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Folpet Permeation Through Nitrile Gloves

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The aim of this study was to investigate whether two different brands of unsupported and unlined nitrile gloves protected against aqueous emulsions of a Folpet wettable powder (50% Folpet) using an ASTM type-I–PTC 600 permeation cell at 30.0 ± 0.1°C held in a shaking water bath. An analytical method to determine Folpet using the internal standard method was first developed based on gas chromatography-mass spectrometry (GC-MS), and gas chromatography-electron capture detection (GC-ECD). A novel pyrolysis GC-ECD technique that quantified the thermal degradation product phthalimide had pg sensitivity suitable to detect the trace amounts of Folpet that permeated. The on-column conversion was (68.0 ± 9.5) percent at 170°C over the folpet injected mass range of 3 to 148 pg. The challenge solution in the permeation cell was 1.4 mg/mL aqueous emulsion of Folpet wettable powder, and 2-propanol was the collection solvent. After evaporation of the collection solvent, the time weighted average rate of permeation of Folpet through SafeSkin nitrile (an exams type of glove) after 8 hours was (42.1 ± 2.9) ng/cm^2/min compared with (2.04 ± 0.69) ng/cm^2/min for the Sol-Vex nitrile (industrial chemical resistant), the latter being about 21 times more protective and also near the limits of detection. The respective values after 4 hours of exposure were (28.4 ± 1.2) and (0.65 ± 0.36) ng/cm^2/min. Diagnostic reflectance infrared minima of both challenge and collection sides of the gloves showed small changes in wave number and intensity values after 8 hours of exposure, with Folpet being detected in dried spots on the challenge side. GC-ECD–based permeation and IR reflectance data indicated high chemical resistance of the Sol-Vex gloves to an aqueous emulsion of Folpet.

Keywords Folpet, Pesticide, Glove, Nitrile, Permeation, Protection

Folpet (N-[trichloromethylthio]phthalimide) is a dicarboximide fungicide of melting point 177°C, log K_{ow} 2.85, water solubility at 25°C 1 mg/L, and vapor pressure 9.75×10^{-6} mm Hg at 20°C.[1] Folpet was first registered as a pesticide in 1948. It is usually formulated under such names as Acryptan, Cosan I, Faltan, Faltex, Folnit, Folpan, Folpel, Folpet, Folpex, Ftalan, Fungitrol, Fungitrol 11, Intercide TMP, Orthofaltan 50, Orthophaltan, Phalatane, Phaltan, Phaltane, Phthaltan, Sanfol, Spolacid, Thiophal, Trifol, and Vinicoll. The major formulation types are wettable powders (44–50%); dusts (88%); and liquid, ready for use (0.3–0.7%). There are many mixed formulations. Its major current use as a pesticide in the United States is on avocados and to preserve wood. It is applied by dip treatment; foliar contact; soaking; spraying; and as a paint, stain, and caulk additive; wood surface treatment; and as a high-volume spray.[2,3] Folpet acts by denaturing fungal proteins after reacting with their sulfhydryl groups.[2]

Folpet is classified[1–3] as a B2 carcinogen (probable human carcinogen) by the U.S. EPA, and a 2A carcinogen (probably carcinogenic in humans) by the International Agency for Research on Cancer (IARC) because it induces carcinoma and adenoma of the duodenum in both genders of CD-1 and B6C3F1 mice. In situ generation of thiophosgene is the current mechanism of duodenal cancer initiation (shared by its analog Captan).[2] Duodenal cancers are not observed in treated rats, but males show C-cell, thyroid, and testicular cancers. Folpet is mutagenic without metabolic activation, clastogenic, teratogenic, and causes chromosomal damage. It can damage the liver and kidney at high doses. It is known to be absorbed through the skin (rats absorb at 2.7% over 72 h), and irritates the eyes and respiratory tract. It causes both allergic and irritant contact dermatitis and skin sensitization in humans. The half-time of Folpet in human blood is about 1 min, degrading[2,3] to less toxic phthalimide,[4] phthalamic acid, and then phthalic acid.[5,6]

The U.S. EPA did have tolerances[2,3] before 1987 in or on raw agricultural commodities of: 50 ppm (w/w) for celery, leeks, lettuce, onions (green), and shallots; 25 ppm for apples, avocados, blackberries, boysenberries, crabapples, cranberries, currants, dewberries, gooseberries, grapes, huckleberries, loganberries, raspberries, strawberries, and tomatoes; and 15 ppm for citrus fruits, cucumbers, garlic, melons, onions (dry bulb), pumpkins, summer squash, and winter squash (40 CFR Part 180.191). Because of a voluntary suspension by one manufacturer for agricultural, ornamental, and greenhouse registrations, the only above tolerance in force in 2003 in the

United States is the one for scab (*Sphaceloma*) control on and in avocados in Florida,[2,3] with the others being import produce tolerances. The other current registered U.S. uses are to control rot fungi, mold/mildew, and spoilage fungi on wood and other surfaces.[2,3] A new tolerance is being drafted for imported raisins.[2,3] The paint additive use is also being studied.[2,3]

Folpet is also used extensively in Europe, especially on grapes, for example, in Switzerland where the tolerance is 3 mg/kg; the European Union has decreed that drinking water concentrations of any pesticide cannot exceed 0.1 μg/L and that the sum for all pesticides cannot exceed 0.5 μg/L.[2,3] Folpet has no OSHA PEL, NIOSH REL, or ACGIH® TLV®-TWA guidelines.

Folpet is not now manufactured in the United States. The major occupational exposures are to handlers (mixers, loaders, and applicators), to reentered field workers (a 24-h reentry interval is recommended), and to loaders of Folpet powder into paint. The major exposure route is through the skin. The above exposures may also occur in residential and agricultural settings as well as in the manufacturing sector.[2,3] The only EPA guidance on personal protective equipment (PPE) for Folpet is the statement "Chemical resistant gloves and a dust/mist respirator are required. If available, engineering controls such as closed loading systems are an adequate substitute for the PPE."[3] No specific materials for glove protection are indicated.

Further protective clothing requirements for ready-to-use Folpet products include long-sleeve shirt, long pants, shoes, and socks. Handlers are also to wear coveralls, chemical-resistant boots, and chemical-resistant headgear. Mixers also need to wear chemical-resistant aprons. Nevertheless, dermatitis has been reported for fruit farmers who used dicarboximide pesticides frequently (Captan, Folpet, and Captafol).[7] There is only one NIOSH report of Folpet and phthalimide exposures during Folpet production.[8]

The major analytical chromatographic methods for Folpet are capillary gas chromatography (GC) and high performance liquid chromatography (HPLC). There are two EPA-referenced GC/electron capture detector (GC-ECD) methods for Folpet crop residues, Method 568W-1 and Method FP/15/91.[2] Method WLS/018 using HPLC is not validated yet.

Since there were no explicit recommendations for the type of chemical-resistant gloves to wear for protection against Folpet exposure, it was decided to evaluate two nitrile glove types with ASTM glove permeation Method F739-99, as modified by our research group.[9–16]

EXPERIMENTAL METHODS

Gloves and Chemicals

The gloves utilized were 11-mil-thick, embossed, unsupported/unlined Sol-Vex nitrile from Ansell Edmont (Coschocton, OH, catalog No. 37-145 and 33 cm in length), and disposable, powderless, unsupported/unlined nitrile latex exam gloves (Safe-Skin, 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, are inexpensive, and their compatibility charts indicated that protection would be likely against aqueous solutions of surrogate weak bases like ammonium hydroxide and aqueous triethanolamine (both have permeation breakthrough >360 min with steady-state permeation rate <0.9 μg/cm^2/min).[17]

The chemicals used were analytical grade Folpet (99%); phthalimide (99.5%); and 4,4′-dichlorobiphenyl (99.4%; used as internal standard [IS] for GC-ECD) procured from Chem. Services (West Chester, PA). The methyl ester of 2,4,5-T (98%) used as IS for gas chromatography/mass spectrometry (GC-MS) was obtained from PolyScience, Niles, IL. Later's Folpet Rose and Garden Fungicide (50% w/w Folpet; 50% inert ingredients) was supplied by Later's Products (Richmond, British Columbia). Nitric acid used to prepare 10 percent nitric acid for cleaning glassware was from Fisher Scientific (Tustin, CA) as were Optima 2-propanol and Optima hexanes.

