Permeation of Herbicidal Dichlobenil From a Casoron Formulation Through Nitrile Gloves

Shane S. Que Hee · Hanaa Zainal

Received: 17 August 2009 / Accepted: 28 September 2009 / Published online: 24 October 2009 © The Author(s) 2009. This article is published with open access at Springerlink.com

Abstract The aim of this study was to measure permeation of the herbicide dichlobenil in Casoron 4G through disposable and chemically protective nitrile gloves using an American Society for Testing and Materials-type permeation cell and a closed-loop system employing two different solvents (hexane and water) and two different challenge situations (aqueous emulsion and solid formulation). Capillary gas chromatography–mass spectrometry was used for quantification purposes. The chemically protective glove did not allow any permeation up to 8 h for the solid-formulation and water-collection challenges, but permeation was detected in all other challenges. The disposable glove allowed the most permeation, and the solid-formulation challenge with water collection necessitated that a dichlobenil equivalent be calculated because of the presence of its hydrolysis degradation product 2,6-dichlorobenzamide. Permeation from the solid formulation was detectable by hexane collection for both the disposable and chemically protective gloves and by water collection for the disposable glove. It was concluded that hexane-solvent collection was not valid for the disposable glove at 4 and 8 h of permeation in the solid Casoron challenge or for the aqueous emulsion challenge at 8 h relative to the water-collection solvent data. The hexane-solvent collection for the chemically protective glove was valid for the 8-h solid-formulation challenge but not for the 8-h aqueous-solution challenge. All water-solvent collections were valid; however, dichlobenil usually permeated the gloves.

Dichlobenil (2,6-dichlorobenzonitrile; Chemical Abstracts Service RN 1194-65-6) is a nonselective systemic soil herbicide applied for pre- and post-emergence weed control in many fruits and flowers as well as in slow-flowing aquatic systems (Hazardous Substances Data Bank 2009). Its major human effects are dermatitis, chloracne, and nasal tissue attack (involving necrosis of the dorsomedial part of the olfactory neuroepithelium with permanent damage to the underlying mucosa [independent of the mode of exposure]). Because exposed rodents developed liver tumors, the United States Environmental Protection Agency (USEPA) has classified dichlobenil as a group C carcinogen (possible human carcinogen). It is volatile (vapor pressure approximately $6.6 \times 10^{-4}$ mm Hg at 20°C), is moderately soluble in water (18 ppm at 20°C), and has a moderate log $p_{OW}$ value of 2.74. Although there are no occupational guidelines, the USEPA in 2008 established combined tolerances for dichlobenil and its metabolite 2,6-dichlorobenzamide on specific crops ranging from 0.06 to 0.15 ppm, although the amide is also a metabolite of the herbicide fluopicolide (USEPA 2008). The acceptable daily intake is 500 ng/kg body weight (Hazardous Substances Data Bank 2009).

No scientific literature has been published on the permeation of dichlobenil through glove materials, which are the chief mode of protection of hand skin. A common message in many material safety data sheets for formulations containing dichlobenil, without specifying the glove material, is to “use chemical resistant protective gloves,” “wear suitable protective equipment,” or “wear protective clothing.” Regarding the emulsifiable concentrates of pesticides, i.e.,
Casoron for dichlobenil, handling, spraying, and formulating the liquid concentrate are probably the most hazardous operations because many chemicals are involved at high concentrations in often quasi-confined unventilated spaces. Worker field re-entry to wet foliage and soil after spraying is another hazardous scenario that has generally been mitigated by respecting the correct re-entry interval. Many pesticides are available in dust form, e.g., Casoron G, G-2, G-4, and 4G for dichlobenil; thus, inhalation protection for particulates may also be needed. We provide here the first reported quantitative permeation of dichlobenil through specific glove materials.

