

Table 16. Studies on Laundering Pesticides from Contaminated Clothing

Reference	Pesticide (water solubility)	Formulation	Fabrics	Laundry or Decontamination Variables	Results
Braun et al. [1989]	Pyrazophos (4 mg/L at 20°C) Spray on three layers of cloth; spill on three layers of cloth	Water solution (450 mg/L)	Cotton polyester coverall fabric, contaminated and uncontaminated clothes washed together	Automatic washing machine, heavy-duty detergent, single wash, 2 rinses; double wash; pre-soak plus double wash.	Single wash removed 78% of pyrazophos from spray-on and 83% from spill-on; double wash removed 92% and 94%, respectively. Pre- soak did not improve on double wash. Transfer fabrics had 68% of the residual contamination of the contaminated fabrics. Second and third layers had traces of pyrazophos when sprayed on and slightly more when spilled on.
Chiao-Cheng et al. [1988]	Carbofuran (700 mg/L) methomyl (60,000 mg/L)	Water suspension Water soluble liquid	100% cotton and 100% polyester	60°C and 49°C washes. Anionic and non- ionic washes.	More than 99% of the pesticides were removed from both fabrics by all laundering methods
Easley et al. [1981b]	Methyl parathion (50-60 mg/L at 20°C)	Emulsifiable concentrate encapsulated wettable powder	Denim, 100% cotton and 50/50 cotton-polyester	Pre-rinse, detergent, ammonia and chlorine bleach.	Fabric was not a factor in removal. For encapsulated and wettable powder forms, 93-99% of methyl parathion was removed; for emulsifiable concentrate, 80-88% was removed by the different laundry procedures. Pre-rinse was the most effective variable; ammonia the least effective.
Easley et al. [1982a]	Methyl parathion	Emulsifiable concentrate solutions 0.25-54%	Denim, 100% cotton twill	Heavy duty liquid detergent, 1 wash cycle, 2 rinse cycles. Repeated up to 10 times.	More than 95% methyl parathion was removed when applied as 0.25 and 0.50% solutions. Only 19.5% was removed by first wash when applied as a 54% solution, and only 67% had been removed after 10 washes.

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Easley et al. [1982b]	Methyl parathion	Emulsifiable concentrate 1.25% solution	100% Cotton and 50/50 cotton-polyester	30°C, 49°C, and 60°C washes detergents: 8.7% phosphate; carbonate; non-phosphate heavy duty liquid; 12% phosphate.	50% removal at 30°C; 70% or greater removal at 49°C and 60°C. Heavy duty liquid detergent slightly better than others at 49°C and 60°C.
Easley et al. [1983]	2,4-dichlorophenoxyacetic acid (2,4-D) ester and 2,4-D amine (ester, insoluble) (amine 4-18 g/L at 30°C)		Denim, 80/20 cotton-polyester contaminated; 50/50 cotton-polyester transfer fabric	60°C wash/49°C rinse; 30°C wash/30°C rinse; pre-rinse/no pre-rinse; heavy duty liquid non-phosphate detergent; 12% phosphate detergent; ammonia/no ammonia; repeated washing.	2,4-D ester, 26-45% removed, 1-2% transferred; pre-rinse had no effect; ammonia had no effect; 30°C wash, 26% removed; 60°C wash 45% removed; non-phosphate detergent removed 31%; one wash removed about 30%; two washes removed about 41%. 2,4-D amine, more than 99% removed by all treatments; transfer 0.02-0.26%.
Easter [1983] Easter and DeJonge [1985]	Captan (3 mg/L at 77°C) Guthion® (29 mg/L at 25°C)	Aqueous suspension Emulsifiable concentrate	Denim 100% Cotton twill Nylon Microporous film fabric, 3 layers	38°C, 49°C, 60°C washes, 2 rinses. Heavy duty liquid detergent with both anionic and non-ionic surfactants.	Captan-cotton, 73%, 98%, and 99% removal at 38°C, 49°C, and 60°C; nylon, 98% removal at 38°C, greater than 99% removal at 49°C and 60°C. Guthion®-cotton, 94%, 96%, and 98% removal at 38°C, 49°C, and 60°C; nylon 86%, 91%, and 92% removal at 38°C, 49°C, and 60°C.
Finley and Rogillo [1969]	DDT (insoluble) methyl parathion	Fabrics worn in cotton fields for 8 hours on the day after spraying	100/0, 35/65, 50/50, 65/35 cotton-polyester shirting type fabric with durable press finish or soil release or soil release finish (65/35 only)	Laundered in automatic washer and electric dryer.	DDT averaged 81.8 ppm in clothing before laundering, 24.9 ppm after; 100/0 and 65/35 cotton-polyester collected and retained more DDT than other fabrics. Methyl parathion averaged 7.7 ppm in clothing before laundering and 0.2 ppm after laundering. 100/0 and 65/35 cotton-polyester collected more parathion than other fabrics and also retained more, but not as much as with DDT.

