

Fluid	Chemical Class or Compound	Viscosity, cs		Specific Gravity (Water=1)	Flash Point °F	Fire Point °F	Autoignition Temperature °F	Decomposition Temperature °F
		100°F	210°F					
Mineral Oils								
MIL-2190	Mineral Oil	37.2	5.8	0.86	~450	--	665(5)	--
Harmony 44 (Gulf)	" "	87.6	9.8	0.88	~460	--	680(5)	--
MIL-O-5731	" " - Naphthenic	--	--	--	--	--	--	640(28)
MIL-O-7277	" " "	--	--	--	--	--	464(50)	725(30)
MIL-O-60-294	" " - Paraffinic, deep de waxed	14	3.15	0.88	385	430	700(27)	~620(35)
Mobil DTE-103	Mineral Oil	124	8.74 to 10.2	0.92	390	--	702, 675(50)	--
MIL-H-6083B	" "	--	--	--	255	--	470(50)	--
MIL-H-5606A	" "	--	--	--	--	--	437(4)	--
MIL-D-5606(Esso Univis J-43)	" "	--	--	--	195	225	437(2)	--
Glycols and Water Glycols								
Ethylene Glycol	Glycol	8.7	--	--	240	--	856(38)	--
Propylene Glycol	"	19.6	--	--	230	235	835(36)	--
Ethylene Glycol + 50% Water	Water-Glycol	2.2	--	--	--	--	903(38)	--
Mought-Safe 271	" "	~43	~16(150°F)	1.045	--	--	767(5)	--
" " 520	" "	43.2	25.1(130°F)	1.075	--	--	--	--
" " 620	" "	43.2	29.8(150°F)	1.055	--	--	--	--
Hyvac 20(Mobil)	Water-Glycol and additives	41	--	1.07	--	--	750(51)	--
Irue 902 (Shell)	Water-Oil Emulsion	97.4	51	0.93	--	--	709(51)	--
Ucon 50HB-260	Polyalkylene Glycol	56	--	--	455	500	743(38)	--
Ucon 50HB-280-X	" "	--	--	--	500	600	743(20)	--
Ucon LB-60	" "	10.7	--	--	310	325	653(38)	--
Ucon LB-600-X	" "	--	--	--	--	--	752(20)	--
Phosphate Esters								
Mought-Safe 1010	Triaryl Phosphate Ester	18.2	5.9	1.20	505	670	>1200(51)	--
" " 1055	" " "	13.0	8.0	1.145	505	680	1020, 810(50)	--
" " 1115	" " "	32.2	4.1	1.165	--	680	>1200(51)	--
" " 1120	" " "	49.8	5.0	1.15	495	690	1020(5)	--
" " 1130	" " "	62.8	6.0	1.145	490	680	>1200(51)	--

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Table 2 (Cont)