Experiment

Materials

Casoron 4G (4.0% dichlobenil) came from Chemtura (Middlebury, CT). The granular formulation also contained an unspecified thickening agent and a proprietary carrier at unspecified concentrations. The recommended application range is 50–300 lb/acre (56–340 kg/ha); the re-entry interval is 12 h. Pure dichlobenil (99.5% purity nominally), 2,6-dichlorobenzamide (99% purity nominally), and internal standard (IS) 4,4’-dichlorobiphenyl (99%) were obtained from ChemService (West Chester, PA). Optimal-grade hexanes (hereafter called hexane) and isopropanol came from Fisher Scientific (Pittsburgh, PA). All water was Millipore triple-cartridge deionized.

Safeskin nitrile powder-free examination gloves (24.1-cm length, unspecified thickness, no. N330; Kimberly Clark, San Diego, CA) were obtained from Fisher Scientific. Solvex unsupported and unlined nitrile chemical protective gloves (33-cm length, 11-mil thickness, No. 37-145) came from Ansell Occupational Healthcare (Coshocton, OH).

Equipment

A calibrated Marathon electronic digital micrometer (model No. CO 030025, 0–25 mm range, 0.001 mm resolution; Fisher) was used to measure glove thickness before and after permeation testing. A calibrated Mettler analytic balance delta range (model No. AE260; Mettler, Hightstown, NJ) was used to weigh gloves before and after permeation.

Infrared (IR) spectra were obtained with an Avatar 360 Fourier-transform (FT) spectrophotometer system (ThermoNicolet, Madison, WI) and a single-beam FT-IR spectrophotometer using the reflectance mode and operated with OMNIC 6.0a software. The crystal was diamond in single-reflection horizontal attenuated total reflectance mode. The spectral range was 4,000–600 cm⁻¹, and the number of scans was 64.

Gas chromatography–mass spectrometry (GC–MS) was performed with an Agilent 6890 N network gas chromatograph (Agilent Technologies, Wilmington, DE) connected to an Agilent 5973 network mass selective detector (MSD). The MSD was a quadrupole with an electron multiplier detector. The GC column was an HP 5-MS 30 m × 0.25 mm i.d. (0.25-μm film) fused silica capillary column (Agilent). The helium carrier flow (99.9999%; Air Liquide, Long Beach, CA) was 3.00 ± 0.20 mL/min. The temperature of the injector was 280°C and that of the transfer line was 280°C. The 70-eV ion source and the quadrupole were held at 230°C and 150°C, respectively.

Water and Hexane Solubility of Dichlobenil

A mass of 10 mg dichlobenil was mixed with 20 mL water in a brown centrifuge tube in triplicate. Each sample was sonicated at 40°C for 60 min with the screw cap on. After cooling to 22.5°C, the solution was centrifuged at 900 g for 30 min; 0.2 mL of the supernatant fraction was transferred to a 4-mL vial; this was extracted consecutively with 0.4, 0.3, and 0.3 mL hexane; and the extracts were combined for analysis. The IS 4,4′-dichlorobiphenyl in hexane was added to a final concentration of 0.5 ng/mL. The amount of dichlobenil was determined by GC–MS using the IS method (see later text). The solubility was then calculated. A similar procedure was performed to determine dichlobenil solubility in hexane.

Dichlobenil Content of Casoron 4G and Stability in Solvents

A 2 mg/mL solution of Casoron 4G was prepared separately in hexane, isopropanol, and water. A subvolume of 0.1 mL was then diluted to 1 mL with hexane and isopropanol, as appropriate, for direct analysis by the IS method (see later text). The 0.1-mL water solution was brought just to dryness in a stream of nitrogen and dissolved to produce 1 mL isopropanol solution for GC–MS analysis (see later text).

Aqueous solutions containing 1 g Casoron 4G in 25 mL volumetric flasks were also sonicated for 1 h at 40°C and filtered the next day. Then 0.1 mL filtrate was evaporated as previously described. The residue was dissolved in isopropanol and then analyzed using the total ion current mode (m/z 50–550) of the GC–MSD to allow hydrolysis products to be identified and quantified.

