COATINGS AS BARRIERS TO PREVENT POLYCHLORINATED BIPHENYL CONTAMINATION OF SILAGE[1,2]

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ABSTRACT

In past years polychlorinated biphenyls (PCB's) were incorporated into a coating material used on the inside of many concrete silos. These residues subsequently diffuse into silages and ultimately pass into food products produced by livestock that consume the PCB contaminated silage. Twelve coating materials were evaluated to determine if they would form a barrier to PCB residues. Coating materials were evaluated by coating PCB contaminated stave blocks, on test sections in a contaminated silo and on dairy farm silos that were contaminated. All coatings were not evaluated at all the test locations.

When PCB contaminated surfaces were treated with various barrier coatings and exposed to silage, 9 of the 12 coatings significantly ($P<.05$) reduced the concentration of Aroclor 1254 in silage compared to silage adjacent to control surfaces. Significant differences in the effectiveness of coating materials as barriers were also noted. Those coatings that were carried by water or a solvent in which Aroclor 1254 is not readily soluble, were among the most effective coatings. Coating materials with a base coat designed to seal the surface prior to application of the surface coating

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were more effective than two applications of a single formulation. Hydraulic cement with an acrylic bonder and water-carried epoxy effectively reduced the PCB residues in silage from contaminated dairy farm silos. The resulting concentrations of PCB in the milk from cows fed these silages were below the Food and Drug Administration "temporary tolerance" level.

INTRODUCTION

Many silos in the Eastern half of the United States have been treated with a coating material that contains polychlorinated biphenyl (PCB) residues. These residues appear in the silage as a result of disbdged chips from the contaminated coating and/or the PCB's from the coating being dissolved by the silage juices (14). This contamination process has continued for many years (more than 16 years observed) after the coating was applied and long after all visible traces of coating were gone (18).

The coating responsible for most, if not all the PCB contaminated silos was called Cumar[3]. Cumar was formulated in 1941 and was used by several silo companies until 1970. This material contained a mixture of coumarone-indene resins, a chlorinated rubber, clay, the PCB Aroclor 1254 (Monsanto Industrial Chemical Co.,St. Louis, Mo. 63166), the polychlorinated terphenyl (PCT) Aroclor 5460 (Monsanto) and carrier solvents. Similar formulations have been shown to provide excellent protection of concrete surfaces (17). Whereas the Aroclors were not specifically manufactured for incorporation into coatings (9), their plasticizing properties made their use advantageous (6, 11). The Aroclors comprised about 42% of the cured

[3] The Aroclor containing silo coating called "Cumar" should not be confused with Neville R-1-6A resin that has the same name.

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Cumar coating.

Consumption of silage from a PCB contaminated silo, by dairy cattle, results in the deposition of PCB residues in the body adipose tissues and secretion into milk via the fat (4, 6, 7). PCB residues in milk are now considered a chemical adulterant, therefore, the Food and Drug Administration in 1970 recommended an "actionable level" for milk at 5 ppm on a fat basis (8). A "temporary tolerance" of 2.5 ppm was established in 1973 (2).

The dairyman that has a PCB contaminated silo is confronted with a two-fold economic hazard: lost income from unmarketable milk and either elimination of the residue from the silo structure or lost use of the silo. Therefore, a research effort was undertaken to evaluate coating materials and systems of application that might be used as a barrier preventing further contamination of the silage with PCB's. The principle objective was to offer the dairyman a low cost alternative to the replacement of the silo structure. A preliminary report has been made (19).

METHODS AND MATERIALS

The coating materials were evaluated on PCB contaminated stave blocks, [illegible] test sections in a contaminated silo, and applied to existing silos on [illegible] western Ohio dairy farms. Twelve coatings were evaluated, however, [illegible] were not included in all of the trials. Coatings which demonstrated poor coverage or were an ineffective barrier to the PCB residues were eliminated from subsequent trials. New coatings, with similar properties as coatings that formed good barriers, were incorporated into subsequent trials.

Coating materials. The coating materials, their principle components

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and location of testing are shown in Table 1. The coatings that were evaluated in these studies, with the exception of VII and XIII, were selected on the basis of properties which were hypothesized to form an adequate barrier to PCB residues and resist the corrosive action of silage juices. These hypotheses were based on the formulation of the coatings and their performance when used in other applications. All were either commercially available or currently under development for application to silos. Coatings VII and XIII did not contain the properties thought to be necessary for a good barrier to PCB's, but since these had been recommended for use on farm silos they were included in the trials. All coatings were applied to the test surfaces in two coats, however, with coatings I, IV,V, and IX each application had a different formulation. With these materials, the first coat was formulated for penetration and sealing of the surface while the second application was to provide the desired surface. Coating XI was the combination of a single coat of an organic solvent-carried epoxy and a surface application of a water-carried epoxy.

Two cumar-Aroclor coatings were used for the stave block trials. In Block Trial 1 the finished cumar coating contained 5% Aroclor 1254. For Block Trial 2 some of the actual Cumar silo coating was obtained. This used coating contained about 32% Aroclor 1254.