Fluid	Chemical Class or Compound	Viscosity, cc		Specific Gravity (Water=1)	Flash Point °F	Fire Point °F	Autoignition ^{1/} Temperature °F	Decomposition Temperature °F
		100°F	210°F					
Silanes (Cont)								
MLO-56-582	Octadecyl tridecyl Silane	33.9	6.8	--	345	595	750(17)	--
MLO-56-614	Dodecyl tridecyl Silane	26.4	5.6	--	535	575	750(17)	--
MLO-56-611	Didodecyl dioctyl Silane	23.1	5.0	--	520	555	750(17)	--
MLO-57-9	Tetra undecyl Silane	29.26	6.11	--	545	600	760(17)	--
Silicates and Silicones								
Tetra (2-ethylhexyl)Silicate	Ethyl hexyl Silicate	--	--	--	--	--	--	638(28)
Orell B.F.1	(2-ethylhexyl) Silicate	--	--	--	--	--	~570(12)	--
Oronite 8200	Silicate Ester	31.75	11.14	--	385	440	716(2)	--
Oronite 8515	" "	24.3	8.11	--	390	450	710(50)	--
MLO-56-645	85% Oronite & 15% Flexol	--	--	--	340	455	716(2)	--
MLO-56-540 (Monsanto OS-45)	Silicate Ester	--	--	--	325	430	703(2)	--
MLO-56-856 (Hollingshead, 72073C)	" "	--	--	--	315	440	716(2)	--
Verillube F-50	Silicone	52	16	1.045	550	640	900(51)	>600(51)
Verillube F-44	"	55	17	1.045	550	640	900(51)	>600(51)
Dow Corning 190	Polymethyl Siloxane	22.6	--	--	240	--	860(38)	--
Dow Corning 400	Polymethyl Siloxane	10.9	--	--	255	280	610(38)	--
Dow Corning 500	Polyethyl Siloxane	44.9	--	--	470	--	900(38)	--
Dow Corning 550	Silicone	65 to 87	--	1.065	600	--	--	740(28)
Dow Corning 700	Poly (methyl, phenyl) Siloxane	2.8	--	--	305	325	940(38)	--
Dow Corning 710	Methyl Phenyl Silicone	220	--	1.112	520	--	--	583(15)
MLO-59-48	50% Methyl Phenyl Silicone (DC 258) plus 50% TMP Adipate Tetracaproate	61.8	13.5	--	--	--	--	625(30)
Halogenated Silicones and Hydrocarbons								
MLO-53-446 (GE 81406)	Chlorinated Silicone	--	--	--	580	710	786(2)	514(15)
MLO-59-287 (GE F-50)	Chlorophenyl Methyl Silicone	--	--	--	--	--	--	630(30)
Fluorolube F-5	Polytrifluorochloroethylene	5	--	1.86	--	--	~1205(12)	>625(51)
Pydraul A-200	Chlorinated Hydrocarbon	49.0	5.0	1.42	350	680	1200(51)	--
Arachlor-1248	Tetrachlorodiphenyl	43.0	3.2	1.41	380	None	~1185(12)	--
Arachlor-1242	Trichlorodiphenyl	17.7	--	--	350	633	1230(30)	--
Arachlor-1254	Chlorinated Hydrocarbon	--	--	--	--	--	~1085(12)	--

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exercized through companies which insure against fire, utilities which supply electrical power, and building codes.

3. Extent of Capacitor Use

Almost all industrial capacitors contain PCBs. In 1968 95 percent of the U. S. production of capacitor liquids (2.46 million gallons) were PCBs (9). Two important types of capacitors are phase correction capacitors on power lines and ballast capacitors for fluorescent lighting. Non-ballast industrial capacitors produced in 1967 had a value of \$112 million (10), and fluorescent lamp ballast capacitors produced that year numbered 21.7 million units with a value of \$15.5 million (10). In 1970 there were 50.9 million ballast units produced with a value of \$163 million (11). These ballast units are in extensive use inside buildings where non-flammability is important.

Phase correction capacitors are necessary on power circuits to correct for the inductive loading of much electrical power equipment. The amount of phase correction capacitance is ordinarily specified in kilovolt amperes of reactive current or kvars. Most power capacitors are rated at from 1/2 to 25 kvars so that the number of capacitors is very roughly the kvar value divided by 10 (12). As examples of the extent of power capacitor use, TVA has 2-1/4 million kvars (13), and a power company serving suburban New Jersey has 3.6 million kvars on their power lines with 1/2 million kvars on order (14). The value of these capacitors is roughly \$5 per kvar (14). More than 20 million kvars of power capacitors were produced in 1970 (16).

The procurement lag for these capacitors is 1-1/2 to 3 years, and estimates for redesigning new systems range from 3 to 10 years, according to power company representatives to ASTM Committee D-27 (14,15). Extensive re-designing is anticipated if distribution capacitors were required to use presently available non-PCB liquids. Askarel capacitors have been developed to the point that failures are considered negligible (13, 15).

