ELSEVIER

Journal of Hazardous Materials B100 (2003) 95–107

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Permeation of captan through disposable nitrile glove

R.N. Phalen*, Shane S. Que Hee

Department of Environmental Health Sciences and UCLA Center for Occupational and Environmental Health, School of Public Health, 650 Charles Young Jr. Drive South, Los Angeles, CA 90095-1772, USA

Received 26 November 2002; received in revised form 12 February 2003; accepted 18 February 2003

Abstract

The purpose of this study was to investigate the permeation of an aqueous emulsion of the pesticide, captan, as a wettable powder (48.9% captan) through a disposable nitrile glove material using an American Society for Testing and Materials (ASTM)-type I-PTC-600 permeation cell. The goal was to investigate the protective capability of the gloves against dermatitis. The analytical method was based on gas chromatography–mass spectrometry (GC–MS) and gas chromatography–electron capture detection (GC–ECD). The least quantifiable limit (LQL) was 6 ng for GC–ECD and 30 ng for GC–MS. Testing was conducted using the ASTM F739 closed-loop permeation method and a worst-case aqueous concentration 217 mg/ml of captan 50-WP. The average permeation rates were low, with 12 ± 5 ng/(cm^2 min) after 2 h, 50 ± 25 ng/(cm^2 min) after 4 h, and 77 ± 58 ng/(cm^2 min) after 8 h. The calculated diffusion coefficient was $(1.28 \pm 0.10) \times 10^{-5}$ cm^2/h. No significant swelling or shrinkage occurred at $P \leq 0.05$. Infrared (IR) reflectance analysis of pre- and post-exposure glove surfaces confirmed no outer or inner surface degradation. The disposable nitrile glove showed excellent resistance to a highly concentrated aqueous emulsion of captan. Because the ASTM normalized breakthrough detection time of 250 ng/cm^2 was <2 h, these gloves should not be reused once worn, and decontamination is not advised. Protection is also advised for agricultural reentry field workers, because captan has been shown to persist on crops with a half-life greater than the current reentry intervals of 1–4 days.

Keywords: Pesticide; Fungicide; Protective glove; Protection; Infrared reflectance

1. Introduction

Many pesticide formulators, farmers, and crop workers are exposed to the hazards of pesticides. The fungicide captan, *N*-trichloromethylthio-4-cyclohexene-1,2-dicarboximide

* Corresponding author. Tel.: +1-310-206-5790; fax: +1-310-794-2106.
E-mail address: rphalen@ucla.edu (R.N. Phalen).

0304-3894/03/$ – see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0304-3894(03)00087-6

(CASRN no. 133-06-2), is one of the more common pesticides utilized [1,2]. In a 1999 report, the US Environmental Protection Agency (EPA) [3] estimated that between 2500 and 3700 km^2 are treated with captan annually in the United States, with 1.8–3 million kilograms applied to foliar crops and 0.8 million kilograms used to treat seed. Captan is one of the top five California Proposition 65/EPA B2 carcinogen pesticides in both use and cumulative acres treated [2].

Captan is a dicarboximide fungicide of melting point 178 °C, log K_{ow} 2.35, water solubility 3.3 mg/l at 25 °C, and vapor pressure $<9.8 \times 10^{-6}$ mm Hg at 20 °C [3,4]. Captan was first introduced as a pesticide in 1949. It is usually formulated under such names as Aacaptan, Amercide, Captaf, Captane, Captex, Ent 26,538, Esso Fungicide, Flit 406, Fungus Ban type II, Glyodex, Kaptan, Malipur, Merpan, Neracid, Orthocide, Stauffer Captan, Vancide, and Vangard K. The major formulation types are wettable powders (50–80%), dustable powders (5–10%), powder for seed treatment (60–75%), and flowable concentrates (30–40%). Many mixed formulations exist. It is applied by dip treatment, foliar contact, soaking, spraying, and as a preservative in paints and adhesives [3,5].

The major analytical chromatographic methods involve capillary gas chromatography (GC) and high performance liquid chromatography (HPLC). A number of US EPA [4] gas chromatography–electron capture detection (GC–ECD) and gas chromatography–mass spectrometry (GC–MS) methods exist for captan, including Method 8270C (GC–MS) and Methods 8081 and 617 (GC–ECD). The National Institute of Occupational Safety and Health (NIOSH) Method 5601 [6] for organonitrogen pesticides utilizes HPLC with UV detection, but is less sensitive than published capillary GC–ECD methods.

Captan has a 2002 American Conference of Governmental Industrial Hygienists (ACGIH) 8 h time-weighted average threshold limit value (TLV-TWA) of 5 mg/m^3 (inhalable fraction) based on its irritative properties [7]. The NIOSH Recommended Exposure Limit (REL) is 5 mg/m^3 [2]. The ACGIH has also designated captan as a sensitizer (SEN) and an A3 confirmed animal carcinogen with unknown relevance to humans. Captan has been classified as a Group 3 carcinogen by the International Agency for Research on Cancer (IARC) [8] and as a potential occupational carcinogen by NIOSH [2].

Dermal exposure has been identified as the major route of exposure with average measured exposures ranging from 15 to 39 mg/h, by Zweig et al. [9] and Stevens and Davis [10]. Kazen et al. [11] found captan to persist on hands for at least 7 days. The importance of the dermal exposure route was demonstrated by Stevens and Davis [10], who found average inhalation exposures of up to 1.7 mg/h versus dermal exposures of up to 15 mg/h in a group of agricultural workers. The US EPA [3] has used a dermal absorption rate of 0.4%/h in risk assessment studies. According to US EPA, the California Pesticide Illness Surveillance Program [3] recorded eye/skin irritation incidents involving captan between 1982 and 1990, among 14 reentry workers, 14 mixer/loader/applicators, and 10 other agriculturally related activities. In addition, dermatitis has been reported in fruit farmers using dicarboximide pesticides, such as captan, folpet, and captafol [12].

