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Pesticide Transmission in Fabrics: Effect of Perspiration

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In our earlier work we reported on the barrier effectiveness of commonly used apparel fabrics toward carbaryl and atrazine solution penetration (Raheel 1987b, 1988a, 1988b). The effects of fiber content and functional textile finishes on transmittance of pesticide solutions through fabrics were delineated. In another paper the effect of particulate soil on the transport of pesticides through fabrics was explored (Raheel 1991). This report focuses on the effect of perspiration as a variable on the transport of pesticide solutions through a variety of commonly used apparel fabrics.

A substantial body of literature exists on the barrier properties of commonly used apparel fabrics (Orlando et al. 1981; Raheel 1985, 1987b, 1988a, 1988b) and special protective apparel fabrics (Branson et al. 1986, Crouse et al. 1990, Leonas et al. 1989) toward pesticide chemicals. Furthermore, extensive research efforts have been directed toward laundering variables that enhance the removal of pesticide chemicals from reusable contaminated clothing (Easely et al. 1982; Easter and DeJonge 1985; Keaschall et al. 1986; Kim et al. 1982; Laughlin et al. 1985, 1987, 1988; Raheel 1987a). However, not much work has been done on the effect of perspiration as a variable on the movement of pesticide chemicals through apparel fabrics. It is a well-recognized fact that as much as 500 mL of perspiration is given out directly through the skin of a human in a single day (Bhat et al. 1990). Perspiration is composed of urea, lactic acid, amino acids, sugar, alkali sulfates/phosphates, etc. (Fishberg and Bierman 1932). The pH of perspiration is about 5 when freshly secreted, but it may turn alkaline with time (Vass and McSwiney 1930). Perspiration induces structural changes in textile fibers (Bhat et al. 1990) that may influence liquid transport property of fabrics. This study explores the movement of carbaryl and atrazine in wettable powder and liquid formulations through fabrics of various fiber contents, geometries, and functional finishes in the presence and absence of perspiration.

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MATERIALS AND METHODS

Sixteen primary fabrics were studied for their pesticide transmission property. Fabric characteristics are given in Table 1. A 100% cotton knit T-shirt fabric served as a collector substrate that absorbed the pesticide solution transmitted through the primary fabrics. Fabrics were obtained from Testfabrics, Inc., Middlesex, NJ, except for the spunbonded olefin fabric which was contributed by E.I. du Pont Company. A test assembly consisted of the primary fabric measuring 8x8 cm as

Table 1. Fabric characteristics

Fabrics	Fabric weight (g/m)	Fabric thickness (mm)	Yarns/cm W F	Yarn twist turns/cm W F
Primary				
100% Cot[a] UN[b]	295.0	0.495	33 x 24	7 x 5
100% Cot DP[c]	296.5	0.495	33 x 24	7 x 5
100% Cot SR[d]	295.1	0.495	33 x 24	7 x 5
#423 twill				
100% Cot UN	222	0.363	44 x 23	7 x 5
100% Cot DP	223	0.363	44 x 23	7 x 5
100% Cot SR	222	0.363	44 x 23	7 x 5
#407 poplin				
50/50 PET[e]/Cot UN	210	0.333	44 x 20	7 x 5
50/50 PET/Cot DP	210	0.337	44 x 20	7 x 5
50/50 PET/Cot SR	210	0.327	44 x 20	7 x 5
#7428 poplin				
65/35 PET/Cot UN	180	0.274	44 x 23	7 x 5
65/35 PET/Cot DP	183	0.274	44 x 23	7 x 5
65/35 PET/Cot SR	180	0.274	44 x 23	7 x 5
#7402 poplin				
100% PET	116	0.236	25 x 19	8 x 7
#767 plainweave				
100% Nylon	150	0.325	21 x 23	6 x 8
#361 plainweave				
100% Acrylic	140	0.325	19 x 5	5 x 5
#864 plainweave				
100% Olefin Spunbonded (Tyvek®)	40	0.091	---	---
Secondary				
100% Cotton, knit	150	0.480	---	---

[a]Cot = Cotton, [b]UN = Untreated, [c]DP = Durable press, [d]SR = Soil-repellent, [e]PET = Polyester.

the top layer, a second layer of the collector fabric 7x7 cm (to avoid migration of pesticide from the edges of the primary fabric), and the third layer consisted of 8x8 cm of aluminum foil.