Permeation Procedure

The permeation procedure was based on a modified American Society for Testing and Materials (ASTM) F739-99a permeation method (2004). Out-of-the-box gloves were conditioned for 24 h in a desiccator, in which the relative humidity was maintained at 55% ± 1% by
saturated aqueous sodium dichromate, as recommended by
the ASTM method. Circular pieces, 42.5 mm in diameter,
were cut from the palm area of six gloves of each glove
type. Just before permeation, glove thickness was measured
using six random readings, and the arithmetic means and
SDs were calculated. The gloves were then weighed. The IR
reflectance spectrum of the material near the cut piece
was then measured at a specific clamp pressure.

Each circular piece was then held between the two
Teflon gaskets/Pyrex chambers of an I-PTC-600 ASTM-
type permeation cell (Pesce Laboratory, Kennett Square,
PA) by a uniform torque with the outer surface of the glove
facing the challenge chamber. The exposed glove material
between the two chambers was 25.4 mm in diameter. A
10-mL volume of aqueous emulsion at a concentration of
2.0 mg/mL was pipetted into the challenge chamber, and
10 mL solvent (hexane or water) was pipetted into the
collection chamber. Solid Casoron 4G powder (8.500 g)
was placed in the challenge side for some challenges.

The permeation cells were clamped and immersed six at
a time in a Fisher shaking water bath (model 127) at
35.0°C ± 0.5°C so that the test material in each cell was
vertical. The permeation cells were agitated for 8 h at an
average horizontal shaking speed of 70 ± 5 cycles/min;
the traveling distance was 10.24 cm/cycle. This assured
that the emulsion did not stratify, that the collection side
did not build up concentration gradients, and that the test
material was wetted continuously on both sides. The col-
collection solvent and the challenge solution were then
weighed. The permeation cells were disassembled, and the
outer surfaces of glove pieces were blotted dry with Kim-

Solvent blank tests with 10 mL solvent in the collection
chamber, with only air in the challenge chamber, were also
performed. Information on back-permeation of the col-
lection chamber solvent was obtained by injecting chal-
collection chamber air samples in gas-tight syringes into the GC–MS.
All tests were performed at least in triplicate.

Quantitation of Dichlobenil After Permeation

The collection and challenge aqueous solutions were
evaporated just to dryness under a flow of nitrogen at 40°C
in a volumetric tube. A volume of 50 μL 100 μg/mL 4,4’-
dichlorobiphenyl IS in hexane was added, and hexane was
added to a final volume of 1.0 mL. A 2-μL aliquot was
injected into the GC–MS for analysis. The final IS con-
centration in the injection was 0.5 μg/mL.

The MS detected ions of mass-to-charge ratio (m/z)
171,173, and 222 in the selected ion monitoring mode. In
some runs, the total ion current mode with m/z 50–550 was
used for identification purposes. The GC column was
operated isothermally at 100°C for 2 min, heated at 20°C/
min to 200°C, and the temperature maintained at 200°C for
30 min at 2.5 mL/min; the solvent delay was 2.0 min. Each
run took 35 min to complete.

Ratios of dichlobenil area for m/z 171 over IS area for
m/z 222 in the chromatograms were plotted versus corre-
sponding dichlobenil mass injected to provide the calibration
curve for dichlobenil. For analyses involving 2,6-dichloro-
benzamide, m/z 189 was also monitored as was m/z 173. It
should be noted that m/z 173 is (M + 2)⁺ associated with the
m/z 171 molecular ion (M⁺) for dichlobenil and is also the
base ion (M-16)⁺ for 2,6-dichlorobenzamide. The linear
portion was determined and subjected to linear regression to
calculate the slope and intercept, their SDs, the correlation
coefficient r, and the p value.

