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Permeation of Chemicals through Glove-Box Glove Materials

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June 30, 1994

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Summary

A study of the resistance of two commercially available glove-box gloves to 20 chemicals commonly used in glove boxes has been carried out. The chemicals tested are from nine classes of organic and inorganic compounds: inorganic acids, inorganic bases, inorganic salts, organic acids, alcohols, glycols, halogen compounds, sulfur compounds, and hydrocarbons. The American Society for Testing Materials (ASTM) cell was used to study permeation of volatile organic compounds through the protective clothing materials using air as the collecting medium and flame ionization detector (FID)/gas chromatography for quantitation. For the nonvolatile organic compounds, a modified version of the ASTM cell was used, with isopropanol as the collecting medium and FID/gas chromatography for quantitation. Permeation of inorganic compounds through the elastomeric materials was studied using the ASTM cell with water as the collecting medium and a conductivity meter for quantitation. Hydrofluoric acid and ammonium hydrofluoride are not compatible with glass; therefore, the ASTM cell cannot be used to study these chemicals. A permeation cell made of Teflon was used for this application.

Hypalon provides protection against all the chemicals except trichloroethylene and carbon tetrachloride. Trichloroethylene (TCE) permeated through hypalon at an extremely high rate after only a few minutes of exposure. With carbon tetrachloride, breakthrough occurred in 57 min. The rate of permeation increased rapidly to an alarming rate a few minutes after breakthrough.

Acetic acid permeated through neoprene with a breakthrough time of 6 h, 28 min and a steady-state permeation rate of $33.7 \mu\text{g}/\text{cm}^2\cdot\text{min}$. With ethanol, breakthrough occurred in 3 h, 28 min, and the steady-state permeation rate was $2.68 \mu\text{g}/\text{cm}^2\cdot\text{min}$. Neoprene showed no protection against TCE and carbon tetrachloride. Both chemicals permeated through the elastomer at a very high rate after a few minutes of exposure. Neoprene exposed to sulfuric acid showed a breakthrough time of 50 min. After 5 h of exposure, neoprene dissolved in the acid. Kerosene permeated through neoprene in about 5 h, and the steady-state permeation rate was $0.19 \mu\text{g}/\text{cm}^2\cdot\text{min}$. Neoprene also was tested against a mixture of 90% cutting oil and 10% TCE. Although neoprene showed good resistance against cutting oil, TCE broke through the material in 61 min. The permeation rate reached $10 \mu\text{g}/\text{cm}^2\cdot\text{min}$ after 6 h of exposure. Neoprene showed good protection against all the other chemicals, with no breakthrough occurring before 6 h.

Introduction

Hazardous chemicals usually are handled in various exhaust systems (fume hoods). However, if the toxicity, radioactivity level, or reactivity of the chemical is too great, the ordinary fume hoods cannot be used. In this case, a totally enclosed glove box is preferred. The main feature of a glove box is the total isolation of the interior of the box from the surrounding environment and, therefore, the need to manipulate items in the box by means of full-length gloves sealed into a sidewall of the box.

The need for a flexible material to isolate the operator from the work but still allow ease of manipulation, sensitivity of touch, and a good working life under a wide variety of operating condition, is extremely important. The glove forms the weakest part of the box assembly; therefore, considerable attention should be given to its performance.

In order to evaluate the relative effectiveness of the glove-box gloves constructed of various materials against hazardous chemicals, permeation measurements should be made. Although a significant amount of data is available for the permeation of chemicals through ordinary glove materials, only limited data can be found for glove-box gloves. This project was undertaken to examine the performance of glove-box gloves against the chemicals (pure and mixtures) that are widely used in glove boxes.

Permeation of chemicals through solid barriers occurs in three steps: the permeating species must enter the membrane (known as solution), pass through the membrane (diffusion), and finally evaporate from the downstream surface.

Solubility of chemical in solid describes the ease with which the permeating molecules go into solution within the matrix of the material. Solubility is determined by many things, including the chemical nature of the polymer and permeating species (e.g., hydrogen bonding, dipole interactions) and sieving action (the molecular size and shape of the permeating species are such that the polymer cannot accommodate it).