Silo test sections. A silo,3.05 x 15.4 m that was built and coated with an Aroclor 1254 containing coating in 1954,was used. Rock fill, to a depth of 1.22 m was placed in the bottom to prevent interference from PCB residues that may have accumulated in the dirt floor. The silo was then divided into seven 1.22 - 2.44 m test sections which were separated by

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FIG. 1

Masonite dividers (Fig. 1). Chips of Masonite analyzed for PCB residues were found to contain .012 ppm. Since this concentration is nearly the same as the lowest levels found in silage, they would not significantly influence concentrations in the silage. The test sections, with the exception of a control, were wire brushed to prepare a sound surface for coating application. Coatings were applied at random to five sections. The test coatings were used to seal the junctions between the Masonite and the silo wall.

The silo was filled three times so that after each filling the settled silage level was even with the top of the sections. Two fillings were chopped corn and one a chopped grass-legume mixture. Sections were vertically sampled four months after each filling at 0, 60, 120, 180 and 240 cm from the base and horizontally at 0, 15, 20, 60, and 90 cm from the wall.

Stave block trials. Two trials were conducted on concrete silo stave blocks. In these trials the stave blocks (30 x 70 cm) were treated on one side with a cumar-Aroclor coating, then the entire block was recoated with the barrier coatings. The blocks used in trial 1 were very porous and the cumar coating contained 5% Aroclor 1254, whereas the blocks in trial 2 were smooth surfaced and treated with 32% Aroclor 1254. Untreated blocks and cumar-Aroclor blocks were maintained as controls.

The blocks were placed on end and at one side of polyethylene lined 208.2 l drums which were then filled with chopped whole corn plant and sealed. After standing for four months, they were sampled every 25 cm along the block and at 0, 25 and 45 cm from the block.

Dairy farm silos. Two silos in use on Northern Ohio dairy farms, which were known to be PCB contaminated, were selected for field tests of

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two coating materials. Samples of silo wall scrapings, silage and milk from the bulk tanks were analyzed to verify the existence of PCB residues.

The first silo was built in 1957 and coated with the PCB containing Cumar at that time. In 1972, this silo was cleaned by wire brush prior to application of two coats of hydraulic cement plus an acrylic bonder (coating VIII). This silo was subsequently filled once with a chopped grass-legume mixture and then once with chopped corn. The second silo was built in 1954 and treated with a PCB containing coating. In 1968 the pit and lower 2.44 m of this silo were treated with a furfuryl alcohol resin coating (coating I). In 1972, this silo was cleaned with high pressure water (51 kg/sq cm) and coated from the base of the pit to 11.3 m above ground level with water-carried epoxy (coating VI). The silo was filled once with chopped legumes and after emptying was refilled with corn silage.

Silage samples were collected from the farm silos at least biweekly. More frequent sampling occurred when the dairyman had to enter the silo to adjust the mechanical unloaders. Each sample consisted of a composite of silage collected adjacent to the wall from the north, south, east and west sides of the silo.

Extraction of silage. All solvents used to extract silage samples were analytical reagent grade. These were glass redistilled before use until a volume equivalent to the quantity used for extraction would yield no interfering peaks when injected into the gas liquid chromatograph (GLC) after being reduced to 1 ml and 5 µl were injected.

Silage samples were mechanically chopped until the largest particles were about 1 cm in size. Twenty-five g were then extracted with 250 ml

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acetone by mechanical shaking for 15 h. The particulate matter was then separated by filtering through Whatman No. 1 filter paper (prewashed with water, methanol and acetone) or glass wool. The acetone extract was taken up in 500 ml of 2% Na_2SO_4 and vigorously extracted with 200 then 150 ml petroleum ether (PE) (boiling range 30° to 60° C). The aqueous phase was discarded and the PE washed with 100 ml of 2% $NaHCO_3$. The PE was concentrated to about 10 ml on a rotary evaporator.

Column chromatography. Organic solvent extracts can be freed from interfering pigments (13) and many pesticides by florisil (12) and/or silica gel columns (1, 16). Columns to clean the PE extracts were prepared by placing 6.0 cm (7.5 g) of activated florisil (Kensington, 650° C activation, 60/100 mesh) in the bottom of a 23 mm column fitted with glass wool in the bottom. On top of this was placed 14.0 cm (26 g) of silica gel (Matheson, Coleman & Bell, grade 923) and 2.5 cm (12 g) of anhydrous Na_2SO_4. Column packing materials were stored in an oven at 110° C until used. The prepared columns were prewashed with 100 ml of PE, the extracts were applied and they were eluted with 250 ml of 2% benzene in PE. The volume of the column eluates was reduced in vacuo on the rotary evaporator (42° C) in preparation for GLC analysis. Care was taken to avoid contamination of the sample by reflux during rotary evaporation.

Saponification and acid extraction. Selected extracts were saponified with alcoholic KOH (2.5% w/v) and extracted with H_2SO_4 (16 normal) by the method described by Monsanto (10) and modified as follows. Methanol was used to prepare the alcoholic KOH and PE was used for extractions. The selected extracts were refluxed for 45 min in 25 ml of alcoholic KOH then

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extracted 2 times with 25 ml of PE. The combined extracts were then extracted with 25 ml of H_2SO_4. The PE extracts were rechromatographed as previously described.

