Monsanto Industrial
Chemicals Co.
St. Louis, Missouri

DLE
Biodegradation Tests

Date: July 29, 1976

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S. Water
Biodegradation

APPLIED SCIENCES REPORT

BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

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BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

OBJECTIVE

To determine the biodegradability of current, potential and competitive products to aid in the assessment of their environmental compatibility.

SUMMARY

Biodegradation testing was carried out on 45 dielectric fluids and components using the semi-continuous activated sludge (SCAS) procedure for primary biodegradability and carbon dioxide evolution procedures for ultimate biodegradability. Among the chemical types studied were polychlorinated biphenyls (PCBs), halogenated diphenylmethanes, halogenated diphenyl and phenylalkyl ethers, and diaryl sulfones. The majority of these materials are multi-component mixtures. The validity of a simple biodegradability classification system is limited for mixtures because the biodegradation rates represent the average value of the components. However, classification is useful as an indicator of possible environmental problems. For the dielectric fluids and components, a biodegradability assessment was made in terms of two groupings (no ranking within groups):

Rapid to Intermediate Degradation Rate

- o-Chlorodiphenylmethane (MCS 1412)
- p-Chlorodiphenylmethane (MCS 1413)
- 3,4-Dichlorodiphenylmethane (MCS 1310)
- 2,4-Dichlorodiphenylmethane (MCS 1561)
- 2,4- and 3,4-Dichlorodiphenylmethane mixture (MCS 1560)
- Trichlorodiphenylmethane mixture (MCS 1558)
- m-Trifluoromethyldiphenyl ether (MCS ~~1340~~ 1311)
- 2,3,4,6-Tetrachloroanisole and pentachloroanisole mixture (MCS 1646).
- ~~Di(heptyl, nonyl, undecyl) phthalate (Santicizer 711)~~
- Di(2-ethylhexyl) phthalate (DEHP)
- Benzylated ethylbenzene (Santosol 100)
- Dimethylbenzophenone (MCS 1342)
- 21% Chlorinated biphenyl (Aroclor 1221)
- 30% Chlorinated biphenyl (MCS 1043)

Slowly degraded to resistant

- 2,4'- and 4,4'-Dichlorodiphenylmethane mixture (MCS 1559)
- 2,3',4'-, 3,3'4', and 4,3',4'-Trichlorodiphenylmethane mixture (MCS 1414)
- Trichlorodiphenylmethane mixture (MCS 1355)
- Bromodichlorodiphenylmethane mixture (MCS 1356B)
- Bis(trichlorobenzyl) benzene (MCS 1756)
- 2,2'-Dichlorodiphenyl ether
- Trichlorodiphenylether (MCS 1315)
- Pentachlorodiphenyl ether mixture
- Hexachlorodiphenyl ether mixture
- 2-Chloro- and 2,4-dichlorophenyl-n-butyl ether mixture (MCS 1239)
- n-Butylpentachlorophenyl ether (MCS 1645)
- 2,3,4,6-Tetrachlorophenyl-1-(2-Chloro-2-propenyl) ether (MCS 1647)

- MCS 1311 (m-trichloromethyl diphenyl ether
- MCS 1663 (tetrachlorothiophene)
- MCS 1664 (Hexachlorobutadiene

SUMMARY (Cont'd)

Slowly degraded to resistant

- Pentachlorodiphenyl sulfide mixture (MCS 1648)
- 2,4,5-Trichlorodiphenyl sulfide (MCS 1649)
- Dichlorodiphenyl sulfide mixture (MCS 1650)
- Diphenyl sulfone
- Tolyl xylyl sulfone (MCS 1302)
- Tolyl ethylphenyl sulfone (MCS 1313)
- Tolyl diethylphenyl sulfone (MCS 1312)
- Tolyl isopropylphenyl sulfone (MCS 1314)
- Ethylphenyl xylyl sulfone (MCS 1732)
- Mixture of di(heptyl, nonyl, undecyl) phthalate and tolyl xylyl sulfone (MCS 1475)
- Mixture of benzylated ethylbenzene, tolyl xylyl sulfone, and alkylbenzene (MCS 1476)
- Arobromclor 1232
- Aroclor 1016
- Aroclor 1242
- Aroclor 1254
- Methylphenylpolysiloxane (Dow-Corning 705)
- Bromodichloro benzene (MCS 1288)

From the biodegradability data obtained on these materials, several structure-biodegradability generalizations may be made:

1. Biodegradability of chlorinated aromatic congeners, e.g. chlorinated biphenyls, chlorinated diphenyl ethers, and chlorinated diphenylmethanes, decreases with increasing level of chlorination.