Diffusion occurs via the movement of individual molecules within the solid barrier. This diffusion process occurs in a series of activated steps or jumps. Molecules come to rest at equilibrium positions and can move if sufficient extra energy is supplied to the region in which the movement occurs. The energy is used to open holes (separate polymer segments) through which the permeating species can pass. The permeation parameters (breakthrough time and steady-state permeation rates) based on this model are therefore dependent on the solubility of the chemical in the membrane, the diffusion coefficient of molecules through the solid, and the thickness of material. Solubility and diffusion coefficient are influenced by temperature and concentration.¹ The variables that influence the permeation parameters of a chemical/protective clothing material pair, therefore, are material thickness, concentration of chemical, and temperature.

As the thickness of the protective clothing material increases, breakthrough time increases and permeation rate decreases.²⁻⁴ Diffusion of molecules through a barrier depends on temperature. As temperature increases, breakthrough time decreases, and permeation rate increases,¹ both exponentially. Permeation of mixtures through protective clothing materials has been studied by a few investigators,⁵⁻⁷ who showed that liquid mixtures can exhibit large, positive synergistic rates. In systems where the solubilities of pure liquids in the elastomer are of the same order of magnitude, the liquids can show permeation enhancement or depression. In systems where the membrane is plasticized strongly by one of the components and weakly by the other,

one component is affected synergetically by the other. The liquid with the smaller permeation rate experiences a permeation enhancement, and the other liquid shows a permeation depression.

Many attempts have been made to predict the effectiveness of protective clothing materials. To analyze the permeation process, diffusion coefficients and solubilities of chemicals in protective clothing materials are needed. Many models have been proposed for estimating these two parameters. Comparisons of measured and predicted values, however, have shown the models to be only marginally accurate. Because of the limitation of the theoretical models, empirical correlations also have been investigated. Southern and Thomas⁸ studied the diffusion of various liquids in natural rubber at 25°C and concluded that the diffusion coefficient depends mainly on the liquid viscosity. Schwoppe and Ried⁹ examined several correlations for diffusion coefficient and solubility. Vahdat¹⁰ studied the diffusion coefficient of chemicals through several protective clothing materials at different temperatures and found that the diffusion coefficients vary linearly (on a log-log scale) with viscosity for each material.

Despite all the correlations and theoretical studies, the best method of ensuring personnel safety is to measure experimentally the permeation rate and breakthrough time of the chemicals through materials. In general, chemical permeation testing requires that a *challenge chemical* be placed in contact with a protective clothing material. The chemical permeates through the material and is collected in an appropriate medium. The method currently used for the evaluation of the permeation of liquids and gases is ASTM F739-91.¹¹ This method uses a glass sampling apparatus that permits either open- or closed-loop testing. In this study, two commercially available glove-box gloves are tested against 20 chemicals at room temperature. The glove materials and chemicals used in the permeation tests were chosen to be representative of those commonly used in glove boxes.

Materials

Two commercially available glove-box gloves were used for the experiments: neoprene (from glove model No. 8N1532, Siebe North Inc.) with a nominal thickness of 0.38 mm (15 mil) and hypalon (from glove model No. 8Y1532, Siebe North Inc.) with a nominal thickness of 0.38 mm (15 mil).

Challenge chemicals were selected based on their degree of relative use in glove boxes at LLNL. Table 1 shows the chemicals used in this investigation. Chemicals were used without additional purification.

Experiment

We used a standard 2-in. ASTM cell¹¹ (Pesce Laboratories, Kennett Square, PA). The cell is constructed of two sections of straight glass pipe, each nominally sized to 51 mm (2 in.) in diameter (see Fig. 1). The volume of the chamber designed to hold the chemical is 45 mL, and the volume of the collecting medium chamber is 100 mL. For each experiment, a 3-in. square section was cut from the elastomer, and its thickness was

measured with a thickness gauge (measurements to the nearest 0.001 in.). The material sample then was conditioned by placing it in a desiccator containing 42 wt% sulfuric acid for a minimum of 24 h. After removal from the desiccator, the sample was clamped in the middle of the cell, and the bolts holding the two chambers together were tightened to a torque of 30 in.-lb with a torque wrench. For organic chemicals, we used an open-loop system (see Fig. 2). Nitrogen with a flow rate of 100 mL/min was passed through the collecting chamber of the cell and was transferred to a gas sampling valve. The 0.25-mL sample loop of the gas sampling valve was purged continuously, and discrete samples were taken for analysis every few minutes.