FT reflectance IR scan analysis of the dry glove mate-
rials was performed from 4,000 to 600 cm⁻¹. The major
reflectance maxima for dichlobenil at 782, 1198, and
1431 cm⁻¹ and those for 2,6-dichlorobenzamide at 1643
and 787 cm⁻¹ were scrutinized.

Results and Discussion

Calibration Data

The GC–MS linear range for dichlobenil using m/z 171 at a
retention time of approximately 5.0 min by the IS method
was 0.03–6 ng; similarly, that for 2,6-dichlorobenzamide
using m/z 173 at a retention time of approximately 7.1 min
was 0.025–0.3 ng. Typical r values were > 0.9990. The IS
4,4’-dichlorobiphenyl (m/z 222) had a retention time of
approximately 8.0 min.

Dichlobenil Water Solubility and Stability in Water and
Hexane

The water-solubility triplicate results were 20.4, 18.9, and
23.1 mg/L to provide an arithmetic mean and SD of
20.8 ± 2.1 mg/L at 22.5°C. The literature solubility value at
20°C is 18 mg/L (Hazardous Substances Data Bank 2009).
There is adequate agreement at p ≤ 0.05. The solubility at a
specific temperature sets the upper concentration that a water
collection vehicle can attain in the absence of adjuvants.

The experiment to test the stability of Casoron 4G in
hexane and isopropanol resulted in no degradation to the
amide. The water solution, analyzed when fresh, also
showed no degradation, but the solution that was ultraso-
nicated at 40°C for 1 h, left overnight, and processed on
day 2 contained hydrolysis products. The chromatogram
also showed the presence of lauric anhydride, probably from
the pyrolysis of sodium laurate surfactant.
Dichlobenil Content of Casoron 4G and Analytic Standard Purity

The dichlobenil contents for three replicates were (w/w) 4.1, 4.3, and 3.5%, with an arithmetic mean and SD of 3.97 ± 0.42%. This is not significantly different from the nominal composition of 4.0% at \( p \leq 0.05 \). There was a trace of 2,6-dichlorobenzamide. The major impurity (<1%) in the analytic standard was also 2,6-dichlorobenzamide. The analytic standard purity from organic solvent studies was determined to be 99.5 ± 0.8%. Dichlobenil in Casoron 4G was stable in isopropanol and hexane for at least 2 days. In water, 2,6-dichlorobenzamide was also produced by day 2. The pH of the aqueous emulsion of 2.0 mg/mL was 6.8. Basic conditions enhance hydrolysis (Hazardous Substances Data Bank 2009).

Permeation

The results, including the resultant mass/area factor and the calculated linear flux, for the two solvent collection systems and for the two different nitrile glove types are listed in Table 1 for the aqueous-emulsion challenge and in Table 2 for the solid-formulation challenge in terms of total dichlobenil permeated during 8 h of exposure. The latter assumes linear (steady-state) permeation kinetics but is not necessarily related to the steady-state permeation rate. Inter-run precision decreased as the permeated mass approached analytic detection limits. Shrinking or swelling of glove materials did not occur, and FT IR reflectance measurements did not detect dichlobenil on the dried inside surface of glove materials or any inner surface damage, although the herbicide was detected on the dried challenge side after permeation experiments. The sole exception for the inner surface was the solid Casoron 4G challenge for Safeskin with water collection, in which the 2,6-dichlorobenzamide amide stretch at 1643 cm\(^{-1}\) was clearly visible.

Table 1 shows that in terms of average total dichlobenil permeated at 8 h for Safeskin disposable gloves, hexane collected approximately 86,000 times more herbicide than water. The results of hexane and water collection disputed whether the glove can be labeled as meeting the ASTM closed-loop system criterion of 250 ng/cm\(^2\) for the mass/area factor to define normalized breakthrough time (ASTM 2004). Similarly, the Solvex challenge with hexane collection allowed approximately 840 times more dichlobenil to be collected than by water, with a similar disagreement on whether the normalized breakthrough time was exceeded. In terms of how much more protective Solvex was than Safeskin for the same collection solvent, the factors were 52 for hexane and 0.51 for water. The results of the water-collection experiments for Safeskin and Solvex inferred that the normalized breakthrough time was >8 h for both gloves.