The major occupational exposures are to handlers (mixers, loaders, and applicators), reentry field workers, and loaders mixing captan into paints and adhesives. The major exposure route is also through the skin. The above exposures may also occur in residential and agricultural settings as well as in the manufacturing sector [3,5]. The only US EPA [5] guidance on personal protective equipment (PPE) is the statement: “All mixers, loaders,

applicators, flaggers, and other handlers must wear: long-sleeved shirt and long pants; shoes plus socks; chemical resistant gloves; and chemical resistant apron when participating in dip treatments". Dust/mist respirators are also required for special applications.

Because no explicit recommendations for the type of gloves to wear for protection against captan exposure are provided, American Society for Testing and Materials (ASTM) glove permeation screening following our research group's published procedures [13–20] was conducted. In addition, Fourier transform infrared (FT-IR) reflectance analysis of pre- and post-exposure glove surfaces was conducted to assess the effects of permeation or degradation on the outer and inner glove surfaces. Surface FT-IR reflectance may provide additional information on the chemical action or permeation of pesticides through protective glove materials. The ultimate goal was to investigate the protective capability of the gloves against dermatitis.

2. Experimental

2.1. Gloves and chemicals

The gloves were disposable, powderless, unsupported/unlined blue nitrile latex exam gloves (SafeSkin, San Diego, CA), of unspecified thickness and 24.1 cm in length. Nitrile gloves were chosen because they are the most used synthetic rubber glove material, inexpensive, and their compatibility charts indicated that protection would be likely against aqueous solutions of surrogate weak acids and bases. The label for the captan wettable powder formulation specified an aqueous pH of 5.0. Measured pH values between 5 and 6 were obtained from aqueous challenge emulsions of the wettable powder. Acids like 10% nitric, 47% sulfuric, and 10% citric acid have permeation breakthrough times >360 min and steady state permeation rates $<0.9\ \mu g/(cm^2\ min)$ for nitrile glove materials [21].

Analytical grade captan (98%) and *cis*-1,2,3,6-tetrahydrophthalimide (THPI) (98%) were procured from Chem Service Inc. (West Chester, PA). The methyl ester of 2,4,5-T (98%) used as the internal standard (IS) was obtained from PolyScience (Niles, IL). Captan 50-WP (nominally 48.9% (w/w) captan; 1.1% related derivatives; and 50% inert ingredients) was obtained from Micro Flo Corporation (Memphis, TN). Nitric acid used to prepare 10% nitric acid for cleaning glassware and Optima grade hexanes were from Fisher Scientific (Tustin, CA).

Water produced from a Millipore Super-Q water deionizing filter system (Marlborough, MA) was utilized for all aqueous solutions. Helium (99.999%), 5% methane in argon, and nitrogen (99.999%) were obtained from Air Products (Long Beach, CA).

2.2. Equipment

The GC was a Hewlett-Packard 5890 with a 30 m × 0.25 mm DB-1701 (1 μm film) chemically bonded, fused-silica capillary column (Alltech, Folsom, CA) and a constant-current pulse modulated ^{63}Ni-electron capture detector (ECD). The signal was displayed on a Hewlett-Packard 3396 reporting integrator. The temperature of the splitless injector was 225 °C, and that for the detector was 260 °C. The column flow of 5:95 methane/argon

carrier gas was 3.3 ± 0.1 ml/min, septum purge was at 1.8 ± 0.2 ml/min, detector makeup at 39 ± 2 ml/min, and anode purge at 4.4 ± 0.2 ml/min. The column temperature was 200 °C with 1.0 μl injections.

The GC-mass spectrometer (MS) had the same GC and column type connected to a Hewlett-Packard 5988A mass spectrometer. The MS was a quadrupole with an electron multiplier detector operated over the *m*/*z* range 50–550 for scan mode analyses. The temperature of the injector was 225 °C and that of the transfer line was 210 °C. The 70 eV ion source was held at 260 °C. The flow of helium carrier was 3.0 ± 0.3 ml/min. The solvent delay was 3 min with 3.0 μl injections. The original Chem Station operating software in Pascal was upgraded to a Windows NT 4.0 controlled Chem Station (CSS Analytical Company, Shawnee, KS). A National Institute of Standards and Technology/EPA/National Institutes of Health (NIST/EPA/NIH) 2001, Version 2a, mass spectral library supported mass spectral assignments. The GC–MS was utilized for identification of captan, possible degradation products, and intermediates.

A SP Temp-Blok Module Heater (American Scientific Products, McGaw Park, IL) was used in conjunction with a 8 mm × 20 mm heating block (Thomas Scientific, Swedesboro, NJ) to evaporate solvents after liquid–liquid extractions and to concentrate collection solutions following permeation.

The ASTM-type I-PTC-600 permeation cells were from Pesce Lab Sales (Kennett Square, PA). The moving tray shaker water bath used for immersion of three permeation cells simultaneously was a Fisher Scientific model 125 no. 429. Three copper metal tubes (23 cm × 15 cm o.d. × 133 mm i.d.) were mounted across the two rails of the shaker after hacksawing 1 mm wide grooves in the bars and using emery paper to smooth the jagged edges. Three-prong clamps allowed suspension of three permeation cells above and into the water as desired. A micrometer screw gauge (L.S. Starrett Co., Athol, MA) was used to measure glove thickness before and after experiments. Vernier calipers (Mitutoyo, Japan) allowed measurement of the glove diameters cut for permeation studies.