Gas chromatography. An F&M model 402 GLC with a ^{63}Ni detector was used for all analyses. A 2.44 m glass column of 4% DC-200 and 6% QF-1 (1:1) on Gas-Chrom Q (80/100 mesh) was used with Argon-Methane (95:5) as carrier and purge. Running conditions were: flash heater 230° C, column oven 210° C, detector 300° C and gas flow 40 to 50 ml/min. All samples were diluted so that they were detected within one linear attenuation range of the detector.

Quantitations. Quantiation of the chromatograms was based on total area under peak F through peak M (Fig. 2). Area was determined by Disc integrator. This quantitation method was used to eliminate the influence of an unidentified contaminant with a short retention time, which appeared in some silage samples.

FIG. 2

Corrections for method loss were based on the extraction of silage to which known quantities of Aroclor 1254 were added. These standards ranged from 0 to 2 ppm. Recoveries did not vary significantly among the various types of silage.

Dry matter determination. The water content of the silages were variable, therefore, the concentrations of Aroclor were expressed on a dry matter basis. Silage dry matters were determined by weight loss of samples oven dried for 48 h at 110° C.

Data Analyses. The data from the three silo trials were analyzed by Least-Squares Analysis of Variance (LSANOV) as a split-split plot model. The variables of this model were the Aroclor levels in silage as influenced

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by the five coating treatments plus the untreated control section; the horizontal and vertical sample collection positions; and the three silo fillings. The PCB values in the silage were highly variable among the various sampling locations. Therefore, the data was transformed to the Log (ppm Aroclor) + 1 prior to analysis. Similar LSANOV analyses were conducted for the two block trials without transformation of the data.

Hartley's Sequential Range Test (15) was used to test for significant differences among treatment means.

RESULTS AND DISCUSSION

Relative peak areas for standard Aroclor 1254 were essentially the same as the Aroclor extracted from silage. Typical GLC tracings of silage ex-
FIG. 3 tracted and standard Aroclor are shown in Fig. 3. Results indicated that the microorganisms or juices in the silage did not alter or selectively extract the Aroclor components. These findings are confirmed by the work of Fries (6) and Skrentny et al. (14). Since there appeared to be no appreciable alteration of the Aroclor by the silage, and saponification plus acid extraction did not alter the relationship between the major peaks, the total area under peak F through peak M was considered a valid quantitation method.

Attempts to detect the PCT's that were also a component of the Cedar silo coating were not made. Even though they were probably extracted by the procedures that were used, the PCT's were not eluted at the maximum temperatures of the liquid phase of the GLC column (5).

The average ppm of Aroclor 1254 in silage from the three silo trials and two block trials are shown in Fig. 3. Each bar of the histograms re-

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presents the average Aroclor 1254 concentration of all samples analyzed representing all sampling locations. The comparisons of significant differences among means are shown in Table 2.

TABLE 2

Generally speaking, all of the coatings that were hypothesized to form barriers to PCB residues did so when evaluated on the silo test sections and/or stave blocks. The two commercial coatings that did not have properties predicted to be necessary for a good PCB barrier were indeed ineffective when tested. The LSANOV for the silo and block trials indicated that the concentration of Aroclor 1254 in the silage was significantly ($P<.01$) affected by coating treatments.

The coatings applied to the silo sections greatly reduced the PCB concentration when compared to the untreated control section, and significant differences were observed between the individual coatings (Table 2). All of the coatings adhered well to the silo wall. With the exception of the water-carried epoxy in coating XI, coverage was good. This water-carried epoxy did not provide desirable coverage over the thinly applied solvent-carried epoxy. The thickness of coatings I, II, and V was about the same and ranged from .01 to .09 cm. The hydraulic cement material (VIII) provided a very thick coating ranging between .35 and .72 cm. A film thickness could not be determined for coating XI.

Results of the silo trials (Fig. 3) suggested that the solvent used to carry the coating materials may influence effectiveness of the coating. Aroclor 1254 has been shown to be readily dissolved in the methyl isobutyl ketone (MIBK), cellosolve and xylene which are found in coatings II, V, and XI (9). The Aroclor has low solubility in isopropanol used in coating I

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and is insoluble in the water used to carry coating VIII. In contrast, coatings IV, V and XI with MIBK, cellosolve and xylene respectively, were among the most effective barriers when evaluated on the stave blocks (Fig. 3).

The coatings maintained their relative effectiveness throughout the three silo trials. There were no significant differences ($P>.05$) between the three silages tested, indicating that different types of silage had no effect on the levels of Aroclor in silage nor did the barriers become less effective with continued usage.

The levels of Aroclor 1254 in the silages from block trial 1 were considerably lower than in either block trial 2 or in the silo (Fig. 3). This probably resulted from the lower concentration of Aroclor 1254 in the cumar coating and porous surfaces of the blocks of trial 1. The porous surface allowed the cumar-Aroclor to penetrate, thus reducing the amount of Aroclor that was in close contact with the barrier coating and silage.