Several private sources reported extensive efforts to find replacements for PCB capacitor fluids, but none reported having a good substitute.

B. TRANSFORMERS

Most power transformers contain a liquid to electrically insulate and remove heat from the core and windings. The properties required of these liquids are:

1. Non-flammability (required for indoor use and desirable in remote location use).
2. High dielectric strength (prevents breakdown and allows transformer size reduction).
3. Low viscosity (promotes convective heat transfer).
4. High chemical stability (allows higher temperature operation and reduces degradation of the transformer).

flammable liquid. An annual report on such failures is compiled by the Edison Electric Institute (19).

II. INDUSTRIAL FLUIDS FOR HYDRAULIC, GAS TURBINE, AND VACUUM PUMP USES

A. HYDRAULIC

Hydraulic fluids are liquids used as force transmitters (20, 21). The characteristics of a good hydraulic fluid are (20):

1. High lubricity (lowers heating and increases lifetime of moving components).
2. Stability (increases lifetime of use).
3. Appropriate viscosity and high viscosity index (24).
4. Low pour point (necessary for material to flow at low temperatures (25)).
5. Compatibility (prevents interactions with other components, for example, rubber seals).
6. Good heat transfer (reduces local heating and large temperature gradients).
7. High bulk-modulus (important for extreme pressure applications).
8. Low volatility (necessary to prevent malfunctioning due to "vapor lock").
9. Low foaming.
10. Low thermal expansion. Aside from the implication of a more constant volume over a wide temperature range, a low thermal expansion implies a high viscosity index and the constancy of certain other properties with respect to temperature.
11. Good demulsibility.
12. Inhibitor (necessary to prevent oxidation of metals or rusting).
13. Good fire resistance (very important in high temperature environments).
14. Low density (desirable in transportation, particularly airborne, applications).
15. Good dielectric properties (reduces arcing or short circuiting should the fluids come in direct contact with electrical components).
16. Non-toxicity (reduces the danger to human beings from rupture of hydraulic equipment or improper disposal and to maintenance personnel during transfer of these fluids).

Since most commercial hydraulic fluid mixtures are proprietary, it is difficult to obtain information with respect to their composition. The results from inquiries with respect to PCB content have been somewhat contradictory. No definite knowledge is available that PCBs are present in commercial hydraulic fluids. Since composition specifications of these fluids are usually not available to the public, PCB content should be established by chemical analysis.

PCBs are useful in hydraulic fluids as lubricating additives in extreme pressure applications (26) and as pour point depressants. Although it is true that the pour point of oils may be lowered by extensive dewaxing, the use of additives is much cheaper. There are other inexpensive additives which are often used for these applications and which appear to be adequate. For

viscosity index, low pour point, and oxidation and foaming resistance. Sample U. S. and U. K. military specifications are given in Table 3 (36). Usually, dibasic acid esters containing appropriate additives meet the above requirements. In the case of the turboprops, the same lubricant is usually used for both the turbine and prop-drive gear.

PCBs would seem to be useful as additives in gas turbine lubricants, but there is no evidence that PCBs are currently used for this purpose. Research along these lines has been done, and there is some indication that some PCBs have on occasion been added to gas turbine lubricants. The objection to PCBs and other chlorinated hydrocarbons is that they tend to be corrosive at the high temperatures reached in gas turbines. This corrosion is accelerated by decomposition of the PCBs and the formation of hydrochloric acid at high temperatures. The corrosiveness of PCBs is a major deterrent against their use in these lubricants. TCP also has the desirable property of reacting with metallic surfaces at high temperatures to form a protective coating.

Jet engines are run for approximately 18,000 hours (37) between overhauls. The lubricants are not usually changed during this period; however, the appropriate "oil level" is maintained at frequent intervals. Immediately before engine overhaul the lubricant is drained and discarded. Unlike the situation with respect to hydraulic fluids used in commercial aircraft, there appears to be no general recycling facility for gas turbine lubricants (37). As a result of their increase in acidity and viscosity during use, recycling of gas turbine fluids would demand expensive redistillation and reblending.