Infrared (IR) spectra were obtained with a Avatar 360 Fourier transform (FT) spectrometer system (ThermoNicolet, Madison, WI), a single-beam spectrophotometer using the reflectance mode and operated with OMNIC 6.0a software controlled by Windows 98. The crystal was zinc selenide in a single-reflection horizontal attenuated total reflectance mode. The spectral range was 4000–600 cm^{-1}. The number of scans was 128.

2.3. Permeation procedure

The detailed procedure used in this study is provided elsewhere [19,20], and is based on the standard ASTM Method F739 [22]. In summary, glove materials were conditioned at least for 24 h in a desiccator with 65.2 ± 0.8% relative humidity (saturated aqueous sodium dichromate). The material was held between two Teflon gaskets and the Pyrex chambers of the I-PTC-600 permeation cell by a uniform torque as specified by the manufacturer. A volume of 217 mg/ml of captan formulation in water was equilibrated to 30.0 ± 0.5 °C for 30 min followed by vortex mixing for 30 s before pipetting into the challenge side of the permeation cells. The three cells were immersed into the water bath at 30.0 ± 0.5 °C, to approximate human hand temperatures, with a horizontal shaking speed of 10.3 ± 0.3 cm/s to ensure a concentration gradient did not exist between the permeate and collection media

components. This was confirmed by prior observation of challenge solution opacity at different shaker speeds and permeation cell orientations. Permeation time intervals of 2, 4, and 8 h were evaluated in triplicate.

Concentration of the collection side solutions 3–80-fold was necessary, depending on the exposure time interval. This was performed at 40 °C in the heating block under a stream of nitrogen in a 4 ml graduated V screw-capped vial. Before injection into the GC, 2,4,5-T methyl ester IS in hexane was added to an injected solution concentration of 0.1 ng/μl.

Quality assurance procedures included tests for leakage of the assembled permeation cell, and challenge and collection side solvent back-diffusion as outlined elsewhere [19,20].

2.4. Degradation of captan in aqueous challenge solution

Degradation studies were performed for dilute aqueous emulsions of the wettable powder. This also served to detect any potential hydrolysis. Volumes of 1.0 ml of diluted aqueous challenge solutions (1:300) at the end of the initial 30 min equilibration, and at the end of 8 h, were extracted three times with 2.0 ml volumes of hexane and the extracts combined in a 8 ml screw-capped vial with a Teflon-lined cap. The hexane and any residual water were evaporated under a nitrogen stream at 40 °C in a heating block (within a fume hood) and then taken up in 2.0 ml of hexane for final analysis using GC–ECD. A fourth extraction was carried out separately for each sample and analyzed to confirm the completeness of extraction.

2.5. Infrared reflectance analysis

Reflectance spectra of both the challenge and collection sides of the conditioned and unconditioned gloves of the same lot were obtained before a permeation experiment. The negative control exposure situation to account for any solvent effects was to expose a piece of the same conditioned glove to distilled water on the challenge side and hexane on the collection side for the appropriate time. The glove piece examined for permeation after experiments was dried to a constant weight in the constant humidity desiccator before being examined on both sides. The challenge side contained many white spots from the dried challenge solution as well as comparatively unspotted areas. The white spots acted as positive controls. Once the gloves were examined for reflectance, the challenge side was washed with distilled water, dried to a constant weight in the desiccator, then reexamined again by reflectance.

The major reflectance peaks were tabulated from the spectra obtained from 4000 to 600 cm^{-1}. Difference spectra for exposure situations of interest were also measured. For example, comparisons were made between (1) white spots and no white spots on the challenge sides; (2) white spots and the water negative control on the challenge sides; and (3) the captan exposed surface and the hexane negative control on the collection sides. When areas were homogeneous for a given glove side, the reflectances at a minimum of three distinct positions were measured and the data averaged. The number of scans for each measurement was 128. The tabulated data facilitated the characterization of changes in reflectance minima and intensities, and the appearance and disappearance of reflectances before and after challenges as well as possible detection of the pesticide, its formulation, and any degradation products.

2.6. Statistics

Student's *t*-test and analysis of variance (ANOVA) analyses were assigned statistical significance at the criterion $P \leq 0.05$. This necessitated at least triplicate samples in each experiment to define arithmetic means, standard deviations (S.D.), and coefficients of variation (CV). Linear regression analyses allowed calculation of slopes, *y*-intercepts, corresponding S.D.s, correlation coefficients (*r*), and *P*-values for internal standard quantification data.

Intrarun and interrun precisions were calculated as part of quality assurance/quality control. The least quantifiable limit (LQL) was defined as 10 times the standard deviation of the standard curve linear slope.

3. Results and discussion

3.1. GC–MS identification and quantitation of peaks

The chromatographic peak eluting at the captan retention time was identified as such by the 2001 NIST/EPA/NIH mass spectral library and showed *m*/*z* 79 (100%), 149 (12%), and 264 (6%). Captan and THPI were quantified with *m*/*z* 79, the base peak for both. The IS 2,4,5-T methyl ester was monitored with *m*/*z* 233 (100%). At a column temperature of 250 °C, THPI was identified with an approximate retention time of 10 min; captan eluted at 25 min. The formation of THPI was not detected at 200 °C. The LQL for captan was about 30 ng.

3.2. GC–ECD quantitative analysis

The captan standard curve at a column temperature of 200 °C was linear between 20 and 150 ng (66–500 pmol) with $r = 0.9990$ ($P \leq 0.05$). The LQL was 6 ng. The linear range for the 2,4,5-T methyl ester IS was 0.02–0.1 ng with $r = 0.9954$ ($P \leq 0.05$). The captan–IS standard curve had an average *r* of 0.9933 at $P \leq 0.05$ between 10 and 150 ng. Intrarun CVs were <10% and consecutive day interrun CVs were <15% for samples stored in amber vials and in a refrigerator (4 °C) overnight for no more than 48 h.