This experiment indicated that a coating that contains a solvent in which Aroclor is very soluble (9) should not be used. Coating VII contained kerosene which resulted in significantly greater contamination of the silage than did the cumar-Aroclor control.

The advantage of two-component coating systems was shown in the block trials. In these studies a two-component coating system utilized a modified formulation to serve as a sealing base coat. Then the second component of similar material formed the coating surface. Coatings I, IV, V and IX were all two-component systems. These materials, with the exception of coating I, were among the most effective in this trial (Fig. 3). Coatings II and

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III were two applications of the single-component equivalents of coatings IV and IX, respectively. The two-component systems were significantly ($P < .05$) more effective than the single-component formulation of the same material (Table 2).

Coating I was not an effective barrier to the PCB residues nor did it form the desired smooth surface in block trial 1. The surface of the coating was not smooth and solid as it subsequently appeared to be on the silo wall and in the second block trial. It was suspected that improper formulation or application was responsible.

In block trial 2, three water-carried systems, two dual-component systems and a commercial silo coating were evaluated on relatively nonporous stave blocks. Coatings I, IV, VI, VII and XII significantly ($P<.05$) reduced the Aroclor 1254 residue in the silages. There were no significant differences among these coatings (Table 2). The commercial coating XIII was not significantly different from the untreated control. This coating was softened by the silage juices, and consequently did not form an adequate barrier to the PCB residues.

Coatings I, IV, VI, and XIII showed signs of physical failure when examined at the end of this trial. These coatings cracked or blistered indicating that they were unable to bond to a smooth Cumar surface. This indicated that these coatings should only be used on silos that no longer have a solid and intact Cumar finish.

The Aroclor 1254 concentration of silage was significantly ($P<.01$) influenced by the distance from the silo wall or the stave block. Significant ($P<.01$) linear and quadratic effects were also noted within the silo.

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FIG. 4 Figure 4 shows the average distribution of Aroclor from the silo test sections. The average from all sections was used.

This distribution was as expected since the mechanism by which the residues migrated was probably diffusion. These results agree with those of Skrentny et al. (14) with the exception that beyond 15 cm from the silo wall, higher levels were detected in this study. This may only reflect silo and methodology differences. Also, these workers (14) did not state whether Aroclor levels of silages were on a wet or dry matter basis.

Concentrations of Aroclor were significantly ($P<.05$) higher near the base of the silo test sections. This may be the result of the downward leaching of the silage juices. Leaching would deposit the PCB residues near the base of the silo. This effect was not observed in the drum experiments. The drums were sealed and contained a relatively small volume of silage, thus extensive leaching would not be expected.

Based on the results of the silo and block trials and commercial availability, hydraulic cement (VIII) and water-carried epoxy (VI) were selected for use on two dairy farm silos. Both silos were known to contain sufficient PCB's to cause the residue level in the herd milk to exceed .2 ppm. The histories and preparations of the silos was previously described (page 5). Concentrations (ppm) of Aroclor 1254 in scraping of the silo walls and in silage before and after recoating are shown in Table 3. TABLE 3

Concentrations of Aroclor were extremely high both in wall scrapings and silage near the base of silo 1. Unfortunately, this silo was nearly empty when located for experimentation so only limited precoating data was available. The concentrations observed near the base may not be repre-

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sentative of the entire silo as the residues may have accumulated near the base, as a result of downward leaching of silage juice. However, the high concentration of Aroclor residue (>.6 ppm) present in the milk produced on that farm indicated that the cows had been consuming considerable quantities of PCB.

The hydraulic cement coating VIII that was applied to this silo, after thoroughly cleaning the walls with a wire brush, provided an effective barrier between the contaminated silo wall and the silage (Table 3). The concentration of Aroclor 1254 did not reach .5 ppm during the two trials and the PCB residue in milk continually declined throughout the experiment. After three fillings of silage there has been no indication of failure of the coating.

The base of silo 2 had been coated by the owner with a furfuryl alcohol resin coating (I) prior to the discovery of the PCB contamination. The concentrations in scrapings of and silage adjacent to this recoated area were considerably less than similar samples collected above the coated area (Table 3).

The entire silo was cleaned with high pressure water (51 kg/sq cm) then recoated to the 11.3 m level with the water-carried epoxy (VI). The levels of PCB in the silage collected above the recoated area were high (Table 3). However, the residues were significantly reduced when collected adjacent to the surfaces coated with the water-carried epoxy. The high PCB concentrations observed near the top of the coated area probably resulted from settling of the silage and the downward leaching of the silage juice. As observed with silo 1 no failure of the coating was evident after two trials.

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GENERAL DISCUSSION

The results of these experiments with barrier coatings have demonstrated that a number of coating materials will form an effective barrier to prevent significant PCB contamination of silage. Two coatings (VIII and VI) have been shown to provide sufficient protection of the silage when used on PCB contaminated silos that were in use on dairy farms. Based on the experimental tests one would expect similar results could be achieved with some of the other coatings that were tested. The vinyl coatings (II, IX) and the organic solvent-carried epoxy coatings (IV,V) were shown to provide a barrier to the PCB residues, but the organic solvents used as carriers may reduce their effectiveness as compared to the water-carried systems. Coating I was effective in the silo trials, block trial 2 and remained as a barrier five years after application to the base of silo 2. Coating XII was a water-carried epoxy similar to VI, therefore, may form a successful barrier to PCB's in a farm silo.

