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Permeation of Comite® through protective gloves

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Abstract

The goal of the study was to assess how protective disposable (Safeskin®) and chemical protective (Sol-Vex®) nitrile gloves were against Comite® emulsifiable concentrate formulation containing propargite (PROP) as active pesticidal ingredient because there were no explicit recommendations for the gloves that should be worn for hand protection. The glove material was exposed in ASTM-type I-PTC-600 permeation cells at 30.0 ± 0.5 °C, and gas chromatography–mass spectrometry used for PROP analysis. Aqueous solutions of Comite® at 40.4 mg/mL permeated both Safeskin® and Sol-Vex® nitrile by 8 h. Safeskin® showed a mean PROP mass permeated of 176 ± 27 μg after 8 h compared with a mean mass permeated for Sol-Vex® of 3.17 ± 4.08 μg. Thus, Sol-Vex® was about 56 times more protective than Safeskin® for an 8-h exposure. However, the kinetics of the permeation revealed that Safeskin® can be worn for at least 200 min before disposal. When undiluted Comite® challenged both types of nitrile, much faster permeation was observed. Safeskin® gloves showed two steady state periods. The first had lag times (t_l) values of about 1 h, although normalized breakthrough times (t_b) were <10 min. The second steady state rate (P_s) was on average four times the rate of the first period, and the second steady state period t_l was about three times as long as that of the first steady state period, and about the same t_l as for the aqueous solution. Sol-Vex® gloves exposed continuously to undiluted Comite® permeated above the normalized breakthrough threshold beyond 2.7 h. A risk assessment revealed that the PROP skin permeation rate of 7.1 ng cm^{-2} h^{-1} was much slower than the first steady state Safeskin® glove P_s of 62,000 ng cm^{-2} h^{-1}. Infrared analysis showed that the glove surfaces were not degraded by the Comite® challenge. The chemically protective Sol-Vex gloves protected adequately against undiluted formulation for about 2.7 h, whereas they provided protection for nearly 8 h when the formulation was diluted with water to the highest concentration for field application. In contrast, the disposable Safeskin gloves did not protect at all for the undiluted formulation, but did for 200 min when the formulation was diluted with water to the highest concentration for spraying.

Keywords: Propargite; Comite®; Glove; Personal protective equipment; Nitrile; Risk

1. Introduction

Propargite (PROP) is the active ingredient in many miticides/acaricides that is the common name of 2-(4-*tert*-butylphenoxy)cyclohexyl prop-2-ynyl sulfite (CAS RN 2312-35-8; molecular weight, 350.15; C_{19}–H_{26}–O_4–S). PROP is a nonpolar aromatic and alicyclic ether and sulfite ester liquid of vapor pressure of 3 Torr at 25 °C or alternatively 4.5 × 10^{-9} Torr [1–4], a log octanol/water partition coefficient (K_{ow}) of 4.624, and a water solubility of 0.5 mg L^{-1} at 25 °C [1]. PROP was introduced in 1964 by Uniroyal. Its commercial formulations have such registered names as Acargil®, BPPS®, Comite®, Cyclosulfyne®, DO 14®, Euromite®, Fenpropar®, Keleran®, Omite®, Ornamite®, Propargil®, and Rabite® [1,2]. It also has weak herbicidal action, being phytotoxic to immature pears, strawberries, roses, beans, citrus fruit, and cotton [2].

PROP is decomposed by strong acids and bases, slowly degraded by heat, but is stable to light [2]. The major hydrolysis and metabolic products appear to be 4-*tert*-butylphenol, cyclohexane-diol, 2-[4-(1,1-dimethylethyl)phenoxy cyclohexanol (CAS RN 1942-71-8; TBPC), and propargyl alcohol [1,2], all of which are also part of its synthesis [3]. Technical PROP has phenol and alcohol impurities. The California EPA has reviewed the environmental fate of PROP [4], and no residues in groundwater from 405 wells were detected in California from 1984 through 1991, but 32 samples contained PROP residues from 330 surface water samples examined from 1993 to 1998. Air residues were also detected in 70 out of 176 air samples col-

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lected in Fresno and King Counties in 1999 with a most elevated concentration of 1300 ng m^{-3} compared with the highest background of 94 ng m^{-3} [5].