Water produced from a Millipore Super-Q water deionizing filter system (Millipore, 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).

Apparatus

The GC-ECD was a Hewlett-Packard 5890 with a splitless 30 m $\times$ 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-ECD, whose signal was displayed on a Hewlett-Packard 3396 integrator. The temperature of the injector was 200°C, and that of the detector was 260°C. The column flow of 5:95 methane/argon carrier gas was 3.0 $\pm$ 0.2 mL/min, 2.5 $\pm$ 0.2 mL/min for the septum purge, 40 $\pm$ 3 mL/min for detector makeup, and 4.0 $\pm$0.3 mL/min for the anode purge. The column was programmed at 170°C for 22 min, raised to 200°C at 30°C/min and maintained there for 30 min.

The GC-MS had the same GC type and column 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 200°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 $\pm$ 0.3 mL/min. The purge delay was 3 min. 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 Wiley 7th Ed/NIST 98 Library supported mass spectral assignments.

Infrared (IR) spectra were obtained with a Avatar 360 Fourier-Transform (FT) spectrometer system (ThermoNicolet,

Madison, WI), a single-beam FT-IR spectrophotometer using 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.

An SP Temp-Blok Module Heater (American Scientific Products, McGaw Park, IL) was used in conjunction with an 8 mm × 20 mm heating block (Thomas Scientific, Swedesboro, NJ) to evaporate solvents after liquid-liquid extractions.

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 OD × 133 mm ID) were mounted on the two rails of the shaker after hacksawing the 1-mm-wide grooves in the bars and using emery paper to smoothe the jagged edges. Three-prong clamps allowed suspension of three permeation cells above and into the bath water as desired. A micrometer screw gauge (L. S. Starrett Co., Athol, MA) was used to measure glove thickness before and after experiments to indicate glove swelling or shrinkage. Vernier calipers (Mitutoyo, Japan) allowed measurement of the glove diameters cut for permeation studies.

Permeation Procedure

The detailed procedure is provided elsewhere[15,16] and is based on the standard ASTM F 739-99 method.[18]

In summary, glove materials cut from out-of-the box gloves were conditioned at least for 24 h in a desiccator with 65.2 ± 0.8 percent relative humidity (saturated aqueous sodium dichromate). The material was held between two Teflon gaskets and the Pyrex chambers by a uniform torque. A volume of 10 mL isopropanol was added as the collection medium, and then 10 mL of aqueous formulation was pipetted into the challenge chamber. The maximum application concentration of 1.4 mg/mL was prepared by weighing the solid Folpet formulation, suspending it in the appropriate volume of water, and then mixing for 30 s by vortexing. Three permeation cells were immersed into the water bath at 30.0 ± 0.5°C and horizontal shaking speed of 8.4 ± 0.5 cm/s was begun to ensure no concentration gradients in the challenge and collection media sides as confirmed by prior challenge solution opacity observations at different shaker speeds. Permeation time intervals of 4 and 8 h were evaluated in triplicate.

Quality assurance procedures included tests for leaking of the assembled permeation cell, and challenge and collection side solvent back-diffusion as outlined elsewhere.[15,16] Aliquots of 1 mL challenge solution were obtained fresh, before the permeation began, and from the solution after each permeation run. Blank runs in triplicate involved exposing the challenge side to Millipore Super Q water with 2-propanol in the collection side.

Laboratory personnel wore laboratory coats, safety glasses, and SafeSkin gloves, and worked in fume hoods whenever possible.

Gas Chromatographic Experiments

Initial experimentation showed an inverse relationship between Folpet mass injected and temperature. The Folpet peak decreased at high temperatures and low mass injected, and increased at high mass injected and lower temperatures. This situation necessitated optimization of these variables. While GC-MS was adequate for the high injected mass end, the low injected mass end required the use of GC-ECD. Furthermore, the low injected mass end for GC-ECD necessitated the use of phthalimide as standard since there was no Folpet peak, only its degradation product phthalimide. Thus, keeping the injection volume constant at 1.0 μL, a peak area versus phthalimide and/or Folpet standard curve was developed for both GC-MS over the range 10–2000 pmol using the internal standard method (m/z 59 used for GC/MS for the methyl ester of 2,4,5-T present at a final IS concentration of 25 ng/μL and m/z 76 to monitor Folpet and phthalimide), and 4,4′-dichlorobiphenyl for GC-ECD at 16 ng/μL.

Intrarun and interrun precision were done as part of quality assurance/quality control. The lower quantifiable limit (LQL) was defined as 10 times the standard deviation of the standard curve linear slope. All standardizations involved at least triplicate samples of each Folpet and phthalimide concentration. SafeSkin gloves, safety glasses, and laboratory coats were worn for all injections. The GC-ECD was vented outside.

Permeation rates in Folpet equivalent were calculated from phthalimide quantifications corrected for fraction injected after collection solution concentration and for the on-column/injector pyrolysis reaction efficiency.

Infrared Reflectance Experiments

Reflectance spectra of both the challenge and collection sides of the conditioned and unconditioned gloves of the same lot were examined before a permeation experiment. The negative control exposure situation to account for any solvent effects was to expose a specimen of the same conditioned glove to distilled water on the challenge side and 2-propanol on the collection side for the appropriate time. The glove specimen examined for permeation after experiments was dried to 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 a positive control. Once the gloves were examined for reflectance the challenge side was washed with distilled water, dried to constant weight in the desiccator, and 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,

white spots and no spots on the challenge side, white spots and water negative control challenge side, and exposed collection side and 2-propanol negative control. When areas appeared visually homogeneous for a given glove side, the reflectances at a minimum of three distinct positions were measured and the data averaged if statistically homogeneous. The number of scans for each measurement was 128 as a compromise between sensitivity and analysis time. 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 pesticide and its formulation.

SafeSkin gloves, safety glasses, and laboratory coats were worn during all operations.

Degradation of Folpet in Aqueous Challenge Solution

Volumes of 1.0 mL of aqueous challenge solutions just before and at the end of each permeation experiment were extracted 3 times with 1 mL hexane and the extracts combined in a 4 mL brown screw-capped vial with a Teflon-lined cap. The hexane was evaporated under a nitrogen stream at 40°C in a heating block in a fume hood, and then 1.0 mL 2-propanol was added. Aqueous samples were also evaporated without extraction and taken up in 1.0 mL 2-propanol. GC-MS was used to ascertain whether the Folpet in the aqueous formulation permeated as Folpet or as phthalimide or both. For confirmatory GC-ECD analysis, a 30-μL volume of the isopropanol final solution was diluted. The same extraction and processing schemes were also applied to 0.4 mg phthalimide. The other Folpet degradation products, phthalic acid and phthalamic acid, would not be detectable on the moderately polar column used, although the pyrolysis product of both of them, phthalic anhydride, would be, and this compound was also searched for by GC-MS.

Statistics

Student *t* and Analysis of Variance (ANOVA) analyses assigned statistical significance ($p \leq 0.05$) necessitated at least triplicate samples in each experiment to define arithmetic means, standard deviations (SD), and coefficients of variation (CV). Linear regression analyses allowed calculation of slopes and intercepts, their corresponding SDs, the correlation coefficient, and p-values.