Analysis was obtained by gas chromatography (Varian 6000, FID, column: 20% PS-2401, 100/120 MR. 20029). The output from the chromatograph was processed by a Varian 402 data system. The minimum detectable permeation rate of acetone observed for this system was $0.05 \mu\text{g}/\text{cm}^2\cdot\text{min}$. Each compound was identified by its retention time and by comparing peak areas to a standard calibration curve generated by injecting known concentrations of the chemical into the gas chromatograph and measuring peak areas.

The specimen test run was terminated after steady-state permeation was obtained or six hours had elapsed with no breakthrough, whichever came first. Triplicate tests were carried out for all chemical/polymer pairs.

A schematic of the permeation measurement system for the inorganic chemicals is shown in Fig. 3. Water was circulated at a rate of 100 mL/min with a Masterflex tubing pump (Model L07015-21 pump head, Cole-Parmer, Chicago, IL). Analysis was obtained by measuring conductivity of the collecting medium (YSI model 33 conductivity meter, Yellow Springs Instrument Company Inc., Yellow Springs, OH). The concentration of chemical in the collecting medium was determined by comparing conductivity meter readings to a standard calibration curve generated by measuring the conductivity of known concentrations of the chemical.

For the nonvolatile chemicals (oils), we used a modified version of the ASTM cell. The sampling chamber of the cell was modified as shown in Fig. 4. The downstream side of the material is washed with a solvent by inserting a syringe through port A of the chamber. Any chemical permeated through the elastomer is dissolved in the solvent and is collected in a vial through port B. The samples are analyzed by gas chromatography. The solvent used in the experiments was isopropanol. Every 10 to 20 minutes, 2.5 mL of isopropanol was injected over the surface of the material.

Hydrofluoric acid and ammonium hydrofluoride are not compatible with glass; therefore, the ASTM cell cannot be used for these chemicals. A permeation cell made of Teflon was used for this application⁶ (see Fig. 5). The internal dimensions of the sampling chamber (lower half of the cell) are 34 mm ID and 50 mm deep; the dimensions of the challenge chamber (top cap) are 34 mm ID and 22 mm deep. Water was circulated at a rate of 100 mL/min through the sampling chamber. The experimental setup is the same as for other inorganic chemicals (see Fig. 3). For our experiment, a 5.4-cm sample was cut. After the weight and thickness of the material were measured, the sample was placed over the O-ring on the base assembly, and the top cap and pressure plate were placed on top and held with three washers and hex nuts. The permeation cell was placed in the system, as shown in Fig. 3, and about 15 mL of chemical was added.

We first compared our experimental data on acetone permeation through neoprene to published ASTM data and observed nearly identical results. We then conducted tests for the permeation of acetone through Teflon and butyl (nylon-coated butyl) materials. Both of these materials are being adopted as ASTM standard materials (in addition to neoprene) in the latest version of ASTM F739.¹¹ The results are similar to the data obtained in the other laboratories participated in the round-robin test of ASTM F739. Once we demonstrated that our experimental setup works, we conducted the permeation study for the glove-box glove materials. Materials, chemicals, and equipment were at room temperature, which varied only slightly (range from 19 to 25°C) over all the experiments. Triplicate tests were carried out for all chemical/glove pairs.

Results

The breakthrough time for each chemical was recorded as the time of the first detection of the component in the collection chamber. For the open-loop system (with nitrogen as the collecting medium), the permeation rate P is calculated as

$$P = \frac{CF}{A} , \quad (1)$$

where

C = concentration ($\mu\text{g}/\text{cm}^3$) of chemical in sampling chamber.

F = flow rate (cm^3/min) of nitrogen.

A = area (cm^2) of material exposed to chemical.

For this study, both the 2-in. ASTM cell and the smaller version (1-in. cell) were used. It has been shown that the two cells are equivalent.¹² The area A is 20 cm^2 for the 2-in. cell and 5 cm^2 for the 1-in. cell. The flow rate was held constant at 100 cm^3/min .