The oral toxicity of PROP in rats of both genders exceeds 1500 mg kg^{-1} [1], but the dermal toxicity is greater, being 250 and 680 mg kg^{-1} for males and females, respectively [1]. PROP is not a mutagen, but it is a B2 chemical carcinogen based on the appearance of extremely rare jejeunal tumors in male and female Sprague-Dawley rats exposed over a lifetime [6].

Omite® as a fine wettable powder formulation caused dermatitis and eye irritation in 1974 after spraying in Tulare County in Central California that led to its temporary registration withdrawal by the State of California with subsequent reregistration with lengthened re-entry intervals from 2–7 days to 14–42 days after spraying [1,7,8]. PROP is regarded as a childhood cancer risk in California [9,10]. PROP caused 20 cases of occupational illness in 1998–1999 in the Sentinel Event Notification System for Occupational Risks [11]. The US EPA has revoked tolerances on specific food items (apples, apricots, succulent beans, cranberries, figs, dried figs, peaches, pears, plums, prunes, and strawberries) because of the non-recommended use on these items by Uniroyal [12].

Arizona has a state drinking water guideline of 160 μg L^{-1} for PROP [1]. The US EPA chronic oral reference dose is 20 μg/kg/day [13]. There is no American Conference of Governmental Industrial Hygienists recommended threshold limit value for personal breathing zone air sampling over 8 h, and there is no corresponding OSHA Permissible Exposure Limit.

There are no peer-reviewed literature data on the types of gloves to protect against PROP exposure, most material safety data sheets recommending "chemically resistant gloves" or the "appropriate gloves" without specifics. There are also no recommendations by glove manufacturers. Fujita [14] found that 5 of 63 female Japanese tea growers in 1982 had contact dermatitis with 19% showing positive patch tests to Omite®, with low rates of dermatitis for growers wearing rubber or cotton gloves. Omite® was a potent skin irritant in animal skin tests. The specimen label for Omite®-6E issued by Uniroyal Chemical Company in 2001 recommended wearing Barrier® laminate, nitrile, butyl, or Viton® chemical-resistant gloves [15].

Because glove manufacturers do not have recommendations for PROP, the method of surrogate compounds can be used to deduce which gloves might be protective [16,17]. Because PROP is a nonpolar aromatic and alicyclic ether and sulfite ester, surrogate compounds might be high molecular weight aromatic ethers and carboxylic acid esters. Ansell Occupational Healthcare [18] has some recommendations for these types of compounds. Dioctyl phthalate (molecular weight (MW) 391) and dibutyl phthalate (MW 278) are both resisted by nitrile and neoprene/natural rubber blend with detection breakthrough times (t_{db}) of >360 min, with unsupported neoprene, supported polyvinyl alcohol, polyvinyl chloride, or natural rubber gloves being inconsistent or not recommended. Amyl acetate (MW 144) and butyl acetate (MW 130) are not resisted as well by nitrile (t_{db} of 60 min for amyl acetate and 75 min for butyl acetate) or neoprene/natural rubber blend (degrades). Cellosolve acetate, a carboxylic acid ester with an ether link of MW 118, shows a t_{db} of 90 min for nitrile and 15 min for neoprene/rubber blend. Similarly, 1-methoxy-2-acetoxypropane of MW 132 shows a t_{db} of 200 min for nitrile, and of 18 min for neoprene/rubber blend. If PROP behaves like carboxylic ester ethers, t_{db} values longer than for cellosolve acetate or 1-methoxy-2-acetoxypropane but shorter than for dioctyl or dibutyl phthalate should be observed. Therefore, nitrile should be the glove of choice apart from the laminated types. This deduction agrees with the specimen label of Uniroyal's Omite®-6E [15].