RESULTS

GC-ECD and GC-MS

Intrarun CVs for GC-ECD and GC-MS injections were <10 percent, and consecutive day interrun CVs were about 16 percent. The phthalimide GC-ECD calibration curve at 170°C was linear between 0.50 ng to 6.0 ng (3.4–41 pmol) with $r = 0.9965$ ($p \leq 0.05$). The LQL was about 0.18 ng. The linear range for the 4,4′-dichlorobiphenyl IS was 1 ng to 20 ng.

The peak area of m/z 76 versus Folpet mass for GC-MS was linear over the range 60–400 ng (202–1349 pmol) at 200°C with $r = 0.987$ ($p \leq 0.05$), and also over this range at a column temperature of 170°C. The LQL at 170°C was about 4 ng. The mass spectrum for Folpet at 70 eV was m/z 104, 100 percent; m/z 260 (2Cl), 88 percent; m/z 130, 75 percent; m/z 76, 69 percent; m/z 117, 68 percent; m/z 150, 24 percent; m/z 179, 20 percent; m/z 78, 19 percent; m/z 232 (2Cl), 16 percent; and m/z 295 (3Cl; M^+), 12 percent. The mass spectrum for phthalimide was m/z 147 (M^+), 100 percent; m/z 76, 76 percent; and m/z 104, 43 percent. At eV lower than 70 eV, the molecular ion of Folpet increased at the expense of the progeny ions. The GC-MS standard curve for the IS (methyl ester of 2,4,5-T) was linear between 10–100 ng with $r = 0.9937$ with $p \leq 0.05$.

Thermal Decomposition of Folpet

Initially it was determined that detector temperature did not influence the pyrolysis of Folpet appreciably, but both the injector and column temperatures did. At injector temperature 250°C, detector temperature 260°C, and column temperature 200°C, the GC-ECD retention times were phthalimide, 6.0 min; internal standard (IS), 12 min; and Folpet, 39 min. When the injector was 200°C and the detector temperature 210°C, the peak area of Folpet increased as decrease in phthalimide peak area occurred, with the retention times staying the same. Initial work over 10 days showed that isooctane solutions gave variable results but isopropanol solutions did not.

Phthalimide from pure Folpet at a column temperature of 170°C produced a linear relationship with a slope (68 ± 10) percent of the theoretical GC-ECD phthalimide calibration curve over the range 10–500 pmol (3.0–148 ng), signifying that on-column pyrolysis was constant with (68 ± 10) percent yield of phthalimide. No Folpet peak appeared under 155 pmol (46 ng) injected. The production of phthalimide became asymptotic after 500 pmol (Figure 1). The disappearance of the Folpet peak below this Folpet injection mass caused the use of phthalimide instead for high sensitivity work. Thus, all such low Folpet injected masses will appear as phthalimide.

Degradation of Folpet in Aqueous Solution

The Folpet content in aqueous solution before glove exposure based on phthalimide measurements yielded a formulation Folpet content of (53 ± 11) percent and after exposure of (50.1 ± 8.0) percent, not statistically different at $p \leq 0.05$, and not statistically different from the nominal Folpet content of 50 percent, assuming the same relative standard deviations for the before and after data. Pooling the data produced an average content of (51.5 ± 7.8) percent, CV = 15 percent. This confirms the very low permeation rates since the content is still not different from nominal at $p \leq 0.05$.

GC-MS allows both Folpet and phthalimide to be distinguished chromatographically at high injected mass. The recovery of Folpet was complete within three hexane extractions for

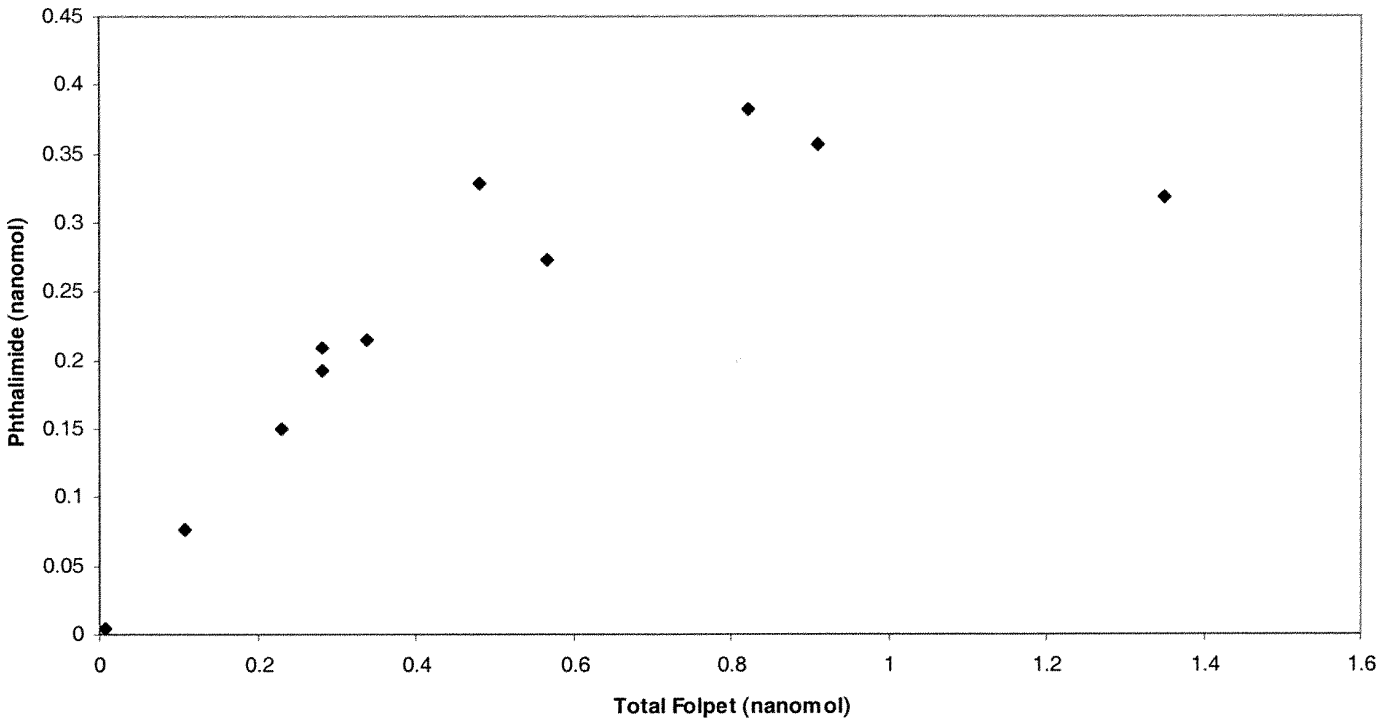

FIGURE 1

On-column thermal degradation of injected Folpet to phthalimide on a 30-m × 0.25-mm DB-1701 capillary column at 170°C and 3.0 mL/min by gas chromatography-electron capture detection (GC-ECD). The injector temperature was 200°C, and the temperature of the ECD was 260°C.

aqueous emulsions. However, phthalimide was only recovered to the extent of about (9.2 ± 1.2) percent, unacceptably low. Thus, the extraction step was deleted to assess whether phthalimide increased during the permeation experiment with the aqueous challenge emulsion. The area ratio of the phthalimide/Folpet peaks before glove challenge was (4.10 ± 0.70) percent compared with (7.20 ± 0.69) percent, (9.00 ± 0.80) percent, and (5.90 ± 0.64) percent for no glove, SafeSkin, and Sol-Vex after 8 h exposure, respectively. There was a significant increase at $p \leq 0.05$ between before challenges and all 8 h data, showing that phthalimide increased over the time of the exposure. When the Folpet content was computed, there was no statistical difference between the Folpet in the challenge emulsion at the start of the challenge and at the end of 8 h for both types of gloves, and all emulsions showed the Folpet content they should have assuming no degradation. Thus, it is possible that the formulation surfactant stabilized Folpet for at least 8 h since the amount formed is very minor compared with the remaining Folpet. Other degradation products like phthalic acid would not be detected directly on this column, although the pyrolysis product phthalic anhydride would be. No phthalic anhydride was detected.