3.3. Thermal decomposition of captan

Initial experimentation revealed that the captan peak area decreased at column temperatures above 230 °C and increased to an optimal peak area near 200 °C. THPI, a thermal degradation product, synthetic intermediate, and metabolite [3,4], was identified by GC–MS at 250 °C. Further GC–ECD testing with column temperatures at 170 and 200 °C resulted in captan peak areas from about 2–10 times larger than those between 210 and 250 °C, respectively. Isothermal column conditions were selected to balance sensitivity and time. Previous studies by Martinez Vidal et al. [23] and Fernandez-Alba et al. [24] reported poor chromatographic signals and possible degradation at temperatures >210–280 °C.

3.4. Degradation of captan in aqueous solution

The calculated formulation captan content at the beginning of glove exposure was 36.4 ± 2.2% and after 8 h exposure 39.7 ± 6.1%, which was not statistically different at $P \leq 0.05$. The latter was also not statistically different at $P \leq 0.05$ from the measured true captan content of 45.6 ± 7.0% (93 ± 14% of the label claim). Pooling the data produced an average content of 39.9 ± 5.8% (82 ± 12% of the label claim), with a CV of 15%. The recovery of captan was complete within three hexane extractions for aqueous emulsions.

The degradation product THPI was not detected chromatographically after permeation experiments. Hydrolysis of captan has been previously reported by Wolfe et al. [25] with a pseudo-first-order rate constant of $1.8 \pm 0.1 \times 10^{-5}\ s^{-1}$ and maximum half-life of 710 min for the pH range 2–6 in hydrochloric acid. However, the commercial formulation appeared to stabilize captan in aqueous solution for at least 8 h. This is consistent with previous field studies showing that captan formulation persisted on crops with a half-life >5 days. De Cock et al. [26] reported a half-life of captan on crops between 10 and 17 days following spraying. Winterlin et al. [27] reported a half-life of 19.6 days following ground application of the wettable powder. Tielemans et al. [28] also reported an estimated environmental half-life of 5–11 days on the basis of glove data.

3.5. Permeation results

For the 4 and 8 h data (Table 1), the time-weighted average permeation rates in ng/(cm^2 min) were not statistically different at $P \leq 0.05$. None of the time-weighted average permeation rates observed after 2 and 4 h exceeded the ASTM [22] normalized permeation rate for open systems of 100 ng/(cm^2 min). At 8 h, 4 of the 11 replicates exceeded the 100 ng/(cm^2 min) threshold. All of the 2, 4, and 8 h data exceeded the minimum ASTM normalized flux of 250 ng/cm^2 for a closed-loop system. The ASTM normalized breakthrough detection time was therefore <2 h. When the average flux (Fl) in ng/cm^2 was plotted against permeation time (t) in hours, a linear relationship with $r = 0.999$ and $P \leq 0.05$ was obtained of the form $\text{Fl} = 5940t - 10{,}968$. At 250 ng/cm^2, $t = 1.89$ h, which was in agreement with the ASTM normalized breakthrough detection time of <2 h. In contrast, the calculated

Table 1
Captan 50-WP wettable powder[a] permeation data for unsupported and unlined SafeSkin blue nitrile gloves at 30 ± 0.5 °C

Duration (h)[b]	Average permeation rate (ng/(cm^2 min))	Average flux (μg/cm^2)[c]	Weight change (mg)	Thickness change (mm)[d]
Control	–	–	0.8 ± 0.1	0.005 ± 0.006
2	12.0 ± 4.6	1.4 ± 0.6	0.1 ± 0.1	0.000 ± 0.003
4	50.0 ± 24.8	12.0 ± 6.0	0.5 ± 0.3	−0.001 ± 0.005
8	76.7 ± 58.2	36.8 ± 27.9	0.4 ± 0.9	0.004 ± 0.004

[a] Captan 50-WP wettable powder aqueous concentration 217 mg/ml, hexane collection.
[b] Sample size: 8 h ($n = 11$), 4 h ($n = 6$), 2 h ($n = 3$), and control ($n = 3$).
[c] Converted to units in μg/cm^2 for comparison to ASTM normalized breakthrough detection time at 0.25 μg/cm^2 for closed-loop systems.
[d] Average of three measurements before and after exposure.

lagtime was 1.85 ± 0.14 h. The latter corresponds to a calculated diffusion coefficient [17] of $(1.28 \pm 0.10) \times 10^{-5}$ cm^2/h, assuming a representative glove thickness of 0.119 mm.

No significant swelling or shrinkage occurred at $P \leq 0.05$. The average thickness for out-of-the-box SafeSkin nitrile gloves was 0.112 ± 0.002 mm relative to 0.119 ± 0.004 mm after conditioning. The negative control blanks (solvents only) resulted in an average thickness of 0.123 ± 0.001 mm after conditioning. The 8 h pesticide exposure resulted in a thickness of 0.122 ± 0.003 mm, the 4 h exposure was 0.121 ± 0.003 mm, and the 2 h exposure was 0.124 ± 0.002 mm. The glove thickness was not significantly affected by any of the exposures after conditioning, but conditioning significantly affected thickness relative to the out-of-the-box state. This finding was supported by Khan et al. [16] showing no significant swelling of a nitrile glove following exposure to the hexane collection solvent for 8 h. The negative control blanks resulted in an average weight change of 0.8 ± 0.1 mg (<1% increase) after conditioning. The 8 h pesticide exposure resulted in a weight change of 0.4 ± 0.9 mg (<1% increase), the 4 h exposure resulted in 0.5 ± 0.3 mg (<0.5% increase), and the 2 h exposure resulted in 0.1 ± 0.1 mg (<0.2% increase). None of these weight changes differed significantly at $P \leq 0.05$ from that of the negative control blank.