One set of primary fabrics (3 specimens per replication and 3 replications) was treated with synthetic perspiration and the other set served as a control. Synthetic perspiration was prepared as a standard solution according to the recommendation in the AATCC test method 15-1985 (1990). The solution contained 10 g sodium chloride, 1 g lactic acid, 1 g anhydrous disodium hydrogen phosphate, and 0.25 g histidine monohydrochloride per liter of the solution. The pH of the solution was 4.3 ± 2. Two methods were used for impregnating the fabrics with perspiration. These methods were: (a) Immersion method. The fabric specimens were individually immersed in excess perspiration solution (150 mL) for 5 minutes while being shaken in a precision shaker at 280 rmp. after which they were removed and placed between paper towels for 1 minute and transferred over the knit T-shirt collector fabric for pesticide contamination. Pilot work showed that in general fabrics retained 42-59% wet pickup OWF except for olefin (Tyvek®) and repellent finished (SR) fabrics. (b) Individual Dynamic Absorption method. This method was adapted from the work of McNally (1988), who had shown that a liquid was uniformly absorbed in their test garment assembly. We placed three fabric specimens of each primary fabric (representing one replication) in a plastic zip-lock bag to which a calculated volume of perspiration solution (50% OWF) was added. The bag was closed, shaken, and allowed to equilibrate at ambient room temperature for 1 hour. The perspiration solution was completely and uniformly absorbed by the fabric specimens except in the case of Tyvek® and SR finished fabrics. The perspiration treated specimens were then placed over the knit T-shirt collector layer for pesticide contamination. Tyvek® and repellent finished fabrics were placed between paper towels for 1 minute before contaminating them with pesticide solution.

The layered fabric assembly was contaminated with 1 mL of 1.25% (a.i) pesticide solution according to the method described by Raheel (1988b). Two pesticides were used for contaminating the fabrics: carbaryl, in wettable powder (Sevin® 50W) and flowable liquid (Sevin® 4L) formulations, and atrazine, also in wettable powder (Aatrex® 80W) and flowable liquid (Aatrex® 4LC) formulations. Transmitted pesticide was extracted from the collector fabric as described by Raheel (1988b). Residue analysis was conducted by gas chromatographic technique, using technical grade carbaryl and atrazine as external standards. Extraction efficiency tests indicated that recovery of carbaryl was 87% and that of atrazine was greater than 90%.

Analysis of variance and F-ratios were used to detect significant differences in pesticide transmittance through fabrics at $\alpha \leq 0.05$. Separation of means was achieved with Least Significant Means and Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Paired comparisons indicated that there were no significant differences between pesticide transmission data when fabrics were treated with perspiration by immersion method or individual dynamic absorption method. Therefore, all data presented in this report are from the immersion method.

ANOVA results (Table 2) indicated that fabrics were significantly different ($\alpha \leq 0.05$) in their ability to transport pesticide

Table 2. ANOVA of the effect of fabric, pesticide and treatment variables on pesticide transmission

Effect	Degrees of freedom	F-ratio	p > F value
Fabrics (F)	15	29.52	0.0000
Treatments (T)[a]	1	59.10	0.0000
F x T	15	28.45	0.0010
Pesticides (P)	3	8.69	0.0180
P x F	45	11.18	0.0290
P x F x T	45	17.00	0.0021

[a]T = No treatment, perspiration treatment.

solutions. The presence of perspiration in the fabrics increased pesticide transmission significantly. In addition, the pesticides (type and formulation) exhibited significantly different levels of transmission through the fabrics. Separation of means as expressed by Duncan's multiple range groupings (DM) was achieved for data subsets, that is, for carbaryl in wettable powder and liquid formulations, as well as for atrazine in the two formulations.

Tables 3 and 4 present quantitative data in $\mu g/cm^2$ for the transmission of carbaryl and atrazine, respectively. Several general observations were made, first, that perspiration treated fabrics transmitted much higher levels of pesticide solutions; second, that larger quantities of atrazine were transmitted compared to carbaryl; and third, that higher levels of both pesticides were transmitted when these were in flowable liquid formulation compared to wettable powder formulation. Table 3 shows that the spunbonded olefin Tyvek® and repellent finished fabrics permitted significantly lower levels of carbaryl transmission, but the amount was much higher for perspiration treated fabrics. In perspiration treated fabrics, 100% cotton and polyester/cotton blend fabrics (50/50 and 65/35) fell in the same Duncan's grouping as the repellent fabrics for wettable powder formulation of carbaryl. However, for the flowable liquid formulation of carbaryl and both formulations of atrazine (Table 4), pesticide

Table 3. Effect of perspiration on the amount of carbaryl[a] ($\mu g/cm^2$) transmitted from primary fabric[b] to the secondary fabric