C. VACUUM PUMP APPLICATIONS (22, 23)

Both mechanical and diffusion pump applications require fluids of one highly fractionated component. Accordingly, additives generally are not used. However, PCBs are used in pure form as a diffusion pump oil in commercial applications.

The characteristics (38) of a good diffusion pump fluid are:

1. Relatively high vapor pressure at operating temperatures.
2. Low vapor pressure at room and lower temperatures. (The vapor pressure imposes a lower limit on the ultimate vacuum).
3. Heat resistance (prevents cracking or molecular degradation at operating temperatures).
4. Narrow vapor pressure range and freedom from contaminants such as absorbed gases and liquids with higher vapor pressures. (This requirement often implies the necessity of a narrow fraction).
5. Oxidation resistance (important because air may enter a diffusion pump during operation either accidentally or through slow leakage).
6. Nonhygroscopic (absorbed water increases pump maintenance and may contaminate the vacuum system).
7. Compatibility (must be compatible with pump and vacuum system components).
8. Stability in the presence of the vapor being pumped.

Some of the pertinent properties of many diffusion pump fluids are given in Table 4 (39). The stability, oxidation resistance, appropriate vapor pressures, and, in particular, the relatively low cost of PCBs make them a desirable choice for many industrial applications. Although the ultimate vacuum using

Table 4

Some Properties of Pumping Fluids

Fluid	Proprietary names	Chemical nature	Molecular weight	Specific gravity (room temp.)	Flash point (open °C)	Viscosity (centistokes) at 20°C	Approx. pour point (or freezing point) °C	Approx. boiling point at 1 torr °C	Estimated true vapour pressure (torr)
Apiezon A	As under "fluid"	Paraffinic hydrocarbons	414	0.872	218	69	-12	190	10^{-8} (20°C)
Apiezon B	" "	" "	463	0.873	235	100	-12	220	5×10^{-8} (20°C)
Apiezon BW	" "	" "	472	" "	" "	" "	" "	225	$\sim 10^{-7}$ (20°C)
Apiezon C	" "	" "	374	0.880	265	295	-9.5	255	4×10^{-8} (20°C)
Apiezon G	" "	" "	445	0.873	232	86	-12	210	2×10^{-7} (20°C)
Apiezon F/W	" "	" "	380	" "	" "	" "	" "	165	5×10^{-8} (20°C)
Convol 10	" "	" "	250	0.91	191	147	-23	150	$6-7 \times 10^{-5}$ (20°C)
Convol 20	" "	" "	400	0.86	218	120	-8.9	195	$2-3 \times 10^{-3}$ (20°C)
Di-n-butyl phthalate	—	$C_{16}H_{22}(COOC_4H_9)_2$	278	1.014	159	19	-71	102	$1-5 \times 10^{-8}$ (20°C)
Di-2-ethyl hexyl phthalate	Octoil	$C_{24}H_{42}(COOC_8H_{17})_2$	391	0.953	196	75	-52	204	10^{-7} (20°C)
Di-2-ethyl hexyl sebacate	Octoil-S	$C_{30}H_{58}(COOC_{10}H_{21})_2$	427	0.912	209	24	-56	215	10^{-8} (20°C)
Di-nonyl phthalate	Narcoil-20 Viacoil-20 Narcoil-40 Viacoil-40	$C_{24}H_{42}(COOC_9H_{19})_2$	419	0.973	215			215	10^{-8} (20°C)
Tri-cresyl phosphate	—	$(C_6H_5)_3C_6H_4_3PO_4$	363	1.17	240	105		219	5×10^{-8} (25°C)
Tri-xylene phosphate	—	$[(C_6H_4)_3C_6H_4_3PO_4]$	414	1.14	243	160		245	
Glycerol	—	$(C_3H_5O)_3$	92	1.26		1180		123	$5-6 \times 10^{-8}$ (15°C)
Mixed chlorinated diphenyls	Aroclor 1248 Convacolor 8 Clophen A-40	Approx. $C_{12}H_8Cl_2$	292	1.45	193	400	-7	137	$1-5 \times 10^{-8}$ (20°C)
Mixed chlorinated diphenyls	Aroclor 1254 Edwards booster fluid A Narcoil-10 Viacoil-10 Convacolor-12 Clophen A-50	Approx. $C_{12}H_8Cl_2$	326	1.54	none	~6000	10	150	8×10^{-8} (20°C)
Silicone D.C. or M.S. 702	As under "fluid"	Methyl polysiloxanes $(CH_3)_2SiO[(CH_3)_2SiO]_n(CH_3)_2Si$ Tetraphenyl tetramethyl trisiloxane Pentaphenyl trimethyl trisiloxane	330	1.071	194	35	-40	173	
Silicone D.C. 703	" "		370	1.039	227	40	-36	206	
Silicone D.C. or M.S. 704	" "		354	1.066	216	47	-38	223	10^{-8} (20°C)
Silicone D.C. or M.S. 705	" "		346	1.095	243	170	-15	254	5×10^{-10} (25°C)
Convalex 10 or V.R.T. fluid E	" "	Mixed 5-ring polyphenyl ethers	447	1.198	288	2500 (25°C)	4.5	285	$1-3 \times 10^{-10}$ (25°C)
Mercury	—	Hg	200.6	13.6	—	1.15 (25°C)	-38.9	127	$1-1 \times 10^{-3}$ (20°C)