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Finley et al. [1974]	Methyl parathion Toxaphene-methyl parathion-DDT (toxaphene 3 mg/L)	Emulsifiable concentrate	100% Cotton. 50/50 Cotton- polyester	60°C, 2 rinses, standard detergent, small (19.85 L) electric portable washer. Contaminated and clean fabrics washed 1, 2, or 3 times.	Toxaphene and DDT were difficult to remove from fabric after first wash. Transfer of all three pesticides when applied as a mixture was much greater for the 50/50 cotton-polyester than for 100% cotton. When methyl parathion was applied by itself, there was no difference in transfer by fabric type. All <i>Drosophila</i> confined on washed fabrics that had been contaminated with the mixture died.
Goodman et al. [1988]	Methyl parathion 5 days contamination with and without daily laundering	Emulsifiable concentrate 1.25%	100% Cotton poplin. 50/50 cotton-polyester poplin finished and unfinished with a fluoro- carbon renewable soilrepellent finish	49°C water, 2 rinses, pre-wash, non-ionic heavy-duty liquid detergent, agitation by 25 stainless steel balls.	Residue after washing daily was less for soil-repellent fabrics. Residue increased daily when washing was not done daily. Both contamination levels and residuals were less with soil-repellent finish when laundering was not done daily. Methyl parathion concentrations in water were much less with daily laundering.
Graves et al. [1980]	Permethrin (0.2 mg/L at 20°C)	Fabrics worn in cotton fields on days 1, 2, or 4 after spraying	Heavy all cotton fabric, 2 layers	Single laundering in hot water, heavy-duty detergent, dry bleach, perborate additive.	Contamination: Outer layer day 1, 25.8 ppm; day 2, 14.4 ppm; day 4, 3.8 ppm; under layer day 1, 19.9 ppm; day 2, 14.4 ppm; day 4, 1.2 ppm. After laundering: Outer layer day 1, 15.3 ppm; day 2, 9.2 ppm; day 4, 1.6 ppm; under layer day 1, 9.4 ppm; day 2, 5.8 ppm; day 4, 0.6 ppm.