Primary fabric	Transmitted pesticide ($\mu g/cm^2$)							
	Wettable powder				Flowable liquid			
	N[c]	DM[d]	P[e]	DM	N	DM	P	DM
100% Cot (UN)	9.60	A	17.58	A	10.70	A	36.00	AB
100% Cot (DP)	9.90	A	17.90	A	10.80	A	36.20	AB
100% Cot (SR) (twill)	0.45	A	3.83	A	0.42	A	2.29	A
100% Cot (UN)	12.40	A	20.86	A	16.60	AB	34.40	A
100% Cot (DP)	12.50	A	20.90	A	15.80	AB	35.60	AB
100% Cot (SR) (poplin)	0.41	A	0.40	A	0.40	A	0.52	A
50/50 PET/Cot (UN)	16.50	AB	20.05	A	20.30	BC	35.00	AB
50/50 PET/Cot (DP)	16.70	AB	20.71	A	26.50	BC	40.70	B
50/50 PET/Cot (SR)	0.09	A	0.23	A	1.80	A	0.52	A
65/35 PET/Cot (UN)	26.80	BC	25.37	A	27.90	BC	42.70	C
65/35 PET/Cot (DP)	29.10	BC	35.84	A	25.00	BC	46.70	CD
65/35 PET/Cot (SR)	0.05	A	0.30	A	1.40	A	2.40	A
100% Polyester	98.90	F	253.8	D	96.00	E	193.2	F
100% Nylon	71.20	D	260.9	C	70.50	D	195.0	E
100% Acrylic	96.70	E	182.8	B	95.80	D	200.8	E
100% Olefin (Spunbonded)	0.04	A	0.35	A	0.07	A	0.25	A

[a] = Mean of nine values, [b] = The primary fabrics were treated with 280 $\mu g/cm^2$ pesticide, [c]N = No perspiration, [d]DM = Duncan's Multiple Range Grouping, [e]p = Perspiration treated.

transport remained a function of fiber content and finish. Cotton fiber and blend fabrics exhibited lower levels of pesticide transport compared to 100% synthetic fiber woven fabrics. Nylon, acrylic, and polyester woven fabrics exhibited significantly higher levels of pesticide transport as indicated by different Duncan's groupings. Among them, polyester fabric exhibited the highest level of carbaryl as well as atrazine transmission.

These results seem to be a logical consequence of liquid transport phenomenon which depends upon capillary penetration as well as liquid holding capacity of fibers and fabrics. Evidently the liquid holding capacity, that is, the saturation point (hence breakthrough point) of perspiration wetted fabrics had been lowered, hence the pesticide solution could move rapidly through already liquid filled capillaries between fibers/yarns and onto the collector fabric. Bhat et al. (1990) have reported that acidic perspiration affects the fine structure of cotton fibers in that the amorphous regions suffer degradation, whereas the crystalline region is somewhat affected. They observed

Table 4. Effect of perspiration on the amount of atrazine[a] ($\mu g/cm^2$) transmitted from primary fabric[b] to the secondary fabric

Primary fabric	Transmitted pesticide ($\mu g/cm^2$)							
	Wettable powder				Flowable liquid			
	N[c]	DM[d]	p[e]	DM	N	DM	S	DM
100% Cot (UN)	13.90	A	63.10	B	16.20	A	44.70	B
100% Cot (DP)	13.80	A	62.70	B	16.20	A	44.90	B
100% Cot (SR) (twill)	3.80	A	6.10	A	6.70	A	4.90	A
100% Cot (UN)	20.90	AB	90.50	C	24.10	AB	44.30	B
100% Cot (DP)	20.80	AB	90.60	C	23.90	AB	41.80	B
100% Cot (SR) (poplin)	0.50	A	3.20	A	0.70	A	3.20	A
50/50 PET/Cot (UN)	27.70	BC	69.10	B	30.90	BC	68.90	C
50/50 PET/Cot (DP)	28.60	BC	58.90	A	37.10	BC	68.17	C
50/50 PET/Cot (SR)	1.20	A	3.70	A	1.70	A	2.20	A
65/35 PET/Cot (UN)	61.70	BC	142.8	D	66.40	DE	74.80	D
65/35 PET/Cot (DP)	62.10	BC	89.80	C	66.50	DE	73.50	D
65/35 PET/Cot (SR)	0.40	A	0.40	A	0.50	A	0.91	A
100% Polyester	148.0	D	189.0	E	169.2	G	261.1	F
100% Nylon	118.0	C	146.0	D	91.60	E	218.4	E
100% Acrylic	117.7	C	128.1	D	148.0	F	240.8	E
100% Olefin (Spunbonded)	0.40	A	1.60	A	0.50	A	0.42	A

[a] = Mean of nine values, [b] = The primary fabrics were treated with 280 $\mu g/cm^2$ pesticide, [c]N = No perspiration, [d]DM = Duncan's Multiple Range Grouping, [e]p = Perspiration treated.

fibrillation and peeling of fibrillar layers after prolonged exposure to perspiration. These microstructural changes do influence liquid penetration and transport property of cotton fibers. Nevertheless, in this study the exposure time to perspiration was limited, hence the increased pesticide transport may be attributed mainly due to changes in liquid holding capacity of fibers and fabrics.

These results point to the importance of donning layered garments while engaged in pesticide handling jobs. An undershirt and long underpants may provide dermal protection not only by absorbing transmitted pesticide from the outer garments, but also by absorbing body perspiration and preventing it from moistening the outer garments.

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