For captan, there was no significant increase in glove swelling following exposure to the formulation. In contrast, Purdham et al. [29] reported a 26% increase in nitrile glove thickness following 16 h exposure to the herbicide MCPA. However, the collection medium was an aqueous solution of 0.01 M sodium hydroxide. Khan et al. [16] showed an average swelling of 3% following 8 h exposure to chlorpyrifos and endosulfan formulations, but this was not significant at $P \leq 0.05$.

3.6. Infrared reflectance analysis

3.6.1. Chemicals

The reflectance spectra were in agreement with previously reported FT-IR reflectance spectral regions by Doran [30] and Doran et al. [31], of 870–934, 1248–1322, and 1729–1760 cm^{-1} for captan and 1692–1729 cm^{-1} for THPI. However, additional spectral regions and peak intensities were identified to allow distinction between captan and THPI on the glove surface. Though the peaks near 637–740, 812–902, 1310–1430, and 1700–1740 cm^{-1} were common, THPI had major diagnostic minima at 1167, 1198, 1436, and 3201 cm^{-1} (Table 2). The corresponding major diagnostic minima for captan were therefore 618, 766, 1056, 1125, and 1257 cm^{-1}. When a residue was formed on the zinc selenide crystal by drying pure captan in hexane (202 μg/ml) and its infrared spectrum measured, no THPI diagnostic minima appeared. The same major wavelengths appeared in its spectrum as fresh captan and the only difference was that the major minimum at 766 cm^{-1} was overlapped by minima at 744 and 809 cm^{-1}. This implied that the captan standard was stable in concentrated solutions with hexane as the solvent.

Captan 50-WP had a moderate (87–90% reflectance) and broad region between 955 and 1000 cm^{-1}, likely associated with added surfactant in the formulation. THPI diagnostic minima could not be detected in the spectrum of the formulation. Using the criterion that reflectance minima belonging to the same absorption should agree within 10 cm^{-1}, other major minima not due to captan were not detected in the formulation. However, three weak (>90% reflectance) minima at 668, 749, and 3690 cm^{-1} were distinctive in comparison

Table 2
Major infrared reflectance minima for captan, captan 50-WP wettable powder formulation, and THPI[a]

Compound	Major wavelength minima in cm^{-1} (% reflectance)[b]
Captan 98% (solid)	690 (77); 738 (83); 1733 (85); 1257 (85); 1125 (86); 766 (86); 1057 (88); 812 (88); 877 (89); 1188 (92); 1042 (94); 902 (94); 618 (95); 1431 (95); 1379 (97); 893 (97); 640 (97); 1309 (97); 1341 (97); 2901 (98); 2959 (98); 1804 (98)
Captan residue (202 μg/ml in hexane)	669 (98); **1737** (**99**); **1260** (**99**); 3727 (99); 744 (99); **1127** (**99**); **809** (**99**); 3705 (99); **1056** (**99**); 3628 (99); **618** (**99**)
Captan formulation (solid)	**690** (**81**); **739** (**87**); 955 (87); **1057** (**88**); **877** (**88**); **1041** (**89**); **1128** (**89**); **766** (**90**); **1735** (**90**); **1258** (**90**); **813** (**91**); **618** (**91**); **902** (**91**); 750 (91); 669 (91); **640** (**93**); **1188** (**95**); **1431** (**96**); **1379** (**97**); **1309** (**97**); 3691 (98); **1804** (**99**); **2901** (**99**); **2959** (**99**)
THPI 98% (solid)	1698 (89); 662 (92); 1167 (93); **638** (**94**); 782 (94); 1356 (94); **688** (**94**); 1199 (95); **1313** (**95**); **816** (**95**); 1332 (96); 729 (96); 1051 (97); 1379 (97); 3201 (97); 1031 (97); **902** (**97**); 1769 (98); **1435** (**98**); 943 (98); 981 (98); **1261** (**98**)

[a] The intrarun uncertainty was $\pm 2\ cm^{-1}$.
[b] Values in bold matched reflectance minima for pure captan, 98% (solid) within $\pm 5\ cm^{-1}$.

with captan and THPI reflectance spectra (Table 2). Ultimately, the data provided in Table 2 aided in the identification of captan and THPI on the surface of exposed nitrile gloves.

3.6.2. Gloves

Both the inner and outer surfaces of the glove palm had diagnostic aliphatic C–H stretches at 2900–3000 cm^{-1}, C≡N triple bond stretches at 2200–2400 cm^{-1}, C=N double bond stretches at 1600–1700 cm^{-1}, C–H bends at 1400–1500 cm^{-1}, C–N and C–C stretches at 900–1000 cm^{-1}, and C–H rocking at 600–700 cm^{-1}.