Chemically resistant nitrile gloves are less comfortable and impede workpiece manipulation more than do disposable exams-type nitrile gloves. This suggested that studies with both glove types were needed to define what gloves would be protective to the undiluted formulation and after dilution with water to its highest recommended concentration for field spraying.

2. Experimental/materials and methods

2.1. Chemicals

Comite® (Ag-miticide emulsion concentrate; nominally 73.6% PROP and 26.4% "inert ingredients") was obtained from Uniroyal Chemical Company. Nitrile, butyl, neoprene, and/or barrier laminate are recommended gloves. PROP (95 and 96%), 4-*tert*-butylphenol (99.5%, TBP), 4,4′-dichlorobiphenyl (99.4%), 2-propyn-1-ol (99.3%), 2-(*tert*-butylphenoxy)cyclohexanol (98.7%, TBPC), and 1,2-cyclohexanediol (98.3%) were from Chem Service, West Chester PA. 2- (99%) and 3- (99%) *Tert*-butylphenol, cyclohexene oxide (98%), hexadecane (99%), and 1-hexadecanol (99%) were from Aldrich, Milwuakee, PA. Optima grade methanol and hexane and concentrated nitric acid (for cleaning glassware) were purchased from Fisher Scientific, Tustin, CA. Helium (99.999%), and nitrogen (99.999%) were obtained from Air Liquide, Long Beach, CA. Personnel handling chemicals wore laboratory coats, safety glasses, charcoal-lined disposable respirators, double SafeSkin™ gloves, and worked in fume hoods when possible.

2.2. Gloves

The gloves utilized were 11-mil thick and 33 cm in length embossed unsupported/unlined powderless Sol-Vex® nitrile (catalog No. 37-145) from Ansell, Coshocton, OH, and disposable powderless unsupported/unlined Safeskin® nitrile exam gloves (Kimberley Clark, San Diego, CA) of unspecified thickness and 24.1 cm in length.

2.3. Equipment

Agilent Technologies Model Number 6890N Network Gas Chromatograph/Agilent Model Number 5973 Network Mass Selective Detector (MSD) equipped with a HP 5-MS 30 m × 0.25 mm (0.25-μm film) fused silica capillary column was used to confirm initial purity and identify components of the formulation as well as to quantify Comite® formulation components. The MSD 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 230 °C and that of the transfer line was 200 °C. The 70 eV ion source was held at 200 °C. The flow of helium carrier was 0.50 ± 0.05 mL/min. The purge delay was 3 min. The column temperature program was initial temperature 70 °C for 3 min (the same as the solvent delay time) and then isothermal heating at 200 °C for 30 min followed by column cleaning at 250 °C for 15 min. Selected ion monitoring involved *m*/*z* 135 and 173, and also *m*/*z* 222 for the 4,4′-dichlorobiphenyl internal standard (IS).

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

American Society for Testing and Materials (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 × 1.50 cm OD × 1.33 cm ID) were mounted on the two rails of the shaker after hacksawing 1-mm wide grooves in the bars and using emery paper to smoothen 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.

2.4. Formulation and PROP GC–MS analysis

The formulation sample was diluted in hexane to allow GC–MS identification of compounds in the formulation. Suspected compounds assigned by the National Institute of Standards and Technology (NIST) library were confirmed by purchasing standards and verifying that the retention times and mass spectra were the same as the candidate compound. Pure PROP and its impurities were examined. The impurities formed from pure PROP at various column temperatures from 180 to 220 °C were determined. The linearity of pure PROP injections up to 940 ng was also found at the optimal column temperature. Standards had to be synthesized with their gas chromatographic, mass spectral, and infrared purities assessed for [2-(4-*tert*-butylphenoxy)chlorocyclohexane (TBPCC). The stability of PROP in Comite® aqueous solution was also investigated.

2.5. Permeation procedure

The detailed procedure is provided elsewhere [19,20], and is based on the standard ASTM F739-96 permeation method [21].