For the closed-loop system, the average permeation rate over a period T_{i-1} to T_i is calculated as follows:

$$P = \frac{V_t(C_i - C_{i-1})}{A(T_i - T_{i-1})} , \quad (2)$$

where

C_i = concentration ($\mu\text{g}/\text{cm}^3$) of chemical in collecting medium at time T_i .

T_i = time (min) at which discrete sample i was removed.

V_t = total volume (cm^3) of the collection medium.

A = area (cm^2) of material exposed to chemical.

The results of the permeation experiments are summarized in Tables 2 and 3. Table 2 summarizes the overall results of the three protective clothing materials challenged by acetone. Table 3 summarizes the results for the two glove-box glove materials challenged by 20 chemicals. The complete results for the individual runs are given in the Appendix.

The results of the experiments for the permeation of acetone through Neoprene, Teflon and Butyl are given in Tables A.1 through A.3, respectively. The results are similar to the data obtained by other laboratories who participated in the ASTM F-23 round-robin tests.

The glove-box gloves were tested against acetic acid, and the results are given in Tables A.4 and A.5. Acetic acid permeated through neoprene with a breakthrough time of 6 h, 28 min and a steady-state permeation rate of $33.7 \mu\text{g}/\text{cm}^2\cdot\text{min}$. No breakthrough was observed for the permeation of acetic acid through hypalon.

The results of experiments for the permeation of ethanol through the two materials are given in Tables A.6 and A.7. The average breakthrough time for ethanol/neoprene system was 3 h, 28 min, and the steady-state permeation rate was $2.68 \mu\text{g}/\text{cm}^2\cdot\text{min}$. No breakthrough was observed for the ethanol/hypalon system.

Both glove-box gloves were tested against trichloroethylene (TCE), and the results are given in Tables A.8 and A.9. TCE permeated through both materials at an extremely high rate after only a few minutes of exposure. The permeation rates were so high that the collecting medium (nitrogen with a flow rate of 100 mL/min) could not remove all the TCE from the collecting side of the cell, and liquid TCE was formed in the chamber.

Carbon tetrachloride permeated both materials at a very high rate (Tables A.10 and A.11). The breakthrough time for the permeation of carbon tetrachloride through neoprene was about 42 min and through hypalon was 57 min. The rate of permeation increased rapidly to an alarming rate a few minutes after breakthrough. Carbon tetrachloride permeated through both materials at such a high rate that the gas chromatograph was overloaded.

The results of experiments for the permeation of 70% nitric acid and 50% nitric acid through neoprene and hypalon are shown in Tables A.12 through A.15. Both materials showed good protection against nitric acid with no breakthrough in 7 h. However, neoprene exposed to 70% nitric acid showed signs of deterioration. Nitric acid in contact with neoprene changed color, indicating chemical reaction with the elastomer. Small pieces of neoprene were also observed in the acid after a few hours of exposure. At the end of experiments, the neoprene specimen were examined. Although no rupture was noticed, the surface of the material in contact with acid was badly deformed.

Tables A.16 and A.17 show the results of permeation tests for hydrochloric acid. No breakthrough was observed in 6 h.

Hypalon showed good resistance against sulfuric acid, with no breakthrough in 6 h (Table A.18). However, the acid permeated the neoprene with a minimum breakthrough time of 50 min (Table A.19), and the permeation rate through the material increased steadily, and after about 5 h, a sudden increase in the rate indicated the disintegration of material.

The glove-box glove materials were tested against phosphoric acid (Tables A.20 and A.21), 10% chromic acid (Tables A.22 and A.23), 5M sodium hydroxide (Tables A.24 and A.25), lactic acid (Tables A.26 and A.27), sewing machine oil (Tables A.28 and A.29), RPM Handy Oil (Tables A.30 and A.31), 10% ammonium hydrofluoride (Tables A.32 and A.33) and 50% hydrofluoric acid (Tables A.34 and A.35). Both materials showed good protection against these chemicals, with no breakthrough in 6 h.