3.6.2.1. Outer glove surface. Following the glove conditioning process only the moderate and weak minima at 697, 711, 1132, 1042, and 832 cm^{-1} of the out-of-the-box glove had disappeared (Table 3). On soaking in water for 4 and 8 h (negative control), the major minima for the conditioned or out-of-box glove did not change within 10 cm^{-1}. On exposure to the aqueous pesticide formulation for 4 h, no major minima of the negative control were affected for the outer surface. However, new moderate minima appeared at 670, 698, and 1018 cm^{-1} (Table 3). When a white spot on this same glove was scanned, the new minima relative to the glove area with no white spot were: 740, 766, 813, 1057, 1127, 1189, 1259, and 1736 cm^{-1}, all of which are contained in the captan formulation (Table 2). In addition, for the no-spot condition the reflectance at 690 cm^{-1} was >98% but for the white spot condition the reflectance was 85%. This was to be expected because 690 cm^{-1} was the most intense formulation minimum. Relative to the glove exposed to water for 8 h, exposure to aqueous pesticide for 8 h caused no wavelength changes in major minima, but all minima decreased in intensity. Because the exposed gloves closely resembled the controls, degradation of the glove material by the formulation was not apparent.

In addition, none of the exposed outer surface spectra contained diagnostic peaks for THPI, implying that captan was not degrading during the 4 and 8 h exposure trials. As

Table 3
Major infrared reflectance minima for the outer surface of SafeSkin nitrile glove materials before and after 4 and 8 h of exposure to aqueous emulsion of captan formulation[a]

Outer surface	Major wavelength minima in cm^{-1} (% reflectance)[b]
Box	**1433** (**47**); **874** (**75**); 968 (77); 713 (88); 697 (89); 611 (89); 1180 (92); 915 (92); 2923 (92); 1132 (93); **1042** (**93**); 1607 (95); 2851 (95); 832 (96)
Humidified	**1428** (**38**); **874** (**72**); 968 (69); 713 (87); 918 (91); 2923 (94); **1186** (**96**); 1606 (96); 2856 (96); 3442 (98)
Control (water)	**1427** (**38**); **874** (**62**); 967 (76); 713 (85); 699 (90); 915 (92); 2922 (94); 1196 (95); 1606 (95); 2849 (96); 3438 (98)
4 h challenge (no solid)	1440 (62); **874** (**74**); 968 (76); 1019 (86); 604 (88); 713 (88); 670 (90); 698 (90); 918 (92); 1173 (93); 2926 (96); 1609 (97); 2849 (98); 3692 (98); 3401 (98); 1725 (98); 1795 (98)
8 h challenge (no solid)	**1430** (**42**); 968 (69); **874** (**72**); 713 (87); 918 (91); 2923 (94); **1186** (**95**); 1606 (96); 3691 (97); 3432 (98); 1795 (98)
4 and 8 h challenge combined (white solid spot)	**1432** (**74**); **874** (**79**); 698 (82); **691** (**85**); 1017 (87); **1057** (**89**); 713 (90); 669 (91); **740** (**91**); **1127** (**91**); **766** (**92**); **1259** (**92**); **813** (**93**); **1736** (**94**); **1189** (**94**); 2927 (97)

[a] The intrarun uncertainty was $\pm 2\,cm^{-1}$.
[b] Values in bold matched reflectance minima for pure captan, 98% (solid) within $\pm 5\,cm^{-1}$.

previously discussed, this was expected because previous field studies [26–28] have shown the captan formulation to persist on crops with a half-life >5 days. However, longer persistence of captan on crops further supports the need for protective gloves and clothing during harvesting and post-application activities. The US EPA's 1999 Reregistration Eligibility Decision [3,5] increased some of the post-application restricted-entry intervals (REIs) up to 4 days based on frequency of exposure. However, a majority of the crops, including strawberries and apples, remained with REIs of 24 h, which does not account for the persistence of captan on these crops. Furthermore, early reentry requires the use of PPE only during the first 48 h of the REI.

3.6.2.2. Inner glove surface. The changes in the inner side of the glove were much less marked than for the outer surface. Conditioning retained all the minima detected for the out-of-the-box glove. New weak minima appeared at 657, 684, 1354, 2857, 1726, and $1769\,cm^{-1}$ (Table 4). Soaking the conditioned inner glove with hexane for 8 h made the weak minimum at $684\,cm^{-1}$ disappear; new weak minima appeared at 875 and $1124\,cm^{-1}$ (Table 4).

Relative to the 8 h exposed hexane glove (control), the inside surface after pesticide formulation challenges at both 4 and 8 h showed no new minima, and corresponding peak intensities were within 5% of one another. Characteristic wavelengths for captan or THPI were also not present. The absence of captan on the glove inside surface was expected because the function of the hexane collection fluid was to solubilize permeated captan.

The collection fluid did not have a marked effect on the reflectance minima relative to the conditioned glove inner surface. Hexane is thus an effective collection solvent that does not impair the glove collection surface. The glove manufacturer [32] literature shows that nitrile has excellent resistance to degradation and permeation against hexane using ASTM

Table 4
Major infrared reflectance minima for the inner surface of SafeSkin nitrile glove materials before and after 4 and 8 h of exposure to aqueous emulsion of captan formulation[a]

Inner surface	Major wavelength minima in cm^{-1} (% reflectance)[b]
Box	969 (85); 698 (91); 1449 (93); 1174 (94); 916 (93); 1036 (94); 2928 (96); 1640 (97); 3417 (98)
Humidified	969 (89); 697 (91); 684 (91); 657 (91); 1175 (94); **1038** (**94**); 917 (95); 1009 (95); 1449 (95); 2928 (97); 1354 (97); 1640 (97); 3418 (98); 2859 (98); 1726 (98); 1769 (98)
Control (hexane)	968 (85); 698 (91); 604 (91); 657 (91); 1449 (93); 916 (93); 1174 (93); 1036 (94); **1124** (**94**); **875** (**96**); 2927 (96); 832 (96); 1356 (97); 1640 (97); 2855 (98); 3417 (98); 1726 (98); 1769 (98)
4 h challenge	968 (88); 698 (92); 605 (92); 686 (92); 658 (92); 627 (93); 1175 (94); 916 (95); **1038** (**95**); **1124** (**95**); 1449 (95); 831 (97); 1356 (97); 2927 (97); 1641 (98); 3416 (98); 1724 (98); 1768 (99)
8 h challenge	969 (87); 697 (92); 917 (94); 1173 (94); 1449 (94); **1037** (**95**); **1122** (**95**); **876** (**97**); 2927 (97); 1355 (97); 1641 (97); 1722 (98); 3429 (98)

[a] The intrarun uncertainty was $\pm 2\,cm^{-1}$.
[b] Values in bold matched reflectance minima for pure captan, 98% (solid) within $\pm 5\,cm^{-1}$.

methods. Under similar permeation conditions, Lin and Que Hee [19] also concluded that nitrile was impermeable to hexane.