Table 2 shows that the solid Casoron 4G challenge produced qualitatively the same results as the solution

| Glove | Solvent | Replicate mass (ng) | Mass/area (ng/cm\(^2\)) | Linear flux (ng/cm\(^2\)/min) |
|-------|---------|---------------------|-------------------------|--------------------------------|
| Safeskin | Hexane | 254,000 | 50,700 | 106 |
| 1 | 181,000 | 36,000 | 75.0 |
| 3 | 199,000 | 39,700 | 82.8 |
| Av ± SD\(^a\) | 211,000 ± 38,000 | 42,100 ± 7600 | 88 ± 16 |
| Water | 1 | 2.10 | 0.420 | 0.000875 |
| 2 | 2.36 | 0.472 | 0.000983 |
| 3 | 2.89 | 0.577 | 0.00120 |
| Av ± SD | 2.45 ± 0.40 | 0.490 ± 0.080 | 0.00102 ± 0.00017 |
| Solvex | Hexane | 4.310 | 861 | 0.179 |
| 1 | 4.490 | 899 | 0.187 |
| 3 | 3.340 | 668 | 0.139 |
| Av ± SD | 4.047 ± 620 | 810 ± 120 | 0.168 ± 0.026 |
| Water | 1 | 5.72 | 1.14 | 0.00238 |
| 2 | 4.12 | 0.823 | 0.00171 |
| 3 | 4.65 | 0.930 | 0.00194 |
| Av ± SD | 4.83 ± 0.82 | 0.96 ± 0.16 | 0.00201 ± 0.00034 |

\(^a\) Av ± SD is average (arithmetic mean) ± SD
challenges, that is, Solvex always protected better than Safeskin, and water collection always resulted in lower collected amounts than hexane collection. Compared with water collection, hexane collected approximately 30,000 times more dichlobenil for Safeskin disposable gloves and approximately 110 times more dichlobenil for Solvex gloves. In terms of how much more protective Solvex was than Safeskin for the same collection solvent, the factors were approximately 2,500 for hexane and 10 times for water. The results of the water-collection experiments for Safeskin and Solvex inferred that the normalized breakthrough time was 8 h for both gloves, and only for Solvex did both hexane- and water-collection data agree that the normalized breakthrough time had not been exceeded. We also performed a 4-h permeation experiment for hexane collection with solid Casoron for Safeskin. The triplicates for mass permeated yielded the following results: 190, 189, and 234 μg (204 ± 26). Similarly, the average mass/area factor was 40,900 ± 5,100 ng/cm², and the average linear flux was 170 ± 22 ng/cm²/min. Clearly, the normalized breakthrough time for Safeskin with hexane collection for this solid-formulation challenge was < 4 h. For Safeskin and Solvex challenged by solid Casoron, the form of dichlobenil detected in the water-collection system was mostly 2,6-dichlorobenzamide, with minor dichlobenil observed, necessitating the quantification of both to obtain a dichlobenil equivalent. This did not occur in the aqueous emulsion challenge liquid and hexane collections. The components of the formulation must stabilize dichlobenil in aqueous emulsion.

Our experimental water solubility of dichlobenil of 20.8 mg/L is equivalent to a 10-mL collection solution containing an analyte mass of 208 μg. No water-collection solution contained this amount of dichlobenil at the end of the permeation period, although this volume of water had such a capacity. It is possible that water is so polar that strong adsorption to the glove surface may not render the permeated herbicide available enough for solubilization from the collection side surface. Any tightly adsorbed permeate would decrease the permeation rate through the membrane and produce a negative bias to the observed concentration in water. In addition, glove manufacturer data show that the normalized breakthrough time of hexane for Safeskin is approximately 21 min (Reyes 2002). Solvex does not break through within 480 min for hexane (Ansell Occupational Healthcare 2007). The validity of the liquid-collection method depends on the solvent being inert to the glove and yet being able to solubilize the analyte. The solvent must prevent a concentration gradient from occurring at the water–surface interface because only permeation through the material is of interest.