In summary, glove materials cut from out-of-the box gloves were conditioned at least for 24 h in a desiccator with 55_1% relative humidity (saturated aqueous sodium dichromate). The glove material was held between two Teflon™ gaskets and the Pyrex™ chambers by a uniform torque. A volume of 10-mL hexane was added as the collection medium, and then 10 mL of formulation (or 0.5 mL formulation in 10 mL aqueous challenge solution) was pipetted into the challenge chamber. 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 begun so as to ensure no concentration gradients in the challenge and collection media. Initially, 0.1-mL samples were withdrawn every hour, and deposited into 1-mL screw-capped vials. After adding the 4,4′-dichlorobiphenyl IS in hexane to a vial concentration of 4 ng/μL, aliquots of 1 μL were injected into the GC–MSD, and quantitation of PROP and other compounds performed by the method of internal standards. After applying any dilution factor, and knowing the fraction of collection fluid injected, the sample PROP or other compound contents were calculated. The permeation curve was then plotted for cumulated mass versus time.

Quality assurance procedures included tests for leaks from the assembled permeation cell, and hexane back diffusion as outlined elsewhere [22,23]. Aliquots of 1-mL challenge solution were obtained immediately after preparation, before the permeation began, and after each permeation run. Method blanks in triplicate involved water or air in the challenge side with hexane in the collection side.

2.6. 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 method blank to account for any solvent effects was to expose a specimen of the same conditioned glove to air on the challenge side and hexane 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 major reflectance peaks were tabulated from the spectra obtained from 4000 to 600 cm^{-1}. Spectra for exposure situations were corrected appropriately for the method blank. When areas appeared homogeneous for a given glove side, the reflectances at a minimum of three distinct positions were measured and the data averaged if they were 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 in disappearance of reflectance minima before and after challenges as well as possible detection of pesticide and formulation components.

2.7. 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 (S.D.), and coefficients of variation (CV).

Linear regression analyses allowed calculation of slopes and intercepts, their corresponding S.D.s, the correlation coefficient r, and p-values.

Thus steady state permeation rates P_s and their standard deviations were calculated from the linear portions of the permeation curve. The normalized breakthrough time t_b was determined at the time when the area mass transport was 0.25 μg/cm^2. The lag time t_l was determined by extrapolation of the steady state rate periods to the time when mass transport was zero.

3. Results and discussion

3.1. Formulation and PROP analyses

3.1.1. GC–MS

A thermal stability study of "pure" PROP at column temperatures of 180, 190, 200, 210, and 220 °C revealed that at 220 °C and above, PROP pyrolyzed so that it represented ≤80% of the entire area at 220 °C. The relative area of the TBP peak at 4.6 min also increased with increasing temperature above 200 °C. There were negligible 2- and 3-TBP in the original PROP and after column injection at all temperatures. At 200 °C, PROP at 20.3 min represented 82% of the area with TBPC [M^+ 248 (9.9%), m/z 150(12%), m/z 107 (7.6%), m/z 231 (5.8%), base peak m/z 135] at 9.1 min comprising 12% (m/z 248), and m/z 266 [TBPCC; M^+ 266 (12%), m/z 251 (8.4%), m/z 150 (8.9%), m/z 207 (7.1%), m/z 107 (6.3%), base peak m/z 135] at 9.3 min, 6.0%. Thus all analyses were performed at a column temperature of 200 °C. Another "pure" PROP sample (96% nominal purity) had a purity of 93.97 ± 0.85% and its only impurity was TBPC at 5.87 ± 0.61%. The PROP mass spectrum showed M^+ at m/z 350 (48%) with a base peak at m/z 135 followed closely by m/z 173 (72%), in addition to m/z 81 (41%), m/z 201 (33%), m/z 57 (26%), m/z 335 (22%), m/z 91 (22%), and m/z 107 (22%) as major m/z.

There were two linear ranges for a 1.0-μL injection of PROP at 200 °C: 200–700 ng, and between 0.41 and 200 ng. At concentrations less than 0.41 ng, the PROP peak disappeared and only 4-TBP was observed on PROP injection. For 4-TBP, the linear range was from 0.2 to 2.5 ng. The 4,4′-dichlorobiphenyl IS of retention time 8.0 min had a linear range of 0.2–4.6 ng.