The experimental results for 90% cutting oil/10% TCE are given in Tables A.36 and A.37. It can be seen that hypalon showed no detectable breakthrough, even for contact

times as long as 23 h. However, the neoprene glove showed measurable permeation. The average breakthrough time was about 61 min, and the permeation rate after a total exposure time of 6 h was approximately $10 \mu\text{g}/\text{cm}^2\cdot\text{min}$.

Hypalon showed good protection against kerosene, with no breakthrough in 16 h (Table A.39). Kerosene permeated through neoprene with an average breakthrough time of 5 h, 10 min, and a steady-state permeation rate of $0.19 \mu\text{g}/\text{cm}^2\cdot\text{min}$ (Table A.38).

Both glove-box glove materials showed no detectable breakthrough when exposed to trichloroacetic acid for 6 h. (Tables A.40 and A.41).

Two sets of experiments were performed for the permeation of 90% ethylene glycol/10% nitric acid through the two protective clothing materials: one set using the permeation measurement system for inorganic chemicals (Fig. 3) and a second set using the permeation measurement system for organic chemicals (Fig. 2). Both materials showed good protection against this binary mixture (Tables A.42–A.45).

The results of experiments for the permeation of dimethyl sulfoxide (DMSO) through neoprene and hypalon are presented in tables A.46 and A.47, respectively. Both materials showed good protection against DMSO.

Discussion

Table 3 contains the data for the entire study. Care must be exercised in interpreting these data, which are limited by the duration of the test and the sensitivity of the detection system. A chemical that permeates a material at a low rate such that the lower detection limit is not reached in the total exposure time will yield a zero permeation rate. Table 4 lists the detection limits for the chemicals used in this study. It should be noted that almost every chemical, given enough time, will permeate to some extent. In a practical sense however, a 6-h test gives a good indication of the protection that chemical protective clothing will provide workers. That is why most of the experiments were terminated after steady-state permeation was obtained or 6 h had elapsed with no breakthrough, whichever came first. Some of the permeation tests were run as long as 20 h. One should also understand that specification of the same generic fabric composition and thickness does not ensure comparable resistance to chemical permeation. Therefore, the test results are specific for the particular manufacturer and model number of the test material. In addition, the manufacturing formulation, quality control, batch-to-batch variability, and processing procedures can change without warning.

Standard deviations of the breakthrough time and the steady-state permeation rate demonstrate some variability, but this is believed to be caused by specimen variations rather than variations in the test system. Similar cases have been reported by other investigators.^{13,14} Test specimens were not rigorously inspected for microscopic defects such as pinholes. There is also a possibility that chemical protective clothing material may have a fractured surface that is pitted. These surface defects could be responsible for part of the observed variations in experimental data.

If a breakthrough criterion of at least 1 h for general-purpose protective clothing for handling hazardous chemicals is taken as a reference, then both neoprene and hypalon gloves are unsafe for handling TCE and carbon tetrachloride. It should be noted that

carbon tetrachloride is a confirmed carcinogen, and TCE is a suspected carcinogen. Neither of these gloves is suitable for handling these chemicals.

Recent publications⁵ have indicated that binary mixtures of solvents change the properties of each component to either enhance or depress permeation. Two binary mixtures were studied here: 90% ethylene glycol/10% nitric acid and 90% cutting oil/10% TCE.

The mixture of ethylene glycol and nitric acid does not break through either neoprene or hypalon, but the mixture of cutting oil and TCE does break through neoprene. Pure TCE permeates through neoprene at an extremely high rate, but adding cutting oil reduces the rate considerably. Further, breakthrough time increases, from 6 min for pure TCE to 61 min for the mixture. Cutting oil did not break through neoprene. The binary mixture does not break through hypalon even though pure TCE breaks through hypalon in 9 min and has a very high permeation rate.

No data are available in the literature for hypalon, but neoprene has been tested against many chemicals.¹⁵ Neoprene permeation data are available for all of the chemicals reported in this study except for chromic acid, sewing machine oil, RPM oil, cutting oil, and the mixture of cutting oil and TCE. Comparison of our permeation data for neoprene glove-box glove material and published data for neoprene glove materials is given in Table 5. The results obtained here are in qualitative agreement with the published data.

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Table 1. Challenge chemicals.

