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Effects of Convection-Oven and Microwave-Oven Drying on Removal of Alachlor Residues in a Fabric Structure

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The objective of this research was to determine the effects of heat used in fabric drying on degradation of alachlor soils in a fabric structure. Attempts were made to remove EC-formulation alachlor soils from clothing fabrics by various laundering methods to reduce hazards for farm workers and pesticide applicators (Kim et al. 1982, 1986). Laundering variables tested included pretreatment type, wash-water temperature and hardness, detergent type, drying method, and immediacy of washing after contamination; fabric-related variables included fiber content and fabric weight. Generally, alachlor removal was greater in lighter-weight fabrics that were washed in hot water with detergent after pretreatment with a dry-cleaning solvent and dried in a clothes dryer (Kim et al. 1986). The various combinations of fabric and laundering variables studied, however, did not completely remove contaminant soils from the fabric. Therefore, it was proposed that some mechanism of degrading the contaminant chemical in combination with textile refurbishing processes might more effectively remove alachlor soils from the fabric. Heat, ultraviolet light, microwave, and antitoxic chemicals have been suggested as soil degraders.

EC-formulation alachlor is stable and lasts at least four years under normal warehouse conditions. The primary method of breakdown is microbial, with chemical breakdown of lesser importance (Monsanto Technical Bulletin 1979). Heat degradation of the chemical takes place by chemical decomposition at around 105°C. Reusable clothing fabrics are subjected to textile refurbishing processes in which the highest heat is used in the drying cycle. Traditionally, convection heat has been a primary source of heat in fabric drying. In the textile industry, however, microwave drying of fabrics has been gaining more acceptance due primarily to its economy and efficiency (Mock and Myers 1983). In addition, it is possible that microwave radiation can degrade a toxic pesticide chemical as well as sanitize against microorganisms.

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MATERIALS AND METHODS

Alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl)acetanilide), a corn and soybean herbicide, was used in the EC formulation (4 lb/gal) at its undiluted initial concentration. Monsanto Company provided the chemical. A 100% cotton twill fabric (250 g/m^2) purchased from Testfabrics, Inc. (Style No. 471) was used. The fabric was cut into 8x8 cm swatches oblique to the warp and filling directions to minimize yarn raveling.

For alachlor contamination, the fabric swatch was placed flat on the sharp edges of aluminum foil pleated to an accordion shape to minimize contact with the foil, and 0.5 mL of EC-formulation alachlor was applied to the swatch in a spiral path from the center of the swatch by using a precision pipet. The contaminated swatch rested for 5 min to allow full penetration of the liquid herbicide into the fabric.

For the convection drying, a Blue M Model OV-18A gravity oven with temperature range of 38-288°C was used. The oven was preheated for 1 hr to the fixed temperature level of the experimental design (60, 100, 150, or 200°C). To avoid contamination of the oven by contact, an accordion-shaped foil was placed on the center rack of the oven; all other racks were removed. Five contaminated swatches as replications were placed on the foil in the oven. As a check for possible cross-contamination among the swatches in the oven, two additional uncontaminated swatches were placed together with the five contaminated swatches. After the temperature reached the assigned level, the swatches were dried for a fixed time (15, 30, or 60 min) according to the experimental design, which was a complete block design with 12 cells (4x3). The treatment on the 12 cells was done in a completely random order.

For the microwave drying, a Sharp Carousel II Model 5980 household microwave oven of 2450-MHz frequency and 500-W output power with a turntable was used. One contaminated swatch was placed on an evaporating glass at the center of the turntable and dried at specified level of microwave intensity (low=50, medium=250, or high=500 W) and exposure time (50, 100, 150, or 200 sec) according to a completely randomized design with 12 cells (3x4). An intermittent check for possible machine contamination was done by running an uncontaminated swatch, and no contamination was traced.

After drying, each swatch was placed in a 250-mL Erlenmeyer flask with 100 mL ethyl acetate and shaken for 1 hr on a mechanical shaker; this extraction was repeated once. From the combined solution of the two 100-mL aliquots, a 20-mL extract was placed in a glass test tube with a Teflon-lined screw cap and stored in a refrigerator for gas chromatograph (GC) analysis. A Varian 3400 GC equipped with a thermionic specific detector and a Varian 4270 integrator were used to analyze the extract solution for alachlor residue amount in the dried swatches. A 2-m universal glass column packed with 3% OV-17 for GC Chrom Q 100/120 was used with helium as carrier gas. The column temperature was set at 200°C with both injector and detector temperatures set at 250°C. For each convection-dried swatch two GC runs were made; for each microwave-dried swatch three.

RESULTS AND DISCUSSION

The mean residue amounts (ng/μL) in the dried swatches by convection oven are shown in Table 1. The data indicate that alachlor began degrading severely after 30 min or a longer heat exposure at 150°C. The mean residue amounts at 60-min exposure at 150°C and at 15-min, 30-min, and 60-min exposure at 200°C are, respectively, 22.2, 25.4, 24.5, and 21.7 ng/μL, which are nearly trace amounts of the chemical. The results imply that alachlor residues in a fabric structure degrade to a trace level when exposed to heat from convection-oven drying at 150°C for 60 min or at 200°C at all three exposure times. The 22.2 ng/μL value at 150°C for 60-min exposure represents 0.0046% of the active ingredient of the initial 0.5-mL EC contamination.