toxicity, a tendency to decompose to form highly corrosive HCl, a lower decomposition temperature than some alternate liquids (43) and relatively poor radiation resistance (44).

B. REPLACEABILITY OF PCBs AS HEAT TRANSFER FLUIDS

Increased risk from fire and explosion is a major disadvantage with most PCB replacement fluids. Other non-flammable fluids are: 1. fluorocarbons, which have low toxicity, high thermal stability, and in spite of high cost are used as convective or evaporative coolants (1), 2. water, which is quite corrosive, has a high temperature limit of 374°C and requires extremely expensive high pressure systems for its use above the atmospheric boiling temperatures and 3. molten salts and metals which, because of their resistance to radiation damage, are useful in reactor applications.

Several liquids are more stable at high temperatures than the PCBs. Table 5 (42) shows the decomposition point range of liquids in a variety of chemical classes. Few of these liquids are non-flammable, however, as can be seen from Table 2. The phosphate esters, silanes, and aromatic ethers have high fire points (around 600°F), but they are flammable and it is not clear how high the fire point must be for a fluid to be safe in a high temperature system, especially in the event of leakage into a furnace. The details of specific heat transfer applications are necessary to evaluate the suitability of PCB replacement fluids.

IV. PLASTICIZER AND MISCELLANEOUS USES *

A plasticizer is a material incorporated in a plastic to increase its workability and flexibility (45,46). The addition of a plasticizer may lower the melt viscosity and flow temperature (increasing the ease with which the plastic can be made to flow), or lower the elastic modulus (making the plastic softer) (46). Plasticizers are generally non-volatile liquids or low-melting solids. A major requirement of a plasticizer is that it have high compatibility* (mixes well to form a homogenous composition with useful properties) (42) with the material being plasticized. Figures are given in Table 6 for the compatibility of some common plasticizers with some common synthetic thermosetting or thermoplastic resins (45). Other properties which are important when considering plasticizers are specific gravity, refractive index, color, odor, moisture sensitivity, vapor pressure (volatility), boiling range, stability (to light and heat) toxicity and cost (47). Of course, the properties of the final plasticized material are of prime importance. Certain plasticizers provide formulations with specific properties such as:

1. phthalate esters - general purpose.
2. adipates and sebacates - low temperature flexibility.
3. highly aromatic esters - fast processing, strain and extraction resistance.
4. epoxies - heat stabilization during processing.
5. phosphate esters and PCBs - fire retardant materials.