With the exception of block trial 2, all of the coatings were evaluated on a rough surface. In these trials the bonding of the materials to the surface was good. The poor bonding that was observed on the smooth blocks in trial 2 suggests that barrier coatings may fail to provide an adequate protective barrier in silos having an intact smooth Cumar coating. Likewise, bonding problems should be anticipated on silos that had been wax treated or were improperly cleaned prior to recoating.

Results of these studies have indicated that PCB contaminated silos can be effectively decontaminated by the application of a barrier coating. The cost of decontamination (labor and materials) ranges from 10 to 18% of

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the silo replacement cost. Thus, on silos with sound porous surfaces, recoating is a practical alternative to the total replacement of the silo structure.

Careful selection of a coating material is advised. The components of certain commercial coatings are not approved by the Food and Drug Administration for use in livestock food storage containers. Likewise, use of some coatings, particularly those that contain organic solvents, cannot be used in certain areas as they will not meet air quality standards or occupational health standards during application.

The effective life span for a barrier coating has not been determined at this time. Continued observation of recoated silos will eventually provide this information. Some silo coatings have remained intact for as long as 10 years when used to seal the inner surfaces of silos. It should be emphasized that the effective life span of a barrier coating will be greatly reduced if the silo surface is improperly cleaned and prepared prior to recoating.

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TABLE 1. The identification, principle components, principle solvents and test locations of the barrier coatings tested.

Coating Numeral	Coating Type	Principle Component[9]	Principle Solvent[9]	Where Tested: Silo	Block	Farm Silo	Name[8]
I	Furfuryl[1]	Furfuryl alcohol resin	Isopropanol	x	x		Silenzcrete[2]
II	Vinyl	Vinyl resin	MIBK[7]	x	x		Monolite[2]
III	Epoxy	Epoxy resin	Xylene		x		Epoxy[2]
IV	Epoxy[1]	Epoxy resin	Xylene		x		Epoxy[2]
V	Epoxy[1]	Epoxy resin	Cellosolve	x	x		808-909[4]
VI	Water epoxy	Epoxy resin	Water		x	x	009[4]
VII	Thermoplastic hydrocarbon	Alkyl aeromatic hydrocarbon	Kerosene		x		Type"O"[6]
VIII	Hydraulic cement	Cement + acrylic	Water	x	x	x	Thoroseal[5]
IX	Vinyl[1]	Vinyl resin	MIBK[7]		x		Monolite[2]
X	CONTROL	Cumar-Aroclor	Mineral spirits or Xylol				
XI	Epoxy + Water epoxy	Epoxy resin	Xylene Water	x			Epoxy[2, 3] Waterpoxy
XII	Epoxy filler	Epoxy resin	Water		x		Block filler[4]
XIII	Phenolic resin	Amberol	Isopropanol Methanol		x		44C Sealer[6]

[1] Two component coating system

[2] Universal Cooperatives, Alliance, Ohio

[3] General Mills Chemicals Co., Minneapolis, Minnesota

[4] Action Plastic, Inc., Charlotte, Michigan

[5] Standard Dry Wall, Inc., Miami, Florida

[6] Whitteker Corp., Wooster, Ohio

[7] Methyl Isobutyl Ketone

[8] The use of trade names is only to identify the products used. The use of trade names is not an endorsement of the products used nor meant to discriminate against similar products not used.

[9] As stated by the manufacturer.

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TABLE 2. The comparison of differences in mean concentrations of Aroclor 1254 in silages from the barrier coating trials. Significant differences were determined by Hartley's Sequential Range Test.

Coating Numeral	Trial	COATING NUMERAL I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
	Silo		<[a]			<			<		<	<		
I	Block 1		>[b]	ns[c]	>	>	>	<	>	>	ns			
	Block 2				ns		ns		ns		<		ns	<
	Silo	>				ns			ns		<	ns		
II	Block 1	<		<	ns	ns	>	<	>	>	<			
	Block 2													
	Silo													
III	Block 1	ns	>		>	>	>	<	>	>	ns			
	Block 2													
	Silo													
IV	Block 1	<	ns	<		ns	<	<	ns	ns	<			
	Block 2	ns					ns		ns		<		ns	<
	Silo	>	ns						>	ns	<	ns		
V	Block 1	<	ns	<	ns		<	<	>	>	<			
	Block 2													
	Silo													
VI	Block 1	<	<	<	>	>		<	>	>	<			
	Block 2	ns			ns				ns		<		ns	<
	Silo													
VII	Block 1	>	>	>	>	>	>		>	>	>			
	Block 2													
	Silo	>	ns			<					<	<		
VIII	Block 1	<	<	<	ns	<	<	<		ns	<			
	Block 2	ns			ns		ns				<		ns	<
	Silo													
IX	Block 1	<	<	<	ns	<	<	<	ns		<			
	Block 2													
	Silo	>	>			>			>			>		
X	Block 1	ns	>	ns	>	>	>	<	>	>				
	Block 2	>					>		>				>	ns
	Silo	>	ns			ns			>		<			
XI	Block 1													
	Block 2													
	Silo													
XII	Block 1													
	Block 2	ns			ns		ns		ns		<			<
	Silo													
XIII	Block 1													
	Block 2	>			>		>		>		ns			

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FOOTNOTES FOR TABLE 2

[a] Coating on vertical axis is significantly more effective than ($P<.05$) coating on horizontal axis.