The Comite® formulation showed the expected peaks at 20.3 min (PROP at 79.0% of the total area), 9.1 min (TBPC at 11.6%), 9.3 min (TBPCC at 6.2%), and 4.4 min (1,4-TBP at <0.1%). In addition it contained smaller peaks at 3.12 min (cyclohexene oxide, <0.1% of the total area), 5.3 min (n-tetradecane, <0.1%), 6.0 min (2,6,11-trimethyldodecane, <0.1%), 7.66 min (0.7%), 7.74 min (1.0%), and 7.88 min (1,2-dimethyl-4-*tert*-butyl-6-cyclopentylbenzene, 1.6%). The nominal PROP content was 73.6% (w/w), and the actual amount was 64.9 ± 7.3%, not significantly different at $p \leq 0.05$, assuming the same relative standard deviation for the nominal amount.

PROP in the Comite® aqueous solution did not hydrolyze markedly in water, the PROP content after 24 h being 69 ± 7% ($n = 3$), this not being significantly different from the initial concentration at $p \leq 0.05$.

The PROP concentration in the aqueous solution was at the maximum recommended for spraying because this maximized P_s and minimized t_b. PROP has been analyzed in various environmental media [1,24–26], but there are no previous reports of its on-column lability at high temperatures. A small amount of 4-TBP is formed by on-column pyrolysis of PROP even at 200 °C.

3.1.2. ATR–FTIR

Pure PROP showed strong reflectance minima in cm^{-1} at: 739.69, 1238.28, 921.62, 902.06, 1510.09, 829.85, 869.85, 1183.10, and 990.88 in the fingerprint region in that order of decreasing intensity, as well as C–H stretches at 2946.23 and 2865.59 cm^{-1} and the S=O stretch at 1607.56 cm^{-1}. There was a weak O–H stretch at 3281.14 cm^{-1}. The Comite® formulation also contained all of these PROP characteristic wavelength minima with greater absorption in the fingerprint region. Previous work using GC–FTIR has suggested the use of 2964 cm^{-1} as the major analytical wavelength for the FTIR absorption spectrum of PROP [27], but the current paper is the first report of its ATR–FTIR spectrum.

3.2. Permeation of gloves

The GC–MS of the concentrated collection side confirmed the presence of PROP, 4-TBP, TBPC, and TBPCC from the formulation as well as hexadecane, a compound in the hexane blank. The nitrile gloves did not shrink or swell.

3.2.1. Permeation

Aqueous solutions containing PROP at 40.4 mg/mL permeated both Safeskin® and Sol-Vex® nitrile by 8 h (Table 1). Safeskin® showed a mean mass permeated of 176 ± 27 μg after 8 h compared with a mean mass permeated for Sol-Vex® of 3.17 ± 4.08 μg. Based on the mass permeated at 8 h, Sol-Vex® was about 56 times more protective than Safeskin®. The kinetics of the permeation revealed that Safeskin® can be worn for at least 200 min before doffing. The Sol-Vex data were variable because two of the masses measured were under the least quantifiable limit (LQL) of mass permeated of 4.1 μg.

When undiluted Comite® challenged both types of nitrile, much faster permeation was observed (Tables 2 and 3).

Table 1
Permeation of propargite through Safeskin® and Sol-Vex® nitrile gloves from Comite® formulation in aqueous solution (40.4 mg/mL) at 8 h

Glove	Run	Propargite permeated (μg)	Mean ± S.D. (CV) (μg)
Safeskin®	1	155	176 ± 27 (15%)
	2	136	
	3	197	
	4	180	
	5	209	
	6	177	
Sol-Vex®	1	7.82	3.17 ± 4.08 (129%)[a]
	2	1.53[a]	
	3	0.167[a]	

S.D., standard deviation; CV, coefficient of variation.
[a] Less than the permeated mass LQL of 4.1 μg.