* The information in this section about specific uses was obtained from Chemical Abstracts (1928-1969) and patent claims. The Task Force has no knowledge whether or not specific applications are in current production or use.

* Note that the term "compatibility", used here, has a meaning very different from its use earlier in this appendix. In the earlier case, compatibility meant that two materials could coexist without either being affected by the other. The present meaning is quite the opposite.

Table 6. Approximate Maximum Compatibility, phr⁺, of Plasticizers with Various Resins

	Phthalates				Adipates		Phosphates			Phthalyl glycolates		Polyesters			Epoxy resins		Sulfonamides		Miscellaneous								
	Dimethyl	Dibutyl	Di-2-ethylhexyl	Ditridecyl	Dicyclohexyl	Benzyl benzyl	Di-2-ethylhexyl	Disodecyl	Triphenyl	Tricresyl	2-Ethylhexyl glycolate	Tri-2-ethylhexyl	Tributoxy ethyl	Methyl phthalyl glycolate	Benzyl phthalyl glycolate	Sebacic acid 400	Sebacic acid 400	Paralox H-211	Paralox G-25	Paralox G-54	Paralox G-62	N-Ethyl-p-toluenesulfonamide	o,p-Toluenesulfonamide	Chlorinated biphenyl	11B-40*	Polyethylene glycol d-2-ethylhexanoate	
poly(vinyl chloride)	100	100	100	100	30	100	100	50	20	100	100	110	60	20	100	100	100	100	10	10	100	100	40	1	35	40	100
poly(vinyl acetate)	100	100	1	1	50	100	1	1	20	40	50	1	40	100	100	75	100	11	11	33	1	100	50	50	1	25	
poly(vinylidene chloride)	50	75	25	10	20	75	15	10	20	75	75		50	75	75	10	25					50	20	50	20		
polystyrene	100	100	50	100	20	100	100	100	25	20	15	50	100	20	30	1	50					20	10	100	100		
ethylcellulose	100	100	100	100	50	100	100	100	30	70	100	100	50	75	75	10	33	1	1	< 11	100	60	75	75	100	100	
cellulose nitrate	60	100	100	100	50	100	35	35	75	100	100	100	100	100	100	100	100	100	100	100	100	80	50	100	10	100	
cellulose acetate	60	25	1	1	1	10	1	1	35	15	20	< 11	10	100	50	1	1	1	1	1	1	100	30	1	1	1	
cellulose acetate butyrate	100	100	50	50	20	100	25	50	50	30	80	< 25	25	100	50	100	100	1	1	100	1	50	25	50	30		
chlorinated rubber	25	100	33	100	20	80	100	100	50	100	100		100	100	80	50	50			100	100	50	25	100	100		
high styrene butadiene copolymer	20	50	50	50	20	50	20	20	20	50	50		50	50	50	15	25					25	25	50	25		
protein-based plastics	20	20	1	1	1	10	1	1	10	30	25		10	20	40	1	1					50	40	1	1		
shellac	5	1	1	1	1	1	1	1	1	1	1		1	10	30	1	1					40	60	1	1		
acrylic resins	100	70	25	25	25	75	10	1	25	25	100	100	25	60	70	1	1	1				25	25	10	20	25	
polyamides	1	25	25	20	10	25	25	25	10	25	25		15	1	20	1	1					50	25	25	1		
polyesters	5	20	20	15	20	20	1	1	10	20	20		20	5	20	5	10					10	5	25	1		
epoxy resins	1	25	1	1	10	25	1	1	10	25	25		25	25	25	1	1					50	50	50	1		
phenolic resins	25	30	25	25	25	50	25	25	50	50	50		50	50	50	15	25					50	50	25	25		
alkyd resins	25	70	25	25	25	50	50	25	50	70	70		50	70	50	20	25					25	25	25	15		
melamine-formaldehyde resins	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1					50	50	1	1		
polyurethane	25	25	25	25	10	25	15	15	10	25	25		25	25	25	10	15					20	10	25	15		
nitrile and neoprene rubber	100	100	50	33	50	100	20	33	50	55	40		50	50	50	25	50			33		50	50	50	50		