[b] Coating on vertical axis is significantly less effective than ($P<.05$) coating on horizontal axis.

[c] Coating effectiveness is not significantly ($P\geq.05$) different.

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TABLE 3. Levels of PCB (ppm Aroclor 1254) in silage and silo wall surfaces collected before and after recoating.

Level silage collected	Silo 1[a]				Silo 2[b]			
	Scrapings before recoating	Silage before recoating[c]	Silage after recoating[c]		Scrapings before recoating	Silage before recoating[c]	Silage after recoating[c]	
			Trial 1	Trial 2			Trial 1	Trial 2
(m)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
13.7			0.013				20.68	
12.2							58.98	13.43
10.7				0.06			28.80	18.23
10.1							1.91	1.31
9.1			0.013	0.05			0.85	0.69
8.2								0.40
7.6			0.08	0.07			1.06	0.62
6.1			0.27	0.02	314.02	5.11	1.00	0.62
5.2				0.07				
4.6			0.38	0.08	175.37	8.04		0.50
3.7				0.10				
3.1			0.42	0.11	705.27		0.88	0.98
2.1				0.16			0.61	0.86
1.5	20155.00	103.00[d]	0.24	0.10		0.99	0.35	0.48
0.3		7131.88		0.11				
0.0			0.29	0.07	4.90	0.03	0.48	
-0.6					3.60		1.56	1.19

[a] Silo was coated with hydraulic cement with an acrylic bonder (coating I).

[b] Silo was coated with water-carried epoxy from the base of the pit to 11.3 m above the ground (coating VI).

[c] Sampled adjacent to the silo wall.

[d] This sample was a blend, not adjacent to the silo wall.

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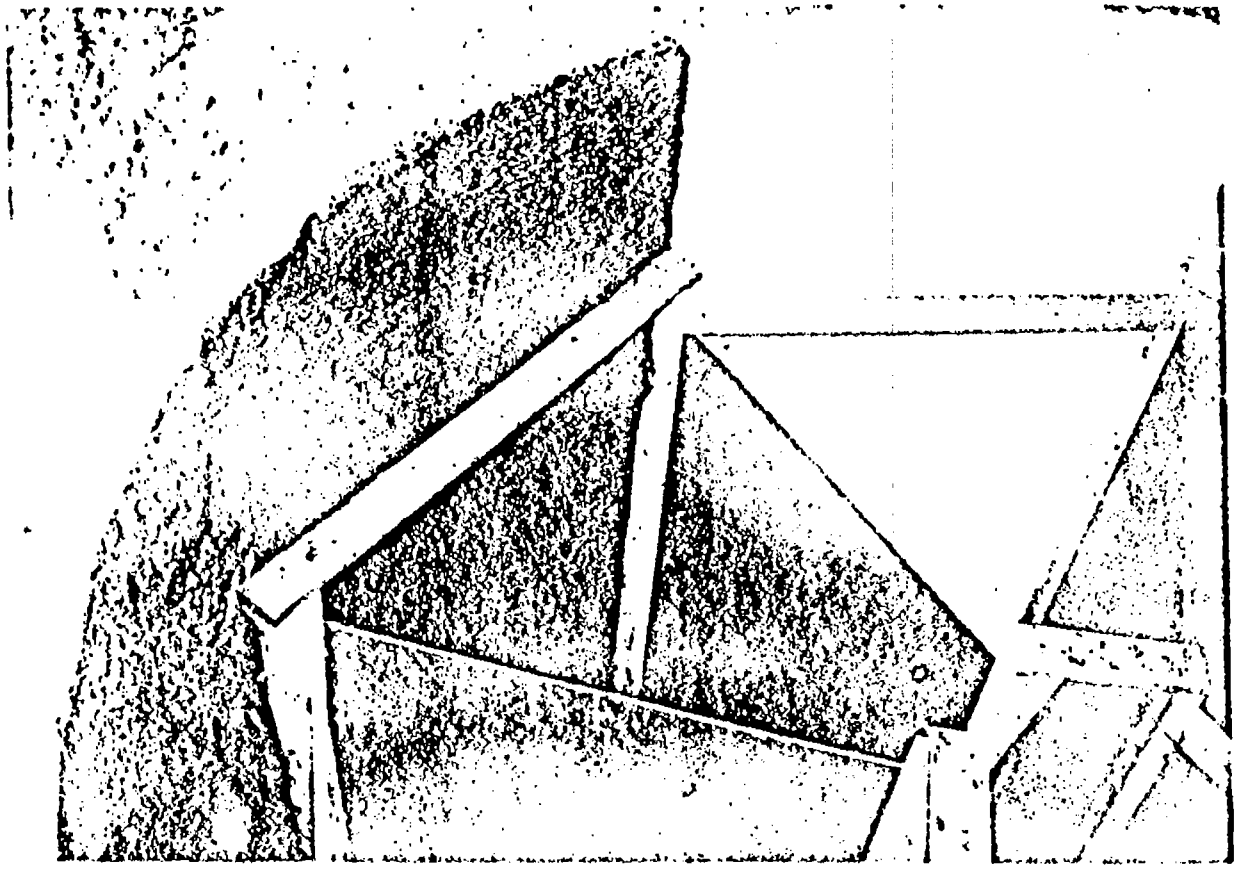