Table 2
Kinetic data for Safeskin® nitrile gloves exposed to undiluted Comite® formulation

Parameter	Stage	Run 1	Run 2	Run 3	Mean	S.D.	CV (%)
P_s	First	4.60	5.79	4.95	5.11	0.61	12
Time		1.0–4.0	1.0–3.0	1.0–3.0	–	–	–
t_l		1.1	1.0	1.0	1.033	0.058	5.8
t_b		<10	<10	<10	<10		
P_s	Second	15.2	27.0	19.4	20.5	6.0	29
Time		4.0–5.0	3.0–5.0	4.0–5.0	–	–	–
t_l		3.10	2.90	3.10	3.03	0.12	3.8
$Mass_{8\text{-h}}$		14056	29928	19032	21005	8118	39

P_s, the steady state permeation rate in units of $\mu g\,cm^{-2}\,min^{-1}$; time, the time range in hours after the challenge began over which the P_s applies; t_l, the lag time in hours; t_b, the normalized breakthrough time in minutes where the permeation is 0.25 $\mu g\,cm^{-2}$; $mass_{8\text{-h}}$, mass permeated after 8 h in μg; first, the initial steady state period; second, the second steady state period; S.D., standard deviation; CV, coefficient of variation; –, not applicable.

Safeskin® gloves allowed two steady state periods. The first steady state period showed t_l values of about 1 h although t_b values were <10 min (Table 2). The second steady state P_s was on average four times the rate of the first period P_s, and the second steady state period t_l was about three times as long as that of the first steady state t_l, and about the same t_l as for permeation of the aqueous solution. Thus the Safeskin® glove was unsuitable for handling undiluted formulation, but was adequate for the aqueous formulation with judicious doffing and donning. The PROP in the undiluted formulation permeated Safeskin® 119 times more than it did in the aqueous solution based on 8-h permeated masses.

In contrast, Sol-Vex® gloves protected 3334 times better against the undiluted Comite® (Table 3) relative to Safeskin® after 8 h, but only 2.0 times better compared with Sol-Vex® against aqueous Comite® solutions. Sol-Vex® is therefore generally much more protective against PROP as an aqueous formulation or undiluted formulation than Safeskin®, a result that was expected because they are thicker than the disposable nitrile gloves and are rendered chemically protective through either a dipping or aerosol process. The ratio of the mass permeated at 4 h relative to at 8 h for the undiluted formulation through Sol-Vex® is 0.65 ± 0.15 (CV = 23%). The average t_l was about 1.8 h, and the average t_b was about 2.7 h. The amounts permeated at 4 h in Table 3 were near 4.1 μg, the LQL. Thus Sol-Vex® gloves exposed continuously to undiluted Comite® start to permeate above the breakthrough threshold beyond 2.7 h. If PROP is treated as a carcinogen under the same exposure conditions, doffing should be done at about 2 h, or at the beginning of a break.

Table 3
Permeation of undiluted Comite® through Sol-Vex® gloves

Permeation hours	Run	Mass (μg)	Ratio of mass at 4 h to mass at 8 h
4	1	4.22	0.607
	2	3.95[a]	0.766
	3	3.94[a]	0.451
	4	3.23[a]	0.771
Mean ± S.D.		3.84 ± 0.42	0.65 ± 0.15
8	1	6.95	
	2	5.16	
	3	8.73	
	4	4.19	
Mean ± S.D.		6.3 ± 2.0	

S.D., standard deviation.
[a] Less than the permeated mass LQL of 4.1 μg.

No peer-reviewed literature exists on protection against Comite® or PROP.

3.2.2. Infrared reflectance

The reflectance spectra of the inner and outer surfaces of Sol-Vex® nitrile gloves have been discussed elsewhere [22]. The reflectance infrared spectra of Safeskin® glove surfaces have also been measured previously by our research group [22,23].