3.7. Glove permeation versus skin absorption

The flux (Fl) of captan through the skin can be predicted using the theoretical formula from Fiserova-Bergerova and Pierce [33]:

$$\mathrm{Fl} = \frac{s}{15}(0.038 + 0.153K_{ow}) \exp(-0.016\,\mathrm{MW}) \quad (1)$$

where MW is the molecular weight in g/mol, s the water solubility in mg/l at a specified temperature, K_{ow} the octanol/water partition coefficient at the same temperature, and Fl is in mg/(cm^2 h). For captan [1], MW = 300.56 g/mol, s = 3.3 mg/l at 25 °C, and K_{ow} = 224 at 25 °C, the resulting Fl is 62 μg/(cm^2 h) or 206 nmol/(cm^2 h). However, de Cock et al. [34] utilized a second reported K_{ow} of 610 at 25 °C; the resulting Fl is 560 nmol/(cm^2 h). Both K_{ow} values are reported in the Agrochemicals Desk Reference [35], but pH conditions were not reported. According to Montgomery [35], K_{ow} is dependent on pH. For the purposes of this study both values were utilized to give a Fl range of 206–560 nmol/(cm^2 h). The maximum observed captan equivalent time-weighted average permeation rate for the nitrile glove at 8 h was about 23 nmol/(cm^2 h). Because the glove permeation rate was less than the estimated potential skin absorption flux, rapid skin absorption of captan should occur as long as the permeated material remains in contact with the skin. However, wrinkles in the glove or other barriers may result in the accumulation of captan on the inside of the donned glove, which would increase the risk of dermatitis and/or sensitization [3–5,11].

Field studies [8,27,28,36,37] using both cotton glove and hand wash methods to assess dermal exposure have reported average hand exposures ranging from about 1 to 44 mg/h. Given an average male with a glove area of 1075 cm^2 [27], typical hand exposures would

range between 0.9 and 41 μg/(cm^2 h) (3–140 nmol/(cm^2 h)). According to the dermal absorption estimates, bare-hand exposures would not be rate limited and near complete dermal absorption is possible. In contrast, the disposable nitrile gloves would provide some level of protection. This conclusion is partly supported by field studies showing significant reductions in absorbed dose associated with the use of gloves. Krieger and Dinoff [38] reported a 38% reduction in absorbed dose (urinary THPI) with the use of 20 mil rubber latex gloves. De Cock et al. [39] reported a 45% reduction in urinary THPI levels with use of gloves, but glove type and thickness were not specified.

4. Conclusions

This is the first report of the permeation of a captan formulation through gloves, and one of the first reports on the use of infrared reflectance to characterize the surfaces of gloves before and after permeation experiments in an ASTM-type permeation cell. Infrared reflectance was able to detect contaminated outer glove challenge surfaces and verified that hexane was a suitable solvent to collect captan without damaging or changing the inner surface of the nitrile glove. Infrared reflectance also showed that extensive degradation in the challenge solution did not occur after 8 h, a conclusion also supported by GC–ECD analysis. GC–ECD based permeation and infrared reflectance data indicated high chemical resistance of the disposable nitrile glove to a highly concentrated aqueous emulsion of captan. Because the ASTM normalized breakthrough detection time was <2 h, these disposable nitrile gloves should not be reused once worn, and decontamination is not advised as an alternative to disposal. Agricultural reentry field workers are also advised to use protective gloves, because captan has been shown to persist on crops with a half-life greater than the current US EPA reentry intervals of 1–4 days. Future studies should attempt to assess the protective properties of different protective clothing materials and thicknesses.

Acknowledgements

The research was funded by CDCP/NIOSH RO1 03754A, ASPH/NIOSH S1891-21/21, the Center for Occupational and Environmental Health at UCLA, and (in part) by a pilot project research training grant from the Southern California Education and Research Center (SCERC), funded by CDCP/NIOSH T42/CCT981726. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health. The technical assistance of Hanaa Zainal of UCLA Department of Environmental Health Sciences is acknowledged.

References

[1] California Environmental Protection Agency Department of Pesticide Regulation, Summary of Pesticide Use Report Data 1999, California Environmental Protection Agency, Sacramento, CA, 2000.
[2] National Institute for Occupational Safety and Health, NIOSH Pocket Guide to Chemical Hazards, National Technical Information Service, PB 97-177-604, Cincinnati, OH, 1999.