2. Degradation of halogenated diphenylmethanes proceeds via a halogenated phenylacetic acid intermediate.

3. Alkyl-substituted diaryl sulfones are moderately resistant to biodegradation.

TEST METHODS

I. Ultimate Biodegradation

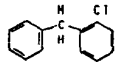
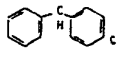
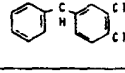
We define ultimate biodegradation as complete conversion of an organic material to carbon dioxide, water, inorganic salts and normal cellular products of bacteria. The rate and extent of CO_2 production by bacterial action is dependent on many variables. However, the extent of CO_2 production in a given time under constant conditions can be used as a measure of ultimate biodegradability of a material. Several test procedures have been developed for this purpose. Readily degradable materials such as dextrose and linear alkylbenzene sulfonate (LAS) typically yield 80-90% and 60-80% of theory, respectively, by these procedures. Since the bacterial systems used in these procedures are relatively weak, a material showing a high degree of conversion to CO_2 during the test interval is not likely to persist in the environment.

A. Thompson-Duthie-Sturm Procedure

In this procedure [J. Amer. Oil Chem. Soc. 50, 159 (1973); J. Water Poll. Control Fed. 40, 306 (1968)] a nine-liter bottle containing 500 ml of acclimated bacterial seed and 5,500 ml of standard BOD water is prepared for each test material and a control. Except for

TABLE I

PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability							
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (DA)		SCAS and PDC Analytical Method	
		Thompson -Duthie -Sturm procedure	Mansano Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc(ppb)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
						+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
				24-Hour Cycle						
MCS 1412 (o-chlorodiphenylmethane)		86 (35-Day)		3	> 97	Volatility loss ≤ 4%.			82.3 ± 8.9	AC-72-M-3
				13	> 99	+ For more detail see AC-73-SS-18.				
MCS 1413 (p-chlorodiphenylmethane)		80 (35-Day)		3	> 97	+			88.1 ± 5.4	AC-72-M-3
				13	> 99	+ For more detail see AC-73-SS-18.				
MCS 1310 (3,4-Dichlorodiphenylmethane)				3	> 98	Volatility loss ≤ 1%.			91.6 ± 3.7	AC-72-M-3
				13	> 99	+For more detail see AC-73-SS-18.				
MCS 1581 (2,4-Dichlorodiphenylmethane)		83 (35-Day)		3	> 97	Volatility loss ≤ 1%.			76.2 ± 5.5	AC-72-M-3
				13	> 99	+ For more detail see AC-73-SS-18.				

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PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

②

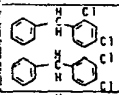
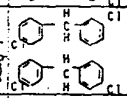
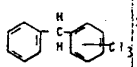
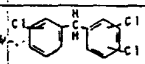
Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (RDA)		SCAS and RDA Analytical Method	
		Thompson -Buthie -Sturm procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc (ppm)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
				24-Hour Cycle		+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
K MCS 1560 (Mixture of 2,4- and 3,4-Dichlorodiphenyl methane)				3 13	> 97 > 99	Volatility loss ≤ 1%. + For more detail see AC-73-SS-18.			79.6 ± 1.6	AC-72-M-3
> MCS 1559 (Mixture of 2,4'- and 4,4'-Dichlorodiphenyl methane)				3	3 ± 6	Volatility loss ≤ 1%. + For more detail see AC-73-SS-18.			89.7 ± 2.3	AC-72-M-3
K MCS 1558 (Trichlorodiphenyl methane) CP 76793		26 (35-Day)		3 13	> 99 63 ± 10 27 ± 12	No detectable volatility loss (<0.1%) + + (13th-23rd week) + (24th-31st week) Slowly degrading trichlorophenylacetic acid metabolite formed.			71.3 ± 6.7	AC-75-M-15
MCS 1414 (Mixture of 2,3',4'-, 3,3',4'-, and 4,3',4'-trichlorodiphenyl methane) FA 76793				3	10 ± 10	Volatility loss ≤ 1%. ++ For more detail see AC-73-SS-18.			84.2 ± 5.1	AC-72-M-3