FIG. 1. Dividers made of Masonite were used to separate the coating test sections in a PCB contaminated silo. The test coatings were used to seal the junctions between the Masonite and the silo wall.

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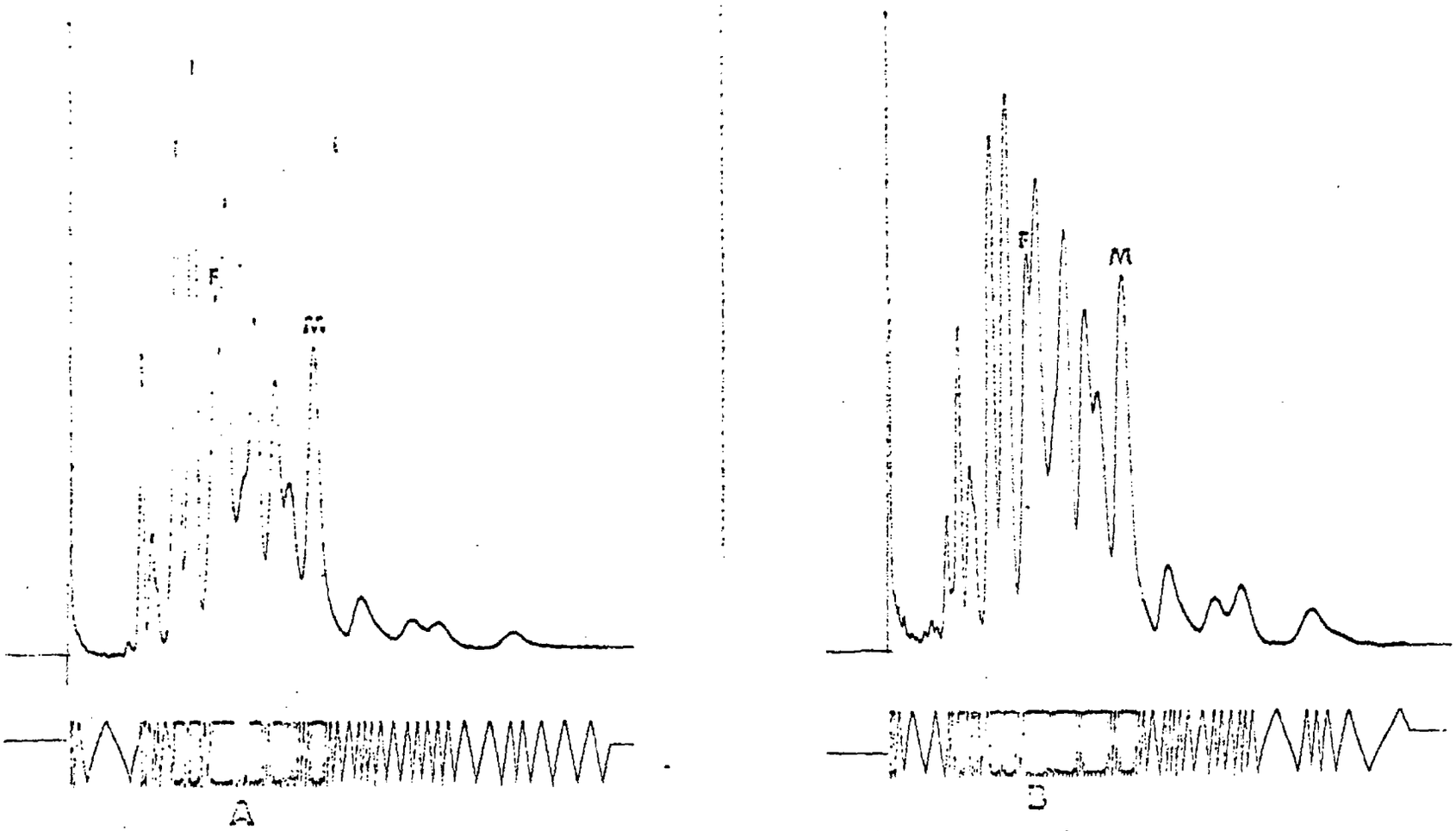

FIG. 2. Typical chromatograms of standard Aroclor 1254 (A) and Aroclor 1254 extracted from silage (B). Quantitations were based on the total areas of peaks F through M.