Permeation Results

The permeation data for both glove types are shown in Table I in terms of raw phthalimide data and its Folpet equivalent. The highest time-weighted average observed (SafeSkin at 8 h) was less than the minimum ASTM normalized permeation rate for open systems of 100 ng/cm^2/min but all data exceeded the minimum normalized flux for a closed-loop system of 250 ng/cm^2.

The average thickness for out-of-the-box SafeSkin gloves was 0.112 ± 0.002 mm relative to 0.127 ± 0.010 mm after conditioning. The 8-h negative control blank (solvents only) resulted in a thickness of 0.127 ± 0.003 mm. The 8-h pesticide exposure caused a thickness of 0.126 ± 0.002 mm, and the 4-h exposure resulted in 0.126 ± 0.004 mm. The SafeSkin glove thicknesses were not significantly affected by any of the

TABLE I

Folpet equivalent and raw phthalimide permeation data for unsupported and unlined SafeSkin and Sol-Vex nitrile gloves at 30°C for triplicates

	Permeation rate in ng/cm^2/min at time			
	Phthalimide		Folpet	
Glove	4 h	8 h	4 h	8 h
SafeSkin	9.43 ± 0.32	14.0 ± 1.0	28.4 ± 1.2	42.1 ± 2.9
Sol-Vex	0.22 ± 0.14	0.68 ± 0.23	0.65 ± 0.36	2.04 ± 0.69

challenges after conditioning, but conditioning significantly affected thickness relative to the out-of-the box state.

For Sol-Vex gloves, the conditioning process did not cause any thickness changes relative to the out-of-the-box state, the thickness after conditioning being 0.312 ± 0.004 mm. The 8-h negative control blank exposure caused a thickness of 0.327 ± 0.004 mm compared with 8-h pesticide solution exposures of 0.293 ± 0.013 mm, significantly different at $p \leq 0.05$. Thus the solvents caused swelling relative to the conditioned glove, but the pesticide aqueous solution exposure caused no change. Similarly, the corresponding data for 4-h exposures were 0.318 ± 0.001 mm and 0.297 ± 0.014 mm. There was no statistical difference at $p \leq 0.05$ between the glove thicknesses measured for the pesticide exposures at 4 h and 8 h, nor between the conditioned glove and after 4-h or 8-h pesticide exposures.

The Sol-Vex gloves are definitely more protective than the SafeSkin ones. Both types of gloves have normalized breakthrough detection times of <4 h (Table I), implying both kinds of gloves cannot be reused without decontamination. On average the Sol-Vex gloves are 21 (at 8 h) to 44 times (at 4 h) more protective relative to time-weighted average permeation rate. Sol-Vex glove protection is expected to be better since it is about three times thicker than the SafeSkin glove, in addition to being dipped to confer chemical resistance.

Infrared Reflectance Analysis

Chemicals

The major (<85%) reflectance minima for Folpet, Folpet formulation, and phthalimide are provided in Table II. Though the peaks near 793–801, 710–713, 665–667, 1466–1467, and 1745–1746 cm^{-1} were common, phthalimide had major diagnostic minima at 645, 1050, and 1305 cm^{-1}. The corresponding major diagnostic minima for Folpet were therefore 1024, 1718, 726, 1270, 801, 1250, and 765 cm^{-1}. When pure Folpet in 2-propanol was allowed to stand for 18 h, dried, and its infrared spectrum measured, no phthalimide diagnostic minima appeared, and the same major wavelengths appeared in its spectrum as fresh Folpet. The only difference was that the major minimum at 726 cm^{-1} in fresh Folpet overlapped more with the 710 cm^{-1} minimum with the lesser minima at 1223 cm^{-1} and 1150 cm^{-1} similarly disappearing. This implies that a Folpet standard is stable in concentrated solutions with 2-propanol as solvent. This shows that solvolytic degradation played no part in the GC-MS results where a dose-response was observed for Folpet mass injected in 2-propanol at a specific temperature.

The Folpet formulation had a moderate (between 85 to 90% reflectance) phthalimide type peak at 646 cm^{-1}, but there were no peaks at 1050 or 1305 cm^{-1}, signifying the absence of detectable phthalimide in the formulation. Using the criterion that reflectance minima belonging to the same absorption should agree within 5 cm^{-1}, other major minima that were not due to Folpet in the formulation were at 1010, 696, 1091, 914, and 1113 cm^{-1}. Three weak (>90% reflectance) minima at 3692, 3635, and 3619 cm^{-1} were also distinctive since both Folpet and phthalimide had no peaks in this spectral region.

Gloves

Both sets of gloves, inside or outside, had diagnostic aliphatic C–H stretches at 2900–3000 cm^{-1}; C≠N stretches at 2200–2400 cm^{-1}; C=N 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}.

SafeSkin Gloves. The reflectance changes observed for the SafeSkin glove at various conditions are presented in Table III.

No major minima were changed by the glove conditioning process on the outer surface. Only the moderate and weak minima at 697, 711, 1132, 1042, and 832 cm^{-1} of the out-of-the-box glove disappeared. On soaking in water for 4 h, all the major minima for the conditioned or out-of-box glove did not change within 10 cm^{-1}. There also were no changes after 8 h of exposure

TABLE II

Major infrared reflectance characteristic minima of study chemicals (the interrun uncertainty is ± 2 cm^{-1})

Material	Major wavelength minima in cm^{-1} (% reflectance)
Folpet	710 (64); 1024 (79); 1745 (80); 1718 (81); 726 (82); 1270 (82); 801 (82) 1250 (83); 765 (84); 865 (86); 1164 (90); 1223 (91); 1150 (91); 1343 (92); 1789 (92); 665 (92); 1467 (95); 978 (95); 1102 (96); 1365 (96); 1609 (97)
Folpet (Iso 18 h, dry)[A]	710 (70); 1024 (83); 1745 (84); 1717 (85); 801 (85); 1270 (86);1250 (86); 764 (87); 865 (89); 1163 (92); 1343 (94); 1789 (94); 1467 (96)
Phthalimide	713 (69); 645 (77); 1050 (80); 1305 (82); 1746 (83); 743 (86); 667 (88); 1374 (88); 1288 (89); 1601 (90); 793 (91); 1466 (92); 1088 (92); 816 (92); 1140 (93); 1071 (93); 1183 (93); 1773 (93); 3188 (93)
Folpet form[B]	1027 (57); 1010 (64); 712 (65); 696 (79); 1091 (80); 914 (81); 801 (82); 1113 (82);1748 (83); 727 (83); 1274 (84); 767 (85); 936 (87); 646 (87); 1720 (87); 866 (88); 743 (90); 1255 (90); 1164 (90); 1222 (95); 1789 (95); 3692 (95); 1345 (95); 3620 (98)

[A]Iso 18 h, dry: dissolved in isopropanol for 18 hours, then dried.
[B]Form: formulation.