Chemical	Grade	Supplier
Hydrofluoric acid	48–51%	Baker, Inc., Phillipsburg, NJ
Hydrochloric acid	37.2% assay	Baker, Inc., Phillipsburg, NJ
Nitric acid	70.7% assay	Baker, Inc., Phillipsburg, NJ
Lactic acid	85–90% GR assay	EM Science, Gibbstown, NJ
Acetic acid	99.7% assay	Fisher Scientific, Fairlawn, NJ
Chromic acid	From chromium trioxide crystals	Baker, Inc., Phillipsburg, NJ
Sulfuric acid	96.6% assay	Baker, Inc., Phillipsburg, NJ
Sodium hydroxide	Analytical reagent	Mallinckrodt
Ammonium hydrofluoride	Technical grade	Baker, Inc., Phillipsburg, NJ
Kerosene	—	Quantum Chemical Co., Cincinnati, OH
Ethyl alcohol	200 proof	Neslab Instrument Co.
Ethylene glycol	Laboratory grade	Tacony Co.
Sewing machine oil	Sew-rite precision	Mallinckrodt
Carbon tetrachloride	Analytical reagent	Chevron, San Francisco, CA
RPM Handy Oil	—	Sigma Chemical, St. Louis, MO
Trichloric acid	100% assay	Baker, Inc., Phillipsburg, NJ
Cutting oil	R&O 32	Texaco
Phosphoric acid	85.8% assay	Baker, Inc., Phillipsburg, NJ
Dimethyl sulfoxide	Reagent	Baker, Inc., Phillipsburg, NJ

Table 2. Summary of permeation results for acetone.

Material	Breakthrough time (min)	Steady-state permeation rate ($\mu\text{g}/\text{cm}^2\cdot\text{min}$)
Neoprene	8.4	235
Teflon	5.6	0.10
Butyl	210	0.32

Table 3. Summary of permeation results.

Chemical	Material	Breakthrough time	Steady-state permeation rate ($\mu\text{g}/\text{cm}^2\cdot\text{min}$)
Acetic acid	Neoprene	6.47 ± 0.18 h	33.70 ± 0.90
	Hypalon	>7 h	—
Ethanol	Neoprene	3.47 ± 0.60 h	2.68 ± 0.80
	Hypalon	>7 h	—
Trichloroethylene	Neoprene	6 ± 1.6 min	Very high
	Hypalon	9 ± 3.0 min	Very high
Carbon tetrachloride	Neoprene	42 ± 5 min	Very high
	Hypalon	57 ± 11 min	Very high
Nitric acid (70%)	Neoprene	>7 h	—
	Hypalon	>7 h	—
Nitric acid (50%)	Neoprene	>6 h	—
	Hypalon	>6 h	—
Phosphoric acid	Neoprene	>6 h	—
	Hypalon	>7 h	—
Hydrochloric acid	Neoprene	>6 h	—
	Hypalon	>6 h	—
Sulfuric acid	Neoprene	1.88 ± 1.0 h	Dissolved
	Hypalon	>6 h	—
Chromic acid (10%)	Neoprene	>6 h	—
	Hypalon	>6 h	—
Sodium hydroxide (5M)	Neoprene	>6 h	—
	Hypalon	>6 h	—
Lactic acid	Neoprene	>6 h	—
	Hypalon	>6 h	—
Sewing machine oil	Neoprene	>6 h	—
	Hypalon	>6 h	—
RPM Handy Oil	Neoprene	>6 h	—
	Hypalon	>6 h	—
Ammonium hydrofluoride (10%)	Neoprene	>6 h	—
	Hypalon	>6 h	—
Hydrofluoric acid	Neoprene	>6 h	—
	Hypalon	>6 h	—
Kerosene	Neoprene	5.17 ± 0.72 h	0.19 ± 0.07
	Hypalon	>16 h	—
90% ethylene glycol/ 10% nitric acid	Neoprene	>6 h	—
	Hypalon	>6 h	—
90% cutting oil/ 10% TCE	Neoprene	61 ± 16 min	11.7 ± 2.5
	Hypalon	>6 h	—
Trichloroacetic acid	Neoprene	>6 h	—
	Hypalon	>6 h	—
Dimethyl sulfoxide	Neoprene	>6 h	—
	Hypalon	>12 h	—

Table 4. Detection limits for chemicals.