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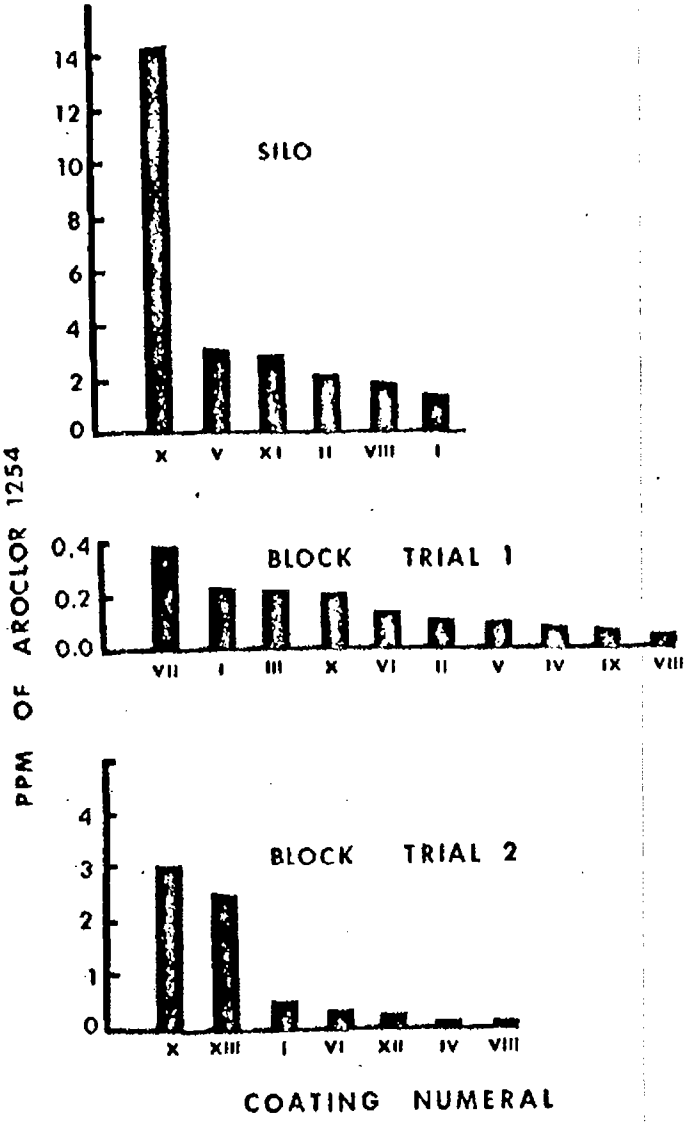

FIG. 3. Average concentrations (ppm) of Aroclor 1254 in silage from the various barrier coatings test locations. Each bar of the histograms represents the average from all sampling locations. The X is the untreated control section in the silo and the Aroclor-cumar coatings in the block trials.

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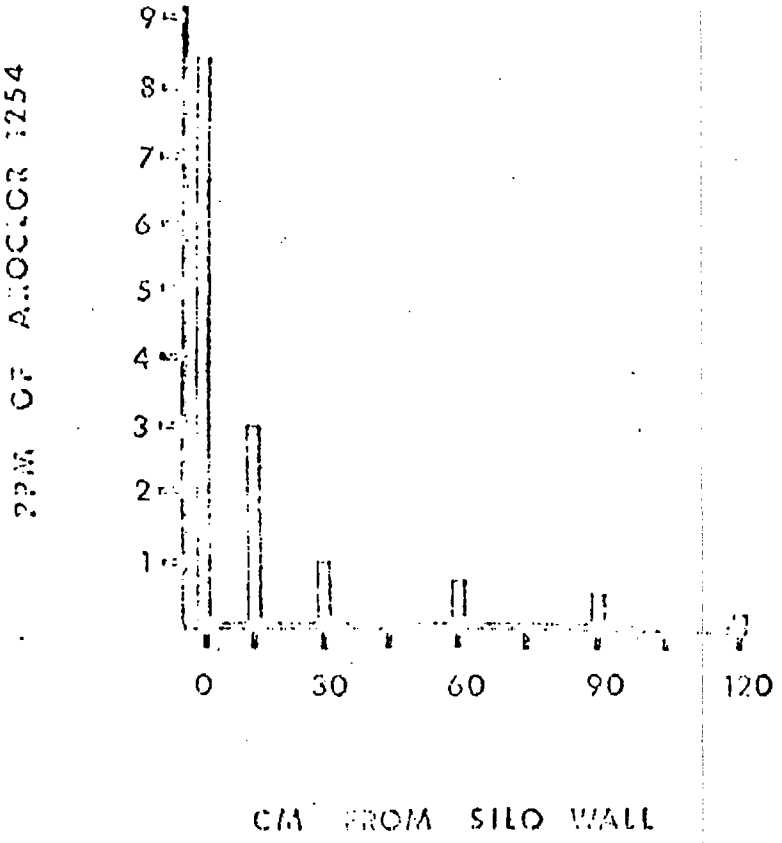

FIG. 4. The average horizontal distribution of Aroclor 1254 in the silo test sections. Each bar of the histogram represents the average from all coating and control sections.

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