TABLE III
Major infrared reflectance minima for SafeSkin nitrile glove materials before and after 4-hour and 8-hour exposure to Folpet (the intrarun uncertainty is ± 2 cm^{-1})

Surface	Major wavelength minima in cm^{-1} (% reflectance)
Outer (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)
Outer (humidified)	1428 (38); 874 (72); 968 (75); 713 (87); 915 (92); 2923 (92); 1181 (93); 1606 (95); 2851 (96); 3440 (97)
Outer (4 h; water)	1433 (50); 968 (77); 874 (76); 713 (88); 915 (92); 2923 (94); 1176 (95); 1038 (95); 1607 (95); 1129 (95); 2850 (96)
Outer (4 h Ch; ns)	1451 (68); 969 (84); 874 (84); 712 (89); 697 (89); 657 (89); 1166 (93); 916 (93); 1125 (94); 1037 (94); 2926 (96); 1640 (97); 2853 (97); 3403 (98); 1725 (98)
Outer (4 h Ch; s)	1444 (75); 969 (81); 1031 (82); 712 (82); 1009 (84); 697 (85); 873 (87); 1097 (88); 915 (88); 1165 (92); 801 (92); 1273 (93); 1747 (94); 2924 (95); 1721 (95); 1346 (95); 1609 (96); 3693 (97); 2852 (97); 3620 (97); 3449 (98); 1790 (98); 3652 (98)
Outer (8 h; water)	1433 (50); 968 (77); 874 (76); 713 (88); 698 (90); 915 (92); 2923 (94); 1176 (95); 1038 (95); 1607 (95); 2850 (96); 3446 (98); 1795 (98); 2237 (98); 3749 (98)
Outer (8 h Ch; ns)	1436 (73); 1030 (82); 713 (82); 874 (82); 1009 (85); 969 (89); 1098 (90); 915 (90); 1274 (92); 801 (93); 767 (93); 1748 (93); 1721 (95); 1346 (96); 1790 (97); 3693 (97); 2926 (98)
Outer (8 h Ch; s)	1030 (60); 1008 (65); 713 (76); 914 (79); 693 (80); 969 (85); 801 (87); 1275 (87); 1748 (87); 767 (88); 1721 (91); 1165 (92); 867 (92); 3692 (95); 1448 (95); 1345 (95); 3620 (95); 1789 (96); 2925 (97)
Inner (box)	969 (89); 697 (92); 1449 (95); 1174 (95); 916 (95); 1037 (95); 2928 (97); 1644 (98); 3410 (98)
Inner (humidified)	969 (89); 697 (91); 684 (91); 657 (91); 1175 (94); 1038 (94); 917 (95); 1009 (95); 1449 (95); 2928 (97); 1354 (97); 1648 (97); 3418 (97); 2857 (98); 1727 (98); 1767 (98)
Inner (4 h; Iso)	969 (86); 697 (90); 659 (91); 916 (94); 1172 (94); 1450 (94); 1036 (94); 1123 (95); 876 (96); 1649 (97); 2928 (97); 1360 (97); 3420 (97)
Inner (4 h Ch; ns)	658 (88); 968 (89); 1173 (93); 1036 (94); 1120 (94); 916 (95); 1008 (95); 1448 (96); 1648 (97); 3404 (97); 1354 (97); 2935 (97)
Inner (8 h; Iso)	969 (86); 697 (90); 916 (94); 1172 (94); 1450 (94); 1036 (94); 1123 (95); 1649 (97); 2928 (97); 3420 (97); 1717 (98); 1542 (98)
Inner (8 h Ch; ns)	969 (89); 697 (92); 916 (95); 1172 (95); 1449 (95); 1037 (95); 2928 (97); 1651 (98); 3402 (98)

Ch = Challenge; ns = no apparent solid; s = white solid spot; Iso = isopropanol.

to water. On exposure to the aqueous pesticide for 4 h, no major minima relative to the 4-h water-exposed glove were affected for the outer surface, except the new reflectance minimum was at 1451 cm^{-1} rather than 1433 cm^{-1}. The weak minimum at 1176 cm^{-1} changed to 1166 cm^{-1}. A new moderate minimum appeared at 657 cm^{-1}.

When a white spot on this same glove was scanned, the new minima relative to the glove area with no white spot were 1009, 1097, 1273, 1747, 1346, 3693, 1790, and 3652 cm^{-1}, all of which are contained in the Folpet formulation (Table II). In addition, for the no-spot condition the reflectance at 1037 cm^{-1} was 94 percent but for the white spot condition this minimum changed to 1031 cm^{-1} with reflectance 82 percent, to be expected since 1027 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. The moderate peak at 698 cm^{-1} for the water exposure was not present, and a new major minimum at 1009 cm^{-1} and a moderate one at 1098 cm^{-1} appeared, in addition to many new weak minima (1274, 801, 767, 1721, 1346, 1790, 3693 cm^{-1}) that were characteristic of the formulation, even though no observable white spot was visible. When a white spot on the same glove was scanned, the largest three minima were $1030 > 1008 > 713$ cm^{-1}, the same order as for the formulation (Table II). None of these spectra contained the diagnostic peaks for phthalimide.

The changes in the inner side of the glove were much less marked. Conditioning retained all the minima detected for the out-of-the-box glove. New weak minima were at 684, 657, 1009, 1354, 2857, 1727, and 1767 cm^{-1}. Soaking the conditioned inner glove with 2-propanol for 4 h made the weak minima at 684 and 1009 cm^{-1} disappear, and new weak minima to appear at 1123 and 876 cm^{-1}. Relative to the 4-h exposed 2-propanol glove, the inside surface after pesticide challenge on the outside surface only showed a new minimum at 1008 cm^{-1}, which, however, was also present for the conditioned glove. In the same comparison for the 8-h exposed gloves, there were no changes

TABLE IV
Major infrared reflectance minima for Sol-Vex nitrile gloves before and after 8-hour challenges to Folpet (the intrarun uncertainty is 2 cm^{-1})

Surface	Major wavelength minima in cm^{-1} (% reflectance)
Outer (box)	970 (87); 1170 (93); 656 (93); 1450 (95); 921 (95); 1649 (97); 3418 (97); 2928 (97); 1767 (98)
Outer (humidified)	970 (88); 1172 (94); 656 (94); 1450 (96); 921 (96); 1641 (97); 2929 (98); 1766 (98); 3412 (98)
Outer (8 h; water)	970 (84); 1166 (93); 690 (93); 1128 (93); 1450 (94); 1010 (94); 1038 (94); 922 (94); 816 (96); 1406 (96); 2928 (96); 1376 (96); 1609 (96); 1646 (96); 1767 (97); 3406 (97)
Outer (8 h Ch; ns)	970 (86); 688 (93); 1450 (95); 1165 (95); 1126 (95); 1649 (97); 2929 (97); 3417 (97); 1766 (98)
Outer (8 h Ch; s)	970 (86); 1031 (87); 713 (87); 693 (88); 1009 (89); 1100 (89); 916 (92); 1166 (92); 1275 (93); 1749 (94); 1450 (95); 3406 (95); 866 (95); 1649 (95); 1346 (96); 1721 (96); 2923 (97); 1539 (97); 3694 (97)
Inner (box)	970 (87); 658 (94); 1172 (94); 1451 (95); 921 (96); 1650 (97); 2928 (97); 1769 (98); 3421 (98)
Inner (humidified)	970 (89); 656 (94); 1174 (95); 1449 (96); 921 (96); 1650 (97); 2929 (98); 3428 (98); 1766 (98)
Inner (4 h; Iso)	970 (84); 1174 (94); 1449 (94); 1104 (94); 921 (94); 1609 (96); 2928 (96); 1609 (96); 3409 (96); 1767 (97)
Inner (8 h; Iso)	969 (88); 697 (91); 658 (91); 1172 (94); 916 (94); 1036 (95); 1123 (95); 1650 (97); 2929 (97); 3420 (98); 1717 (98); 1542 (98)
Inner (8 h Ch; ns)	970 (84); 1172 (92); 1449 (94); 1101 (94); 921 (94); 3403 (94); 1643 (95); 2929 (96); 1766 (97)

Ch = Challenge; Iso = isopropanol; ns = no white spots; s = white solid spot.

except for the disappearance of the weak minima at 1123, 1717, and 1542 cm^{-1}. None of the wavelengths were characteristic of Folpet or phthalimide.