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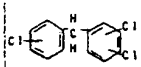
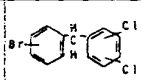
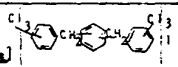
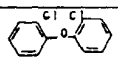
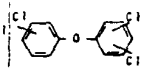
TABLE I

PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

③

Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (RDA)		SCAS and RDA Analytical Method	
		Thompson -Duthie -Sturm procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc(ppm)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
				24-Hour Cycle		+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
376793										
CS 1355 (Trichlorodiphenyl methane mixture)				3	6 ± 11	Volatility loss ≤ 1%. + For more detail see AC-73-SS-18.			77.5 ± 2.2	AC-72-M-3
CS 1356 (Bromodichlorodiphenyl methane mixture)				3	1 ± 10	Volatility loss ≤ 1%. + For more detail see AC-73-SS-18.			94.1 ± 4.8	AC-72-M-3
CS 1756 (Bis(trichlorobenzyl) benzene)		3 1 (35-Day)		3	7 ± 10	Volatility loss ≤ 1%. +			74.4 ± 4.5	AC-75-M-13
2,2'-Dichlorodiphenyl Ether				3	10 ± 4	+			87.3 ± 4.2	AC-71-M-17
CS 1315 (Trichlorodiphenyl ether)				48-Hour Cycle 3	24 ± 9	Volatility loss ~7%. ++ For more detail see AC-72-SS-13.			95.1 ± 6.3	AC-72-M-24

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PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

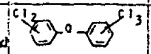
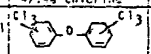
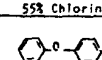
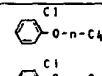
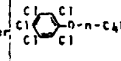
Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						SCAS and RDA Analytical Method	
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (RDA)				
		Thompson-Duthie-Stuma procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc (ppm)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
				24-Hour Cycle		+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
Tetrachlorodiphenyl ether mixture	 47.4% Chlorine			1	1 ± 12	Volatility loss not significant.			72.8 ± 2.6	AC-74-M-24
Trichlorodiphenyl ether mixture	 55% Chlorine			1	-4 ± 15	Volatility loss not significant.			78.9 ± 5.3	AC-74-M-24
MCS 1311 (Trifluoromethyl-phenyl ether)				3 13	68 ± 15 35 ± 12	Volatility loss 8-10%. ++ ++ For more detail see AC-72-SS-13.			83.9 ± 3.7	AC-72-M-24
1239 (Mixture of 2-chlorophenyl-butylether and 2,4-dichlorophenyl butyl ether)				3	45 ± 6	Volatility loss ~32%. ++ For more detail see AC-72-SS-13.			103.4 ± 11.2	AC-72-M-24
1645 (4-Butylpentachlorophenyl) ether				1	-1 ± 17	Volatility loss < 1%. +			70.2 ± 2.8	AC-74-M-5