Another interesting result is that nitrile challenge with dry Casoron 4G powder produces the same generalized results as aqueous emulsion challenges, with higher levels of dichlobenil permeated for Safeskin but not for Solvex gloves. Thus, at 8 h for Safeskin gloves, the ratios for

| Table 2 Permeation after 8-h dichlobenil exposure from solid Casoron 4G formulation (8.5 g) in the challenge side of a ASTM-type permeation cell using 10 mL water or hexane as collection solvent for disposable Safeskin or chemically protective Solvex nitrile gloves |
|-----------------|-----------------|-----------------|-----------------|
| Glove           | Solvent         | Replicate mass (ng) | Mass/area (ng/cm²) | Linear flux (ng/cm²/min) |
| Safeskin        | Hexane          | 1 642,000         | 128,000          | 268                      |
|                 |                 | 2 1,120,000       | 225,000          | 468                      |
|                 |                 | 3 755,000         | 151,000          | 314                      |
|                 | Av ± SD         | 839,000 ± 250,000b | 168,000 ± 51,000 | 350 ± 100                |
| Water           |                 | 1 32.3            | 6.47             | 0.0135                   |
|                 |                 | 2 30.0            | 5.20             | 0.0108                   |
|                 |                 | 3 20.4            | 4.08             | 0.0085                   |
|                 | Av ± SD         | 27.6 ± 6.3b       | 5.3 ± 1.2        | 0.0109 ± 0.0025          |
| Solvex          | Hexane          | 1 447             | 89.4             | 0.186                    |
|                 |                 | 2 179             | 35.8             | 0.0746                   |
|                 |                 | 3 369             | 73.7             | 0.154                    |
|                 | Av ± SD         | 330 ± 140         | 66 ± 28          | 0.138 ± 0.057            |
| Water           |                 | 1 <3              | <0.6             | <0.0012                  |
|                 |                 | 2 <3              | <0.6             | <0.0012                  |
|                 |                 | 3 <3              | <0.6             | <0.0012                  |
|                 | Av ± SD         | <3                | <0.6             | <0.0012                  |

a Av ± SD is average (arithmetic mean) ± SD
b Computed from 2,6-dichlorobenzamide and dichlobenil in the collection side
solid-to-aqueous solution dichlobenil ratio data for water and hexane were approximately 11 and 4, respectively. The corresponding data for Solvex gloves are ≈0.62 and 0.82, respectively, thus reflecting the general protectiveness of Solvex gloves.

The phenomenon of organic solids producing permeation across glove material was first observed by Fricker and Hardy (1992, 1994), who used a modification of the ASTM permeation cell. Other such data have been published by Bunge and others for methylparaben and 4-cyanophenol (Parks et al. 1997; McCarley and Bunge 2003; Romonchuk and Bunge 2006; Ley and Bunge 2007). The mechanism to explain the results of the present study probably involves the collection medium wetting the material enough to back-permeate to the challenge surface or the production of a wet membrane interior from which some solid is dissolved to then diffuse back to the collection medium compartment. Another possibility is the presence of microholes in the glove material that constitutes a penetration component, but such microholes were not observed by microscopic observation in any of the materials examined. Back-permeation experiments with an empty challenge side showed that Safeskin gloves allowed hexane vapor to be detected in the challenge chamber air, but Solvex gloves did not.