The outer surface but not the inner surface of the glove material showed the presence of PROP and some hydrolysis of PROP in the aqueous carrier (the appearance of a broad hydrogen-bonded hydroxy band). The most intense PROP peaks were slightly red-shifted. ATR–FTIR analysis showed no damage to the inner or outer glove surfaces.

3.3. Glove permeation skin risk assessment

Because the EPA chronic oral reference dose is 20 μg/kg/day [13], this is equivalent to a dose of 1400 μg/day for a 70 kg reference adult Caucasian man. Exposure of both Safeskin® and Sol-Vex® to aqueous Comite® (Table 1) and Sol-Vex® to undiluted Comite® (Table 3) did not exceed this threshold over 8 h of continuous exposure. This is not the case with Safeskin® exposed to undiluted Comite® for 8 h (Table 2) where the threshold was exceeded after 2 h of exposure. If an arbitrary safety threshold of 10% of the threshold is assumed (as for 10% of lower explosive limit (LEL) to define a warning threshold for immediately dangerous to life or health (IDLH) conditions), then Safeskin® gloves should be removed ("doffed") after 1 h of continuous exposure to undiluted Comite®, and an unexposed pair donned. This 1-h guideline agreed with the value of t_l for the first slow permeation stage (Table 2), but not t_b which was of the order of <10 min. If the latter is taken as the reference

time, then Safeskin® is completely unsuitable to protect against undiluted Comite®. Relative to the proposed safety threshold of 140 μg/day, 8-h exposures to aqueous Comite® will exceed this limit for Safeskin® but not for Sol-Vex®, and the latter even for undiluted Comite®.

Because the above treatment assumes that all permeated PROP is absorbed, it is important to be able to model how much chemical permeates through the skin to assess risk. Many such models exist [28], and for $\log K_{ow}$ values in the −1 to 5 range, the revised Potts and Guy model provides about the same results as the more complex revised Robinson model. The Potts and Guy model assumes the stratum corneum is the only resistance to a saturated aqueous exposing solution. For PROP with a $\log K_{ow}$ of 4.624 (at 25 °C), and a water solubility of 0.5 mg L^{-1} at 25 °C, the maximum permeation flux F through the stratum corneum can be calculated using Eq. (1) [28]:

$$F = sK_P \quad (1)$$

where s, the PROP water solubility at room temperature, is in mg mL^{-1}, F is in mg cm^{-2} h^{-1}, and K_p is the effective partition coefficient so that

$$\log K_p = -1.326 + 0.6097 \log K_{ow} - 0.1786 M^{0.5} \text{ (from the revised Potts and Guy eqn.)} \quad (2)$$

where M is the molecular weight, and $\log K_p$ and $\log K_{ow}$ are at room temperature.

F is 7.1 ng cm^{-2} h^{-1}, and will be larger at body temperature. If the total surface area of both hands and lower forearms is 2000 cm^2 [29], then the F is equivalent to a skin permeation rate of 14.2 μg h^{-1}. The time to reach the 1.4 mg toxicity threshold is therefore 99 h, or 9.9 h for the 10% warning threshold. The observed glove P_s of PROP in the slow first permeation stage is between 276 and 348 μg cm^{-2} h^{-1} for Safeskin® gloves, much greater than F. Thus PROP will predominantly stay in contact with the stratum corneum and be an outer skin irritant rather than being absorbed.

4. Conclusions

The disposable nitrile glove did not protect against undiluted Comite®, but can be worn for about 1 h for Comite® diluted to its highest recommended spraying concentration in a water carrier. Chemically protective Sol-Vex® nitrile protected against the aqueous solution and the undiluted formulation. If PROP is regarded as a carcinogen, Sol-Vex provides the best protection to the undiluted formulation but it still allowed PROP to permeate. More resistant gloves such as Viton or laminated ones are required depending on how long the gloves are to be worn. ATR–FTIR analysis showed that the inner and outer surfaces were not degraded, and that PROP could be detected on the outer surface but not on the inner one. A risk assessment revealed that skin absorption was much slower than the steady state rate of Safeskin permeation.

Acknowledgments

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