Sol-Vex™ *Gloves.* There were no important spectral changes for the outer surface for the out-of-the-box state and the conditioned state (Table IV). The glove soaked for 8 h in water also did not have much change relative to the conditioned glove except the 656 cm^{-1} minimum disappeared, and new weak minima appeared at 690, 1128, 1010, 1038, 816, 1406, 1376, and 1609 cm^{-1}. There were also no appreciable changes for a surface with no visible white spots relative to the latter exposure to aqueous pesticide. When a spot on the pesticide-exposed surface was scanned, the new wavelengths were 1031, 713, 1009, 1100, 916, 1275, 1749, 866, 1346, 1721, 1539, and 3694 cm^{-1}, again characteristic of the presence of formulation on the surface.

There were no differences for the inner surface for the out-of-the-box and conditioned states. Soaking in 2-propanol for 8 h relative to the conditioned glove saw the appearance of new minima at 697, 1036, 1123, 1717, and 1542 cm^{-1}, and disappearance of the minimum at 1449 cm^{-1}. The comparison for the inside surface whose outside surface was exposed relative to the glove soaked in 2-propanol for 8 h showed that the weak minima at 697, 658, 1036, 1123, 1717, and 1542 cm^{-1} disappeared and new weak minima appeared at 1449, 1101, 3403, and 1766 cm^{-1}.

DISCUSSION

This is the first report of the permeation of a Folpet formulation through gloves and one of the first reports of the use of reflectance FT-IR to characterize the surfaces of gloves before and after permeation experiments in an ASTM type permeation cell.

The FT-IR potassium bromide disk absorption spectrum for phthalimide shows the following major minima and transmittances in the Sigma Aldrich library:[19] 2923 (1); 2852 (12); 1750 (12); 717 (22); 1780 (29); 1055 (29); 1305 (29);1470 (37); 1380 (39); 3200 (40); 3070 (51); 1605 (57); 530 (59); 1290 (62); 746 (62); 650 (65); 550 (69); 1090 (69); 1145 (74); and 796 (82). The Sadtler index spectrum shows the following order[20]: 1745 (1.6); 1775 (15); 717 (17); 1050 (25); 1308 (25); 3200 (43); 1385 (47); 1470 (56); 538 (58); 1602 (58); 650 (68); 1090 (69); 550 (69); 3070 (71); 3100 (72); 1390 (74); 1070 (79); and 360 (79).

The reflectance minima wavelengths agreed within 10 cm^{-1} for about 75 percent of those of both reference absorption spectra, but the intensity order was variable even for the literature absorption spectra, but especially for the C–H and N–H stretch and bend wavelengths. All the wavelengths < 85 percent reflectance were contained in both absorption spectra. The reflectance spectrum generally has the intensities at lower wave numbers favored over those at higher wave numbers. Reflectances at 667, 816, and 1183 cm^{-1} were not observed in both reference absorption spectra.

The IR absorption spectrum for Folpet[21] in a KBr disk has absorption maxima at 1750 (5); 1270 (7); 717 (15); 1725 (15); 1030 (26); 1780 (30); 860 (36); 805 (37); 1160 (41); 790 (45); 760 (45); 725 (44); 1340 (47); 1460 (55); 530 (60); 1225 (68); 575 (72); 3430 (73); 430 (77); and 1150 (78). The absorption at 865 cm^{-1} is assigned to be the S–N stretch.[22]

The absorption spectrum contained 70 percent of the reflectance minima, and the reflectance spectrum contained 60 percent of the absorption maxima. The intensity order did not agree. All the reflectance minima with reflectance < 85 percent were in the absorption spectrum except at 1010, 1091, 914, and 1113 cm^{-1}.

The glove FT-IR study revealed that while Folpet formulation could be detected on the outside challenge surface of the gloves even in some cases for surfaces of no discernible residue. For example, the outer surface of the SafeSkin glove had a reflectance minimum at 874 cm^{-1} that interfered with the 866 cm^{-1} S–N reflectance minimum of Folpet (Table III). However, this minimum did shift to 867 cm^{-1} for a white spot after the 8-h challenge. Since the outer surface of the Sol-Vex glove had no such interference, a similar white spot after 8 h showed a reflectance at 866 cm^{-1} that was not present in the glove spectra involving no pesticide exposure. The absence of Folpet on the glove inside surface is expected since the function of the 2-propanol collection fluid is to solubilize permeated Folpet. The collection fluid did not have a marked effect on the reflectance minima relative to the conditioned glove inner surface. 2-Propanol is thus an effective collection solvent that does not impair the glove collection surface.

FT-IR also showed no presence of phthalimide or phthalic or phthalamic acids in the white spots of dried formulation residue on the outer exposed glove surface. This implies that extensive degradation in the challenge solution did not occur, supporting the GC-MS data of the challenge emulsions.

The literature mass spectra of phthalimide at 70 eV contained the following m/z ions and relative abundances:[23] m/z 104, 100 percent; m/z 76, 92 percent; m/z 147, 69 percent; m/z 103, 26 percent; m/z 75, 14 percent; m/z 74, 14 percent; m/z 66, 12 percent; and m/z 105, 9 percent. The observed mass spectrum at 50 eV had m/z 147 as base peak, followed by m/z 76 (76%) and then m/z 104 (43%). The literature mass spectrum for Folpet at 70 eV was[23] m/z 104 ($C_7H_4O^+$; 100%); m/z 117 (CCl_3^+; 50%); m/z 119 (CCl_3^+; 48%); m/z 260 (M^+-Cl; 48%); m/z 76 (m/z 104-CO; 45%); m/z 50 ($C_4H_2^+$; 37%); m/z 130 ($C_8H_2O_2^+$; 28%); m/z 262 (M^+-Cl; 25%); and m/z 295 (M^+; 12.5%). The literature also shows some variation in intensities.[24] The observed m/z above 25% intensity relative to the base peak agreed with the literature but the order was m/z 104 > 260 > 130 > 76 > 117.

The literature contains conflicting reports on the stability of Folpet in water with disagreement over rates. Degradation of the same trace concentrations in distilled water has been shown to be slower than in natural waters.[25] Folpet hydrolyzed in aqueous solutions to phthalimide, carbon dioxide, hydrochloric acid, and sulfur (or hydrogen sulfide).[26] The half-life of Folpet at pH 7.14 in 0.2 M phosphate buffer was 83 min corresponding to a pseudo first-order rate constant of $(1.4 \pm 0.1) \times 10^{-4}$ sec^{-1}. This half-life was shorter[26] than that of Captan. This confirmed the results of Polizu and Greger,[27] who also found that Folpet at pH 6.0 and 20°C degraded faster than Captan.

Folpet at 10 mg/L decomposed completely within 24 h to phthalimide at alkaline pH or at pH 7.6 at 22°C in 0.1 M Tris buffer.[28] The presence of 10% ethanol in water at pH 3.4 caused Folpet stabilization, the apparent pseudo first-order half-lives being 8.4 days for the first 3-day period, and then a half-life of 20 days from day 3 to 30; a concentration of 20 percent glucose in water at pH 3.4 also similarly stabilized Folpet but the stabilization was only about half that of 10 percent ethanol.[28] In addition, 5 mg/L Folpet in 0.9 percent sodium chloride solution at 22°C showed pseudo first-order half-lives of 3.49 h after 1 h, and 18 h after 12 h.[28] The degradation half-life and rate constant are concentration-dependent, and therefore not first order overall.