Table 1. Mean alachlor residue amount after convection-oven drying (ng/μL)[a]

Exposure Time (min)	Temperature (°C) 60	100	150	200
15	986.4	981.3	536.1	25.4
30	945.5	720.7	129.4	24.5
60	1077.3	695.7	22.2	21.7

[a]Mean of two replications

To determine the effect of heat from the convection oven on degradation of alachlor in a fabric structure, the analysis-of-variance (ANOVA) procedure and Duncan's multiple-range test were used; results are shown in Table 2. Alachlor residue amounts differed significantly ($p<.01$) by temperature and exposure time. Duncan's multiple-range test shows that the mean residue amounts differed among all four temperature levels; for exposure time, however, they differed only between 15-min exposure and 30- or 60-min exposure. The mean residue amounts did not differ significantly ($p<.05$) between the 30- and 60-min exposure. Although statistically significant, the differences in residue amounts at other temperature and exposure levels and the interaction effect between temperature and exposure time are beyond our interest for the purpose of this research, which is to find ways to completely remove any toxic chemical residues from the clothing fabric.

The mean residue amounts (ng/μL) in the dried swatches by microwave radiation are shown in Table 3. The largest residue

Table 2. Summary of ANOVA and Duncan's multiple-range test on alachlor residue amount after convection-oven drying

Source	DF	F Value	Level	Grouping	N	Mean
Temperature	3	214.13**	60°C	A[a]	30	1003.1
			100°C	B	30	799.2
			150°C	C	30	229.2
			200°C	D	30	23.9
Exposure time	2	14.04**	15 min	A	40	632.3
			30 min	B	40	455.0
			60 min	B	40	454.2
Temp x exp time	6	6.78**				
Replication	1	6.76*				

*Significant at p<.05 **Significant at p<.01
[a]Means with the same letter are not significantly (p<.05) different

amount was 863.7 ng/µL at high intensity for 50-sec exposure and the smallest 450.7 ng/µL at high intensity for 200-sec exposure, a range of 413.0 ng/µL. This range is much smaller than 1055.6 ng/µL for the swatches dried by convection oven. This may imply that the levels of variables chosen for the microwave drying were inadequate to cause sufficient degradation of the chemical contaminant. The least mean residue amount among the 12 (4x3) experimental design cells was 450.7 ng/µL at high microwave intensity for 200-sec exposure. However, this value still represents 0.094% of the active ingredient of the initial 0.5-mL EC contamination; this is more than 20 times the least residue amount for the convection-oven drying. The results indicate that a longer exposure time at the high microwave intensity may further reduce the residue amount. Table 3 shows that, only at the high microwave intensity, do the mean residue amounts exhibit a decreasing trend as the exposure time increases. At the low and medium intensities, no clear pattern of change was observed.

The ANOVA results in Table 4 show that alachlor residue amounts differed significantly (p<.01) by microwave intensity and exposure time. Duncan's multiple-range test shows that the mean residue amounts differed significantly (p<.05) only between high and medium and between high and low microwave intensities; they did not differ significantly between the low and medium intensities. A similar decreasing trend is shown in mean residue amounts by exposure time as by microwave intensity, but they did not differ significantly between 100-sec and 150-sec exposure times (Table 4).

In the textile industry, most high-power industrial heating

Table 3. Mean alachlor residue amount after microwave-oven drying (ng/μL)[a]

Microwave Intensity	Exposure Time (sec) 50	100	150	200
Low	843.7	799.6	761.5	818.5
Med	789.0	779.1	820.5	752.9
High	863.7	707.1	648.1	450.7

[a]Mean of three replications

Table 4. Summary of ANOVA and Duncan's multiple-range test on alachlor residue amount after microwave-oven drying

Source	DF	F Value	Level	Grouping	N	Mean
MW intensity	2	36.51**	Low	A[a]	60	805.8
			Med	A	60	785.4
			High	B	60	667.4
Exposure time	3	20.73**	50 sec	A	45	832.2
			100 sec	B	45	761.9
			150 sec	B	45	743.3
			200 sec	C	45	674.0
MW int x expos	6	15.09**				
Replication	2	14.58**				

**Significant at p<.01
[a]Means with the same letter are not significantly (p<.05) different

equipment is operated at 900 MHz, which is capable of producing an output of 25 kW, whereas the domestic 2450-MHz ovens are limited to a 2.5-kW output (Delaney and Seltzer 1972). Microwaves are high-frequency radiation capable of producing rapid and uniform heating throughout the material exposed to them--liquid in a fabric structure in this research. In the presence of a high-frequency electromagnetic field, the liquid molecules oscillate synchronously with the field; this molecular oscillation generates heat through intermolecular friction. The heat, in turn, seems to cause alachlor residues in the fabric structure to degrade. Although the frequency and power of the microwave oven used in this research were not sufficient to cause a much lower residue amount of alachlor in the contaminated fabric swatches, a further study is recommended involving industrial-power microwave as well as domestic ovens at longer exposure times.

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