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Hild et al. [1989]	Methyl parathion	Emulsifiable concentrate	50/50 Cotton-polyester with and without soil repellent	40°C wash, non-ionic heavy-duty liquid detergent; phosphate-based powdered anionic detergent: Prewash product, air dried, 50, 100, 150, and 225 mL water, 0, 10, 25, 50 steel balls.	No effect of detergent type. Increasing detergent decreased residue, increasing water level decreased residue, agitation (steel balls) had no effect. Residues always greater with soil repellent. All treatments removed more than 98% of contaminant.
Keaschall et al. [1986]	Organophosphates: chlorpyrifos (2 mg/L) dichlorvos (5 g/L) diazinon (40 mg/L) dimethoate (25 g/L) malathion (200 g/L) methyl parathion Carbamates: carbofuran (700 mg/L) propoxur (2 g/L) Organochlorines: aldrin (30 mg/L) chlordane (1 mg/L) lindane (10 mg/L)	All emulsifiable concentrates except carbofuran which was a flowable formulation	50/50 Cotton-polyester, unfinished and fluorocarbon finishes consumer applied and commercially applied	49°C wash, 2 rinses, detergent, pre-wash spray or degreaser.	Dichlorvos, dimethoate, malathion, carbofuran and propoxur were effectively removed from all fabrics by washing; chlorpyrifos, aldrin, and lindane were least effectively removed. Fluorocarbon finishes reduced absorption of pesticides by the fabrics, but did not facilitate removal by laundering. The laundry additives significantly aided residue removal.
Kim and Wang [1992]	Atrazine 30 mg/L at 20°C	Water-dispersible granules, unground and ground (dust) 1 gram sewed into pockets	Heavy weight cotton twill	60°C and 49°C, heavy duty liquid detergent with anionic and non-ionic surfactants, 10 and 30 steel balls (agitation), machine and air drying, accelerated laundering apparatus, 300 mL water, clean cloths laundered with contaminated ones.	Over 99% of the initial contamination was removed by the washing and drying process. The amounts in the transfer cloths were 0.05-0.25% of the initial contamination. The 60°C water removed more atrazine and resulted in lower transfer to clean cloths. Drying methods had no effect.

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Kim et al. [1993]	Atrazine (30 mg/L) Metolachlor (530 mg/L)	Water dispersable granules Wettable powder Flowable liquid Emulsifiable concentrate 1 gram sewed into sockets	100% Cotton heavy weight twill	60°C wash, heavy duty liquid detergent, 2 rinses, machine dried.	More than 99% of all atrazine formulations were removed, but only 90% of metolachlor. Emulsifier appeared to inhibit removal of the more soluble metolachlor. Atrazine in transfer cloths was 13-50% of residues in contaminated cloths, but only 0.2% for metolachlor.
Kim et al. [1982]	Fonofos (13 mg/L at 20°C) Alachlor (242 mg/L at 25°C)	Emulsifiable concentrate	100% Cotton 6 oz. shirt wt. 14 oz. pants wt. denim	40°C, 49°C, 60°C, detergent/no detergent, immediate wash/24-hr wash, 2 cold rinses, air dried, 150 mL water, 30 steel balls.	Remaining residues after laundry (ratio of residue peak to standard peak) 42-81% for fonofos, 2-47% for alachlor. Heavier fabrics contained more residues, hot water removed more of both substances from heavier fabrics, detergents resulted in lower residues, as did immediate washing.
Kim et al [1986]	Alachlor	Emulsifiable concentrate	100% Cotton and 65/35 polyester-cotton broadcloth. 100% and 65/35 polyester-cotton twill.	49°C, 60°C, 150 mL water, standard detergent with 12.4% phosphate, commercial detergent with 6.1% phosphate, heavy duty detergent with no phosphate, three pre-treatments: denatured ethyl alcohol (7.5 mL/150 mL); perchloro-ethylene (7.5 mL/150 mL); distilled water 150 mL each for 2 minutes at 49°C; 9-minute wash, 2 rinses at 49°C. Air and machine dry.	Hot water removed more alachlor than warm water. Dryer drying reduced residues compared to air. Light fabrics had much lower residues than heavy fabrics; 65/35 polyester-cotton twill had more residue than 100% cotton twill. Perchlorethylene removed significantly more alachlor than alcohol or water. Phosphate detergents decreased residues in broadcloths.