The type of aqueous matrix also affects degradation kinetics. Folpet showed resistance to being washed off when adsorbed to leaf and grape surfaces.[29] In addition, recovery of spiked Folpet at 0.1–10 μg/L in different surface, ground, and distilled waters was 73–123 percent at pH 2–6, but decreased at pH 10 where alkaline hydrolysis was appreciable.[30] The latter study showed that freshly spiked Folpet could be recovered quantitatively from these waters. No storage stability studies were done, however. The GC-MS data for the aqueous challenge solutions in the present study showed that there was a small increase in phthalimide during the 8-h pesticide exposures, but the concentra-tion of Folpet before the challenge was the same as after 8-h exposure to both types of gloves.

Folpet thermal degradation has also been studied.[31–36] The first evidence came[31] in 1970. Flora et al. reported in 1981 that Folpet was more thermally unstable than ditalimfos and phosmet during differential thermal analysis.[32] In 1981 Saito et al.[33] found that Folpet in a sealed tube showed < 85 percent decomposition at 250°C for 30 min. The on-column degradation of Folpet was first noted on an OV-101 (methyl silicone) packed GC column in 1982.[34] On-column Folpet decomposition during packed-column GC was minimized by use of a trifluoropropylmethyl silicone stationary phase (SP-2401).[35] The nearest equivalent to the DB-1701 (14% cyanopropyl-phenyl/86% dimethyl polysiloxane) capillary column of the present study was OV-225 (cyanopropyl-phenyl methyl silicone), which facilitated Folpet adsorption and partial degradation to phthalimide. It is interesting that EPA-referenced method 146-002 to analyze Folpet and phthalimide in soils by GC-ECD[36] uses the same DB-1701 column as the present study but with a temperature program of 100°C starting temperature with a ramp at 15°C/min to 200°C at injector temperature 150°C. Our present results at low injected masses on this column are based on the pyrolysis yield of phthalimide (Figure 1) < 0.5 pmol (150 pg), a novel application of pyrolysis chromatography.

The GC column used in EPA FP/15/91 for non-oily crops[37] like lettuce, onions, and tomatoes was the very nonpolar DB-1 column at 200°C with the injector at 210°C and the detector at 300°C. Recoveries of about 95 percent were obtained for freshly spiked Folpet with recoveries of 77 percent after 7 months of storage at −18°C. Phthalimide was recovered at about 85 percent for fresh spiking and about 65 percent after 7 months of storage at −18°C. Since the two substrates were recovered by different procedures and quantified by different GC detectors, no Folpet on-column decomposition was looked for, especially since there were many peaks in the neighborhood of phthalimide.

The large negative intercept on the Folpet standardization linear regression curve is suggestive of unreliability at injected

masses <100 pg. The slope of the regression line below 100 pg in the same injected mass region as our present GC-ECD study is about 75 percent of that above 100 pg. The EPA-referenced Method 568W-1 to analyze Folpet in oily crops like avocados utilized the same DB-1 column at the same injector and detector temperatures but with a temperature program of 200°C for 15 min, and then 15°C/min to 280°C and holding there for 5 min for column cleaning.[38] The reported limit of detection was 50 pg, with recoveries being between 89 to 104 percent. The retention time for Folpet was variable. There were two other unidentified peaks in the Folpet standard chromatogram for 100 pg injected. Again there was a large negative intercept to the linear regression equation for all standardization data, with the linear portion under 100 pg having a slope 75 percent of that above 100 pg. Pyrolysis on the more non-polar DB-1 column is clearly less than on the DB-1701 column, but it still occurs.

Although many pesticides like the organochlorine hydrocarbon ones are extremely stable, persistent, nonvolatile, and lipophilic, some nonvolatile pesticides like Folpet are not as stable. This has ramifications on the choice of personal protective equipment and, particularly, gloves. The situation could arise that the protection against an active ingredient might not be effective against its degradation product. In the case of Folpet, the major degradation product is phthalimide,[1–3] a less toxic compound. Since a toxic effect depends on dose, duration, and agent potency and because nonvolatile pesticides are mostly absorbed through the skin as the major route of exposure, it is instructive to compare the flux (Fl) of Folpet and phthalimide through the skin by a well-known relationship[39] (Eq. 1):

$$\mathrm{Fl} = (\mathrm{s}/15) \times (0.038 + 0.153\mathrm{K_{ow}}) \exp(-0.016\mathrm{M}) \qquad [1]$$

where M is the molecular weight, s is water solubility in mg/L, K_{ow} is the octanol/water partition coefficient, and Fl is in mg/cm^{-2}/h^{-1}.

For Folpet,[1] M = 296.58, s = 1.0 mg/L, and K_{ow} = 708 with Fl = 63 μg/cm^{-2}/h^{-1} or 210 nmol/cm^{-2}/h^{-1}.

For phthalimide,[4] M = 147.13, s = 360 mg/L, and K_{ow} = 14.1 with Fl = 5.0 mg/cm^{-2}/h^{-1} or 34,000 nmol/cm^{-2}/h^{-1}. Thus on a molar basis, the skin flux of phthalimide is about 160 times that for Folpet assuming Eq. 1 applies.

This means that the maximum observed Folpet equivalent permeation time-weighted average rate of 142 pmol cm^{-2} h^{-1} for the SafeSkin glove at 8 h should still allow fast skin absorption of Folpet if the permeated material contacts the skin, since the glove permeation rate is below the skin absorption Fl. However, if there is accumulation on the inside of the worn glove, high local Folpet skin coverages might result that could approach saturation and hence be responsible for the known skin-sensitizing properties of Folpet and its propensity to cause irritant and allergic contact dermatitis.[2,3,6] In contrast, phthalimide has a very high skin-absorbing capacity that far exceeds the observed permeation rates even if all permeated Folpet degraded to phthalimide during permeation (Table I), but its irritant properties are caused by its basicity.[4]

The other degradation products of Folpet are caused by further degradation of phthalimide to phthalamic acid and phthalic acid.[5] No hydrogen bonded carboxyl OH bands were observed at low and high wavelengths in the FT-IR reflectance spectra of the challenge solution or for formulation spots on exposed gloves, implying their presence, like phthalimide itself, was not detectable. The GC-ECD and GC-MS methods employed for Folpet would not detect these two degradation products either. Any phthalic acid present would form phthalic anhydride near 191°C during GC,[5] but this was not detected.

CONCLUSIONS

Industrial hygienists should be aware of pesticides that are potentially unstable in water and the nature and toxicity of their degradation products. Health professionals should try to ensure that personal protective equipment selected will protect against both the pesticide and its degradation products, especially if the latter are more toxic than the pesticide.

In the case of Folpet, phthalimide, the major degradation product in water and on heating is much less toxic than Folpet itself but it also is calculated to permeate 160 times faster than Folpet itself through human skin on a molar flux basis. Since the aqueous formulation exhibited minimal degradation and permeation, the risk from phthalimide exposure is low. Infrared reflectance was able to detect contaminated outer glove challenge surfaces and verified that 2-propanol was a suitable solvent to collect Folpet and phthalimide without damaging the inner surface of the glove. The infrared data of dried spots of formulation on the challenge surfaces of the gloves also indicated no detectable degradation of Folpet to phthalimide.

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REFERENCES

1. Hazardous Substances Data Bank: Folpet. Toxnet Computer Data Base, National Library of Medicine (2002). http://toxnet.nlm.nih.gov/cgi-bin/sis/search.
2. U.S. EPA: Reregistration Eligibility Decision (RED): Folpet, EPA-738-R-99-011. U.S. EPA National Center for Environmental Publications and Information, Cincinnati, OH (1999).
3. U.S. EPA: R.E.D. Facts: Folpet, EPA-738-F99-016. U.S. EPA National Center for Environmental Publications and Information, Cincinnati, OH (1999).
4. Hazardous Substances Data Bank: Phthalimide. Toxnet Computer Data Bank, National Library of Medicine (2002). http://toxnet.nlm.nih.gov/cgi-bin/sis/search.
5. Hazardous Substances Data Bank: Phthalic Acid. Toxnet Computer Data Bank, National Library of Medicine (2002). http://toxnet.nlm.nih.gov/cgi-bin/sis/search.