Relative to worker risk assessment for dichlobenil exposure, the allowed daily intake of 500 ng/kg body weight (Hazardous Substances Data Bank 2009) is equivalent to a dose of 35 μg for a 70-kg reference man. If all of this mass is absorbed through the skin with 100% efficiency, then the mass collected in the permeation cell collection solvent should not exceed 35 μg during 8 h. Clearly, Safeskin permeations with hexane collection exceed this threshold, but the water collections and all of the Solvex permeations did not. Because the normalized breakthrough time threshold of 250 ng/cm² was exceeded, hexane was not a valid solvent for Safeskin gloves for 4- and 8-h exposures times in the solid-formulation challenges, nor was it valid for 8-h exposure in the aqueous emulsion challenges. Similarly, hexane was a valid 8-h collection solvent for Solvex gloves in solid-formulation challenges but not for 8-h aqueous emulsion challenges. Water was a valid collection solvent for all challenges, although permeation of dichlobenil was usually detected.

**Conclusion**

Permeation of the herbicide dichlobenil from both concentrated aqueous emulsion and dry solid Casoron 4G through disposable and chemically protective nitrile gloves is reported here for the first time. The permeation results differ with collection solvent, with the amount for water collection being much lower than for hexane collection. The chemically protective glove was permeated the least for each solvent. Hexane was not an adequate collection solvent relative to water for the disposable nitrile glove during 4- or 8-h or for 8-h aqueous emulsion challenges. Hexane solvent was adequate in solid-formulation challenges for the chemically protective glove during 8 h, but not for the 8-h aqueous emulsion challenge. The possible mechanisms to account for the observations were discussed in the previous text.

**Acknowledgements** This project was funded by the UCLA Center for Occupational and Environmental Health and National Institute for Occupational Safety and Health Grant No. OH03754.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

**References**

Ansell Occupational Healthcare (2007) Chemical resistance guide, 8th edn. Ansell, Coshocton

American Society for Testing and Materials (ASTM) (2004) Standard test method for resistance of protective clothing materials to permeation by liquids or gases under conditions of continuous contact, ASTM method F739-99a. In: Annual book of ASTM standards, vol 11. ASTM, West Conshohocken, pp 1299–1309

Chao KP, Lai JS, Lin HC (2007) Comparison of permeation resistance of protective gloves to organic solvents with ISO, ASTM, and EN standard methods. Polym Test 26:1090–1099

Fricker CM, Hardy JK (1992) Protective glove material permeation by organic solids. Am Ind Hyg Assoc J 53:745–750

Fricker CM, Hardy JK (1994) The effect of an alternate environment as a collection medium on the permeation characteristics of solid organics through protective glove materials. Am Ind Hyg Assoc J 55:738–742

Henry NW III, Stull JO (2003) Test methods and standards. In: Anna DH (ed) Chemical protective clothing, 2nd edn. AIHA Press, Fairfax, pp 175–268

Hazardous Substances Data Bank (HSDB) (2009) Dichlobenil. Available at http://toxnet.nlm.nih.gov/cgi-bin/sis/search

Ley EE, Bunge AL (2007) Chemical transport in silicone rubber membranes from pure powders and saturated aqueous solutions. J Memb Sci 292:35–44

McCarley KD, Bunge AL (2003) Absorption into silicone rubber membranes from powders and aqueous solutions. Int J Pharm 250:169–180

Mellstrom GA, Carlsson B, Boman AS (1994) Testing of protective effect against liquid chemicals. In: Mellstrom GA, Wahlberg JE, Maibach HI (eds) Protective gloves for occupational use. CRC Press, Boca Raton, pp 53–77

Parks JM, Cleek RL, Bunge AL (1997) Chemical release from topical formulations across synthetic membranes: infinite dose. J Pharm Sci 86:187–192

Reyes RM (2002) Chemical permeation data purple nitrile. Kimberly-Clark, San Diego

Romonchuk WJ, Bunge AL (2006) Permeation of 4-cyanophenol and methyl paraben from powder and saturated aqueous solution through silicone rubber membranes and human skin. J Pharm Sci 95:2526–2533

United States Environmental Protection Agency (USEPA) (2008) Dichlobenil: pesticide tolerances. Fed Regist 73(167):50563–50570

© Springer