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Kim [1989]	Alachlor	Emulsifiable concentrate	100% Cotton twill	Convection oven 60°C, 100°C, 150°C, 200°C, 15, 30, 60 min drying time. Microwave 2450 MHz, 50, 250, 500 1st, 50, 100, 150, 200 seconds.	Alachlor degraded rapidly at 200°C in the convection oven and after 30 minutes at 150°C. At 60 minutes and 150°C, the residue was 0.004% of the contamination level. The microwave was not very effective.
Laughlin and Gold [1989a]	Methyl parathion	Emulsifiable concentrate 1.25% and 54%	100% Cotton. 50/50 cotton-polyester. Unfinished or with fluoroaliphatic soil repellent.	60°C, 2 rinses at 49°C, non-ionic liquid detergent, 12 minute wash, storage at 0°C, 20°C, and 20°C with airflow, and 20° with relative humidity at 65. 54% formulation stored only at 20° with airflow.	Initial contamination with 1.25% formulation was 50 µg/cm ² for unfinished fabric and 22 µg/cm ² for finished. The finished material had greater residues (3.63 µg/cm ²) than unfinished (0.35-1.33 µg/cm ²). Residues decreased with storage time in moving air at 20°C.
Laughlin and Gold [1989b]	Methyl parathion	Emulsifiable concentrate Wettable powder encapsulated	50/50 cotton polyester Unfinished durable press Fluorocarbon soil repellent	69°C wash or 49°C wash, 49°C rinse, heavy duty liquid non-ionic detergent or standard detergent, accelerated laundering apparatus. Also 1 m ² fabrics laundered in automatic home washing machines at 49°C.	Laundering significantly reduced contamination of all fabrics, but the fluorocarbon soil repellent fabric was more resistant to cleaning. Residues were less with the encapsulated formulation. Study demonstrated spread of contaminant from point of contact during laundering as well as contamination of laundry equipment.

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Laughlin et al. [1985]	Methyl parathion	Emulsifiable concentrate 0.25- 54% Wettable powder	100% cotton and 50/50 cotton-polyester denim fabrics. All cotton batiste was used for transfer studies.	60°C wash, 49°C pre-rinse/no pre-rinse, phosphate detergent, two rinses at 49°C, ammonia/no ammonia, bleach/no bleach. Clean fabric laundered immediately after contaminated fabric. Four detergents each at 30°C, 49°C, and 60°C. Multiple launderings (up to 10).	80-99% of parathion removed, no differences between fabrics. Emulsifiable concentrate, 80-89% removal, other forms more than 90%. Pre-rinse resulted in greater removal. Laundry equipment was sufficiently contaminated that the transfer fabrics (laundered immediately after contaminated fabrics) contained 0.0061-0.00181% of the original contamination. The four detergents tested gave similar results. Hot water (49°C and 60°C) was better than cold. With 1.25% methyl parathion, 18% remained after first wash and 4% after second wash and 0.37% after the tenth wash. With 54% methyl parathion, 84% remained after the first wash and 33% remained after the tenth wash. Ammonia and bleach had no effect.
Lillie et al. [1982]	Diazinon Chlorpyrifos	Emulsifiable concentrate	100% Cotton	One-speed washing machine, 30°C, 40°C, 60°C, detergent, detergent plus bleach, plain water, 2 rinses, 30 minute gas dryer.	78-96% of diazinon removed; 52-77% of chlorpyrifos removed; 30-84% of chlordane removed. Removal increased with hotter water and detergent in all cases.

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Lillie et al [1981]	Diazinon (40 mg/L) Chlordane (1 mg/L) Carbaryl (120 mg/L) Prometon (750 mg/L) Bromacil (800 mg/L) Propoxur (2 g/L) Malathion (200 mg/L)	Emulsifiable concentrate Emulsifiable concentrate Wettable powder Emulsifiable concentrate Oil formulation Emulsifiable concentrate Oil formulation	100% Cotton 100% Polyester	One-speed washing machine, 68 agitations/min. 43°C wash cycle, non-phosphorus detergent, 14 minute wash, 2 rinses, gas dryer. Effect of 30°C, 43°C, and 60°C water temperatures on removal from 100% cotton fabric.	Absorption by cotton was greater than for polyester with chlordane, diazinon, and prometon. Penetration was greater for the polyester. The particles of the wetttable powder of carbaryl were probably large enough to prevent penetration. 90-99% of all pesticides were removed by washing. Hotter water removed more pesticide except for chlordane where there was no effect of water temperature.