[3] US Environmental Protection Agency, Reregistration Eligibility Decision (RED): Captan, US EPA National Center for Environmental Publications and Information, 738-R-99-015, Cincinnati, OH, 1999.
[4] Hazardous Substances Data Bank, Toxnet Computer Data Base, http://www.toxnet.nlm.nih.gov, National Library of Medicine, 2002.
[5] US Environmental Protection Agency, Reregistration Eligibility Decision (RED) Facts: Captan, US EPA National Center for Environmental Publications and Information, 738-F99-015, Cincinnati, OH, 1999.
[6] M.E. Cassinelli, P.F. O'Connor (Eds.), National Institute for Occupational Safety and Health Manual of Analytical Methods, fourth ed., Publication 94–113, Department of Health and Human Services, Government Printing Office, Washington, DC, 1994, available at http://www.cdc.gov/niosh.
[7] American Conference of Industrial Hygienists, Documentation of the TLVs and BEIs, seventh ed., American Conference of Industrial Hygienists, Cincinnati, OH, 2002.
[8] International Agency for Research on Cancer, Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man, vol. 30, Suppl. 7, World Health Organization, International Agency for Research on Cancer, ISSN 1017 1606, Geneva, 1987.
[9] G. Zweig, R. Gao, W. Popendorf, J. Agric. Food Chem. 31 (1983) 1109.
[10] E.R. Stevens, J.E. Davis, Bull. Environ. Contam. Toxicol. 26 (1981) 681.
[11] C. Kazen, A. Bloomer, R. Welch, A. Oudbier, H. Price, Arch. Environ. Health 29 (1974) 63.
[12] Y.L. Guo, B.J. Wang, C.C. Lee, J.D. Wang, Occup. Environ. Med. 53 (1996) 427.
[13] M. Mikatavage, S.S. Que Hee, H.E. Ayer, Am. Ind. Hyg. Assoc. J. 45 (1984) 617.
[14] J. Harville, S.S. Que Hee, Am. Ind. Hyg. Assoc. J. 50 (1989) 438.
[15] S.S. Que Hee, in: J.L. Perkins, J.O. Stull (Eds.), Permeation of Some Pesticidal Formulations Through Glove Materials in Chemical Protective Clothing Performance in Chemical Emergency Response, OH-010370-55, American Society for Testing and Materials, Philadelphia, PA, 1989, p. 157.
[16] A.A. Khan, X. Chen, S.S. Que Hee, Appl. Occup. Environ. Hyg. 12 (1997) 413.
[17] Y.-W. Lin, S.S. Que Hee, Appl. Occup. Environ. Hyg. 13 (1998) 158.
[18] X. Lu, S.S. Que Hee, J. Hazard. Mater. 59 (1998) 279.
[19] Y.-W. Lin, S.S. Que Hee, Appl. Occup. Environ. Hyg. 13 (1998) 286.
[20] Y.-W. Lin, S.S. Que Hee, J. Hazard. Mater. 60 (1998) 143.
[21] Ansell Protective Products, Chemical Resistance Guide: Permeation and Degradation Data, sixth ed., CRG-GC-Rev. 9–98, Ansell Protective Products, Coshocton, OH, 1998.
[22] American Society for Testing and Materials, Standard Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids or Gases Under Conditions of Continuous Contact, Method F739-96, American Society for Testing and Materials, West Coshohocken, PA, 1996.
[23] J.L. Martinez Vidal, M.C. Pablos Espada, A. Garrido Frenich, F.J. Arrebola, J. Chromatogr. A 867 (2000) 235.
[24] A.R. Fernandez-Alba, A. Valverde, A. Agüera, M. Contreras, J. Chromatogr. A 686 (1994) 263.
[25] N.L. Wolfe, R.G. Zepp, J.C. Doster, R.C. Hollis, J. Agric. Food Chem. 24 (1976) 1041.
[26] J. de Cock, D. Heederik, H. Kromhout, J. Boleij, F. Hoek, H. Wegh, E. Tjoe Ny, Am. Ind. Hyg. Assoc. J. 59 (1998) 166.
[27] W.L. Winterlin, W.W. Kilgore, C.R. Mourer, G. Hall, D. Hodapp, Arch. Environ. Contam. Toxicol. 15 (1986) 301.
[28] E. Tielemans, E. Louwerse, J. de Cock, D. Brouwer, G. Zielhuis, D. Heederik, Am. Ind. Hyg. Assoc. J. 60 (1999) 789.
[29] J.T. Purdham, B.J. Menard, P.R. Bozek, A.M. Sass-Kortsak, Appl. Occup. Environ. Hyg. 16 (2001) 961.
[30] E.M. Doran, Measuring and Modeling Dermal Absorption of Pesticide Residues, Ph.D. Dissertation, University of Washington, 2000.
[31] E.M. Doran, M.G. Yost, R.A. Fenske, Bull. Environ. Contam. Toxicol. 64 (2000) 666.
[32] Safeskin, Chemical Resistance and Barrier Guide, Safeskin Corporation, San Diego, CA, 2001.
[33] V. Fiserova-Bergerova (Thomas), J.T. Pierce, Appl. Ind. Hyg. 8 (1989) F14. See also: A.L. Bunge, Am. J. Ind. Med. 34 (1998) 81.
[34] J. de Cock, D. Heederik, H. Kromhout, J. Boleij, Ann. Occup. Hyg. 40 (1996) 611.
[35] J.H. Montgomery, Agrochemicals Desk Reference, second ed., CRC Press, Boca Raton, 1997, p. 69.
[36] R.A. Fenske, S.G. Birnbaum, M.M. Methner, R. Soto, Bull. Environ. Contam. Toxicol. 43 (1989) 805.
[37] J. de Cock, D. Heederik, H. Kromhout, J. Boleij, F. Hoek, H. Wegh, E. Tjoe Ny, Am. Ind. Hyg. Assoc. J. 59 (1998) 158.
[38] R.I. Krieger, T.M. Dinoff, Arch. Environ. Contam. Toxicol. 38 (2000) 398.
[39] J. de Cock, D. Heederik, F. Hoek, J. Boleij, H. Kromhout, Am. J. Ind. Med. 28 (1995) 245.