* Trademark Monsanto Co.

* Trademark Union Carbide Corp.

* Trademark Rohm and Haas Co.

⁺ parts per hundred

Table 7. General Properties of Some Aroclors (PCB)

Material	Form and color	Specific gravity	Distillation range, ^a °C (corr)	Flash point, ^b °C	Fire point, ^c °C	Pour point, ^d °C	Softening point, ^e °C	n _D ²⁰	Viscosity, /sec	
									27.5°C	28.9°C
Aroclor 1221 ^f	colorless, mobile oil	1.182-1.192 (25/15.5°C)	275-320	111-150	176	crystals at 1°C		1.017-1.018	34-41	39-31
Aroclor 1232	almost colorless, mobile oil	1.270-1.280 (25/15.5°C)	290-325	152-154	215	-35.5		1.020-1.022	44-51	51-32
Aroclor 1242	almost colorless, mobile oil	1.381-1.393 (25/15.5°C)	325-366	176-180	none	-19		1.027-1.029	82-92	34-35
Aroclor 1248	yellow-green tinted, mobile oil	1.405-1.415 (65/15.5°C)	310-375	193-196	none	-7		1.030-1.031	183-210	36-37
Aroclor 1254	light yellow, viscous oil	1.495-1.505 (65/15.5°C)	365-390	none	none	10		1.039-1.041	1890-2500	41-15
Aroclor 1260	light yellow, soft, sticky, resin	1.555-1.566 (90/15.5°C)	395-420	none	none	31		1.047-1.049		72-78
Aroclor 1263	light yellow, sticky, clear resin	1.572-1.583 (90/15.5°C)	395-425	none	none	35-38		1.0501-1.0517		86-100
Aroclor 1268	white to off-white powder	1.801-1.811 (25/25°C)	435-450	none	none		150-170 ^g			
Aroclor 1270	white crystalline powder	1.911-1.980 (25/25°C)	450-460	none	none		249-300 ^g			
Aroclor 4185	transparent, yellow, brittle resin	1.670 (25/25°C)	230-320 (4 mm Hg)	none	none		60-66	1.064-1.067		90-150 (130°C)
Aroclor 5112	yellow, transparent, sticky resin	1.470 (25/25°C)	215-300 (4 mm Hg)	217	>350	40	46-52			300-400
Aroclor 5180	clear, yellow-bean-ber, brittle resin	1.670 (25/25°C)	280-315 (5 mm Hg)	none	none		98-105.5	1.080-1.065		
Aroclor 2565	black, opaque, brittle resin	1.731 (25/25°C)		none	none		66-72			

^a ASTM D-20 (modified). ^b Cleveland open cup. ^c Cleveland open cup; none indicates no fire point up to boiling temperature. ^d ASTM D-97. ^e ASTM E-28. ^f Saybolt Universal, ASTM D-88. ^g Last two digits indicate approximate chlorine content, ie, Aroclor 1221 contains about 21% chlorine. ^h Hold point on solidification.