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Nelson et al. [1992]	Carbamates: carbaryl (insecticide) (120 mg/L at 30°C)	Wettable powder and flowable liquid	100% Cotton and 50/50 cotton-polyester twill.	49°C, 2 rinses, pre-wash/no pre-wash, heavy duty liquid detergent, air drying	Prewash product lowered residue for all pesticides. The residue remaining ranged from zero for carbaryl wettable powder to 48% for deltamethrin emulsifiable concentrate without prewash. Residues were greater on the cottonpolyester for organophosphates and lower for atrazine.
	triallate (herbicide) (4 mg/L at 20°C)	Emulsifiable concentrate			
	Organophosphates: methyl parathion (insecticide) (50 mg/L at 20°C)	Liquid			
	fonofos (insecticide) (13 mg/L at 20°C)	Emulsifiable concentrate			
	terbufos (insecticide) (10-15 mg/L at 25°C)	Liquid			
	Pyrethroids: deltamethrin (insecticide) (0.002 mg/L at 20°C)	Emulsifiable concentrate			
	cyfluthrin (insecticide) (2 mg/L at 20°C)	Wettable powder and emulsifiable concentrate			
	cypermethrin (insecticide) (0.01-0.02 mg/L at 20°C)	Wettable powder and emulsifiable concentrate			
	Alachlor (herbicide) (242 mg/L at 25°C)	Emulsifiable concentrate			
	Atrazine (herbicide) (30 mg/L at 20°C)	Wettable powder and flowable liquid			
Trifluralin (herbicide)	Emulsifiable				

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Oakland et al. [1989]	Atrazine (30 mg/L) Diazinon (40 mg/L) Metolachlor (530 mg/L)	Not stated	100% Cotton knit 65/35 Cotton-polyester chambray, 100% Cotton denim, 65/35 polyester-cotton with fluorocarbon finish	27°C and 60°C wash, detergent (not described), contaminated and non-contaminated fabrics washed together.	The only atrazine cross-contamination was from denim to denim in cold water. Diazinon cross-contamination was greater than metolachlor except transfer to denim. Cross-contamination was significantly greater in hot water for diazinon and metolachlor. Atrazine did not cross-contaminate in hot water. Both denim and knit fabrics accepted cross-contamination.
Obendorf and Solbrig [1986]	Malathion Methyl parathion (tagged with osmium tetroxide)	Not stated	50/50 Cotton-polyester with and without durable-press finish	200 mL water (temperature not reported), 10 steel balls (agitation), anionic surfactant with carbonate and zeolite builders, 2 rinses, air dried. X-ray analysis for fabric distribution of pesticides.	Washing removed 30-40% of both pesticides, but did not reduce the amounts in the lumen of the cotton fibers.
Rigakis et al. [1987]	Trifluralin (1 mg/L) Triallate (4 mg/L) Deltamethrin (0.002 mg/L)	Emulsifiable concentrate	100% Cotton fabric	50°C wash, 2 rinses at 40°C, pre-wash/ no pre-wash each with one or two washes, air dried.	Trifluralin removal was 77% after one wash and 91% after two washes with pre-wash. Triallate removal was 52% after one wash and 82% after two washes with pre-wash. Deltamethrin removal was 84% after one wash and 99% after two washes with pre-wash.
Satoh [1979] Note this article and the next article in the journal had the authors and titles switched. See Finley et al. [1979] for correct title and author.	Methyl parathion	Contamination by wearing clothes in cotton field for one day	50/50 Cotton-polyester twill pants and shirts	140°F wash, rinse, heavy duty carbonate laundry detergent, machine dry at 190°F for 30 minutes. Repeat procedure.	Contamination levels ranged from 0.07 to 28.97 ppm. One washing reduced residues by 75-95%. Washing seemed to be less effective as contamination level increased. The second wash removed a smaller percentage of the remaining residue.