6. Fabro, S.; Smith, R.L.; Williams, R.T.: Embryotoxic Activity of Some Pesticides and Drugs Related to Phthalimide. Food Cosmet Toxicol 3:587–590 (1965).
7. Guo, Y.L.; Wang Jr., B.; Lee, C.C.; Wang, J.D.: Prevalence of Dermatoses and Skin Sensitization Associated with Use of Pesticides in Fruit. Occup Environ Med 53:427–431 (1996).
8. Burroughs, G.E.; Hora, J.: Health Hazard Evaluation Report No. HETA-80-147-1076, Calhio Chemical Company, Perry, Ohio. National Institute for Occupational Safety and Health, Cincinnati, OH (1982).
9. Mikatavage, M.; Que Hee, S.S.; Ayer, H.E.: Permeation of Chlorinated Aromatic Compounds Through Viton and Nitrile Glove Materials. Am Indus Hyg Assoc J 45:617–621 (1984).
10. Harville, J.; Que Hee, S.S.: Permeation of a 2,4-D Isooctyl Ester Formulation Through Neoprene, Nitrile, and Tyvek Protection Materials. Am Indus Hyg Assoc J 50:438–446 (1989).
11. Que Hee, S.S.: Permeation of Some Pesticidal Formulations Through Glove Materials in Chemical Protective Clothing Performance in Chemical Emergency Response, J.L. Perkins, J.O. Stull, Eds., pp. 157–164. ASTM Public. No. OH-010370-55. ASTM, Philadelphia (1989).
12. Khan, A.A.; Chen, X.; Que Hee, S.S.: Permeation of Chlorpyrifos and Endosulfan Formulations Through Protective Materials. Appl Occup Environ Hyg 12:413–417 (1997).
13. Lin, Y.-W.; Que Hee, S.S.: Permeation of Malathion Through Glove Materials. Appl Occup Environ Hyg 13:158–165 (1998).
14. Lu, X.; Que Hee, S.S.: Permeation of a Methomyl in Lannate L Through Nitrile Gloves. J Hazard Mat 59:279–285 (1998).
15. Lin, Y.-W.; Que Hee, S.S.: Permeation of a Malathion Formulation Through Nitrile Gloves. Appl Occup Environ Hyg 13:286–298 (1998).
16. Lin, Y.-W.; Que Hee, S.S.: Permeation of a Malathion Formulation Through Butyl Gloves. J Hazard Mat 60:143–158 (1998).
17. Ansell Protective Products: Chemical Resistance Guide: Permeation and Degradation Data, 6th ed., Form No. CRG-GC-Rev. 9-98. Ansell Protective Products, Coshocton, OH (1998).
18. American Society for Testing and Materials (ASTM): Standard Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids or Gases Under Conditions of Continuous Contact, ASTM Method F739. ASTM, West Coshohocken, PA (1996).
19. Sigma Aldrich FT-IR Library: Phthalimide. Aldrich Chemical, Milwaukee, WI (2000).
20. Sadtler Research Library. Phthalimide in Standard Infrared Grating Spectra, Spectrum 516K. Sadtler Laboratories, Philadelphia (1983).
21. Gore, R.C.; Hannah, R.W.; Pattacini, S.C.; Porro, T.J.: Infrared and Ultraviolet Spectra of Seventy-Six Pesticides. J Assoc Offic Anal Chem 54:1040–1082 (1971).
22. Abe, Y.; Horii, T.; Oka, K.; Kawamura, S.; Nakabayashi, T.: S-N Stretching Bands in Infrared Spectra of N-(Organothio)imides. Ann Rep Radiat Cent Osaka Prefect 21:67–70 (1980).
23. Grasselli, J.G.; Ritchey, W.M.: Phthalic Acid Imide in Atlas of Spectral Data and Physical Constants for Organic Compounds, 2nd ed., vol. IV; p. 145. CRC Press, Cleveland, OH (1983).
24. Mass Spectrometry Data Centre.: Eight Peak Index of Mass Spectra, 3rd ed., vol. 1, Part 2, p. 843. Mass Spectrometry Data Center, Royal Society of Chemistry, Nottingham University, Nottingham, UK (1983).
25. Parrilla, P.; Martinez Vidal, J.L.; Martinez Galera, M.; Garrido Frenich, A.: Degradation of Fenamiphos and Folpet in Water. Int J Environ Anal Chem 63:137–145 (1996).
26. Wolfe, N.L.; Zepp, R.G.; Doster, J.C.; Hollis, R.G.: Captan Hydrolysis. J Agric Food Chem 24:1041–1045 (1976).
27. Polizu, A.; Greger, H.: Degradability of Captan and Phaltan. Rom An Inst Cercet Prot Plant, Acad Stiinte Agr Silvice 1968(6):495–499 (1970).
28. Viviani-Nauer, A.; Hoffmann-Boller, P.; Gafner, J.: In Vitro Detection of Folpet and Its Degradation to Phthalimide in Aqueous Solutions and in Yeast Suspensions. Am J Enol Viticul 48:63–66 (1997).
29. Cabras, P.: Angioni, A.; Garau, V.L.; Melis, M.; Pirisi, F.M.; Cabitza, F.; Pala, M.: The Effect of Simulated Rain in Folpet and Mancozeb Residues on Grapes and on Vine Leaves. J Environ Sci Health, B36:609–618 (2001).
30. Lambropoulou, D.A.; Konstantinou, I.K.; Albanis, T.A.: Determination of Fungicides in Natural Waters Using Solid-Phase Microextraction and Gas Chromatography Coupled with Electron-Capture and Mass Spectrometric Detection. J Chromatogr A 893:143–156 (2000).
31. Pfeifer F.T.; Pfeifer, G.: Thermal Decomposition of Fungicides of the Phthalimide Type. In: Proc. Anal. Chem. Conf., 3rd., I. Buzas, ed., 2:371–377 (1970).
32. Flora, T.; Simon, Z.; Bokor-Lanszky, E.: Thermal Decomposition of Phthalimide-Type Pesticides. Nehezvegyip Kut Intez Kozl 11:105–129 (1981).
33. Saito, K.; Saito, N.; Nagayoshi, H.; Suzuki, K.: Studies on Thermal Decomposition of Pesticides. Noyaku Kensasho Hokuku 21:25–31 (1981).
34. U.S. Food and Drug Administration (U.S. FDA): Pesticide Analytical Manual, vol. 1; Secs. 212.1, 211.14d, and 252.101. U.S. FDA, Washington, DC (1982).
35. Gilydis, D.M.; Walters, S.M.: Gas Chromatographic Determination of Mixtures of Captan, Folpet, and Captafol. J Assoc Off Anal Chem 66:1365–1370 (1983).
36. U.S. EPA: Determination of Folpet and Phthalimide Residues in Soils Using Gas Chromatography, Method No. 146-002, EPL-BAS-146-002. Environmental Chemistry Laboratory, Research Triangle Park, NC (June 14, 1989).
37. Schlesinger, H.M.: A Method for the Determination of Folpan and Phthalimide Residues in Non-Oily Crops, U.S. EPA Residue Analytical Method FP/15/91. Analyst Research Laboratories, Makhteshim Chemical Works Ltd., Beersheva, Israel (1991).
38. Nishioka, L.T.; Rose, J.E.; Ruzo, L.O.: A Method for the Determination of Folpet Residues in Avocados and Other Oily Crops, U.S. EPA Residue Analytical Method 568W-1. PTRL West Inc., Richmond, CA (1996).
39. Fiserova-Bergerova, T.V.; Pierce J.T.: Biological Monitoring. V. Dermal Absorption. Appl Indus Hyg 8:F14–F21 (1989).