D. SEALANTS

Sealing and caulking compositions include a wide range of compounds which can be used to seal joints or voids against water and water vapor, air and other gases, dust, sound, vermin, heat and cold (88). Specialized applications require resistance to certain chemicals or atmospheric environments. PCBs can be used as plasticizers in the formulation of putties from copolymers or ethylene-vinyl acetate or styrene (89). The products are non-hardening, and resistant to moisture and frost and show good weatherability. A non-sticky, non-hardening putty was also prepared from polysulfide mixtures which employs PCB as the plasticizer. This putty gave good bonding to building materials and had good extrudability and shape retention (90). Elastic pavement or concrete sealing compositions, used for traffic markings, were prepared from coal-tar-polysulfide mixtures which are plasticized with PCB (91). A sealant, effective for concrete and asphalt applications, can be formulated from a mixture of polysulfide, chlorinated rubber, and polyisocyanate, and plasticized with PCB (92).

E. PRINTING

Chlorinated biphenyls have been employed as part of the formulations used to prepare pressure-sensitive record (93, 94) and colored copying papers (95, 96, 102, 103). They have been used to coat papers used in thermographic duplicating processes (97-101) as well as in xerographic transfer processes (104, 105). Solvent-free printing on polyolefin plastics can be accomplished by heating a mixture of low molecular weight material, chlorinated biphenyl or terpene resin, and suitable pigments and dyes. Durable prints can be made on the surface of the polyolefin at the time of their thermoplastic shaping (106). Printing plates, hard enough for high quality letterpress printing, and sufficiently flexible for use as flexographic plates, can be prepared from compositions containing a liquid resin such as epoxy, polyester, urethane, acrylic or vinyl with an excess of curing agent and PCB as the plasticizer (107). The extent, if any, of current uses of PCBs in printing application is unknown.

F. FIRE RETARDANT AND FLAME-PROOFING COMPOSITIONS

When PCBs are used as plasticizers, they impart a certain degree of non-flammability to the objects as described previously. However, for increased effectiveness in flame retardant applications, the PCBs can be admixed with various metal oxides. Some flame retardant compositions based upon these mixtures are: polyolefin yarns (108); organopolysiloxane sealants (109); thermoplastic poly (hydroxyethers) (110); fireproof panels made from starch which can be used for doors, floors, ceilings, and partitions (111); polyamides (112); and in fireproof fiberboards (113). Rigid polyurethane foams (114-116) and hardboard compositions (117), when treated only with PCBs do not show any significant increase in flame retardance.

G. MISCELLANEOUS APPLICATIONS

The wide range of chemical and physical properties exhibited by the PCBs (see Tables 6 and 7) make them desirable for an assortment of miscellaneous uses. Some of the more interesting and non-conventional uses are as follows:

transformers would require considerable time and money for reengineering, manufacture, and application of substitute equipment.

PCBs are useful in hydraulic systems where leakage onto hot metal surfaces could cause a dangerous fire. Hydraulic fluids can also be made with phosphate esters which are toxic and which will burn at high temperatures. Replacement of PCBs in some hydraulic systems could increase loss of life due to fire. Gas turbines require lubrication at high temperatures. PCBs can be used but tend to be corrosive. Phosphate ester lubricants seem better in this respect. Chemical stability is more important for high temperature lubricants than is non-flammability. PCB fluids are useful in diffusion booster pumps to produce moderately high vacuums with relatively poor fore vacuums. Non-flammability is not especially important for diffusion pump liquids, and with a few possible exceptions alternative liquids are available.

Flammable heat transfer fluids present a fire hazard if they leak into a furnace or onto hot surfaces. The use of PCBs can prevent this danger. In some cases water is a suitable substitute at moderately high temperatures. Other heat transfer fluids are commercially available and in use. Replacement of PCBs is satisfactory in some, but may be dangerous in other heat transfer uses.

The PCBs are good plasticizers for use with adhesives, textiles, surface coatings, sealants, and copy paper. In some cases the PCBs act as fire retardants. There are no particularly unique properties of PCBs for plasticizer uses, and equally effective alternatives are generally available (e.g. phosphate esters are often used as fire retardants). The extent of current use, if any, in such applications has not been determined.

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