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TABLE I

PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

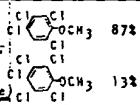
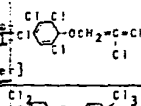
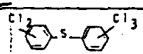
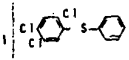
Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (RDA)		SCAS and RDA Analytical Methods	
		Thompson -Duthie -Sturm procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc(ppm)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
				24-Hour Cycle		-, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
MCS 1646 (Mixture of 2,3,4,6-Tetrachloroanisole and pentachloro anisole)	 87% 13%	82(28-Day)		1 3 13	> 95 > 99 > 99				78.8 ± 3.2	AC-74-M-6
MCS 1647 [2,3,4,6-Tetrachlorophenyl-1-(2-Chloro-2-propenyl) ether]				1	9 ± 5	Volatility loss ≤ 1%.			69.4 ± 3.7	AC-74-M-7
MCS 1648 (Pentachlorodiphenyl sulfide mixture	 50% Chlorine			1	5 ± 11	Volatility loss ≤ 1%. ++			100.6 ± 13.1	AC-74-M-8
MCS 1649 (2,4,5-Trichlorodiphenyl sulfide)				1	4 ± 6	Volatility loss ≤ 1%.			83.2 ± 3.3	AC-74-M-9

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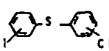
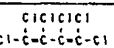
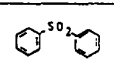
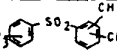
TABLE I

PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						Spill and Fire Ampliation Tests
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (Ala)			
		Thompson -Duthie -Stuvm procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±5% C.L.	Comments	Initial Conc(ppm)	Days Req'd for 90% Primary Degradation	% Recovery (Mass Balance Extraction)	Notes
				24-Hour Cycle		+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
MCS 1650 (Dichlorodiphenyl sulfide mixture)				1	19 ± 5	Volatility loss ≤ 1%. ++			101.6 ± 9.2	AC-74-M-40
MCS 1563 (Tetrachloro thiophene) CP 30487				1 3	Not detectable	Very high volatility losses.			71.4 ± 7.7	AC-74-M-11
MCS 1664 (Hexachloro butadiene) CP 45942				1 3	Not detectable	Very high volatility losses.			68.8 ± 2.6	AC-74-M-12
Diphenyl Sulfone				3	1 ± 6	Volatility loss ≤ 1%. For more detail see AC-72-SS-16.			94.0 ± 3.4	AC-72-M-6
MCS 1302 (Tolylxylyl sulfone) CP 16697				3 48-hour Cycle 3	23 ± 10 42 ± 12	+ Volatility loss ≤ 1%. + For more detail see AC-72-SS-16.			98.8 ± 6.5	AC-71-M-28 AC-72-M-4

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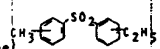
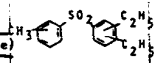
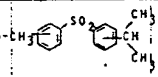
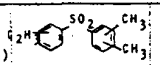
PRIMARY AND ULTIMATE BIODEGRADABILITY OF DIELECTRIC FLUIDS AND COMPONENTS

⑦

Test Material	Structure/ Composition	Ultimate Biodegradability (% of Theoretical CO_2 Evolution)		Primary Biodegradability						
				Semi-Continuous Activated Sludge (SCAS)			River Die-Away (ASA)		SCAS and [illegible] Individual Extracts	
		Thompson -Duthie -Sturm procedure	Monsanto Shake Flask procedure	Addition Rate (ppm added per cycle)	Primary % Degradation Rate ±95% C.L.	Comments	Initial Conc (ppm)	Days Req'd for 50% Primary Degradation	% Recovery (Mixed Liquor Extraction)	Method No.
				24-Hour Cycle		+, ++, and +/- indicate moderate, strong, and variable inhibition of sludge growth rate respectively.				
MCS 1313 (Tolylethyl phenyl sulfone)				3	36 ± 6	Volatility loss ≤ 1%. For more detail see AC-72-SS-16.			105.6 ± 14.3	AC-72-M-6
MCS 1312 (Tolyldiethyl phenyl sulfone)				3	13 ± 4	Volatility loss ≤ 1%. For more detail see AC-72-SS-16.			97.6 ± 3.8	AC-72-M-6
MCS 1314 (Tolyl isopropyl phenyl sulfone)				3	27 ± 8	Volatility loss ≤ 1%. For more detail see AC-72-SS-16.			111.2 ± 10.0	AC-72-M-6
MCS 1732 (Ethylphenyl xylyl sulfone)				3	17 ± 6	Volatility loss ≤ 1%.			96.8 ± 1.6	AC-75-M-14

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