Chemical	Detection limit (ppm)
Ethanol	1
Acetic acid	40
Carbon tetrachloride	3
Trichloroethylene	1
Nitric acid	1
Hydrochloric acid	1
Phosphoric acid	2
Lactic acid	10
Sodium hydroxide	1
Chromic acid	10
Sulfuric acid	1
RPM Handy Oil	50
Sewing machine oil	10
Trichloroacetic acid	5
Hydrofluoric acid	1
Ammonium bifluoride	5
Cutting oil	50
Kerosene	5
Ethylene glycol	1

Table 5. Comparison of experimental and published permeation data for neoprene glove-box glove material.

Chemical	Breakthrough time (h)		Permeation rate (g/cm ² .min)	
	Literature	Experiment	Literature	Experiment
Lactic acid	>6	>6	—	—
Kerosene	>6	5.17	—	0.19
Phosphoric acid	>6	>6	—	—
Trichloroethylene	0.05	0.13	>566	Very high
Sodium hydroxide	>6	>6	—	—
Dimethyl sulfoxide	>6	>6	—	—
Ethanol	1.5, 9.25	3.47	0.90—8.9	2.68
Carbon tetrachloride	0.24	0.70	1998	Very high
Sulfuric acid	1.17	1.88	—	Dissolved
Acetic acid	7.00	6.47	—	33.70
Nitric acid	2.67	>6	—	—
Hydrochloric acid	>6	>6	—	—
Hydrofluoric acid	1.00	>6	—	—

Figure 1. ASTM F23 chemical permeation cell.

Figure 2 Open-loop permeation setup.

Figure 3. Permeation setup for inorganic chemicals.

Figure 4. Modified ASTM cell for nonvolatile chemicals.

Figure 5. Permeation cell used for hydrofluoric acid and ammonium hydrofluoride: (a) cross section of permeation cell; (b) exploded view of cell.

Appendix

Permeation Results

<u>Table</u>	<u>Permeation results for</u>
A.1–A.3	Acetone
A.4–A.5	Acetic acid
A.6–A.7	Ethanol
A.8–A.9	Trichloroethylene
A.10–A.11	Carbon tetrachloride
A.12–A.13	Nitric acid (70%)
A.14–A.15	Nitric acid (50%)
A.16–A.17	Hydrochloric acid
A.18–A.19	Sulfuric acid
A.20–A.21	Phosphoric acid
A.22–A.23	Chromic acid (10%)
A.24–A.25	Sodium hydroxide (5M)
A.26–A.27	Lactic acid
A.28–A.29	Sewing machine oil
A.30–A.31	RPM Handy Oil
A.32–A.33	Ammonium hydrofluoride (10%)
A.34–A.35	Hydrofluoric acid
A.36–A.37	90% cutting oil/10% TCE
A.38–A.39	Kerosene
A.40–A.41	Trichloroacetic acid
A.42–A.45	90% glycol/10% nitric acid
A.46–A.47	Dimethyl sulfoxide

Table A.1
Permeation of acetone through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.051	22	6	0.02	212
2	0.41	0.052	22	8	0.17	267
3	0.41	0.052	19	10	0.07	225

Average permeation rate: 235 ± 29 µg/cm²·min.

Average breakthrough time at 0.1 µg/cm²·min: 8.4 ± 1.4 min.

Table A.2
Permeation of acetone through Teflon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.10	0.0108	22	8	0.05	0.10
2	0.10	0.0109	19	6	0.04	0.05
3	0.10	0.0108	21	4	0.02	0.13
4	0.10	0.0110	22	4	0.09	0.08
5	0.10	0.0109	22	6	0.02	0.13

Average permeation rate: 0.10 ± 0.02 µg/cm²·min.

Average breakthrough time: 5.6 ± 0.8 min.

Table A.3
Permeation of acetone through butyl.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	—	22–23	2:53	0.04	0.407
2	0.43	—	21–22	4:10	0.04	0.203
3	0.41	—	23	1:28	0.019	0.350

Average permeation rate: 0.32 ± 29 µg/cm²·min.

Average breakthrough time: 2 h, 50 min.

Table A.4
Permeation of acetic acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.055	23	6:16	—	32.68
2	0.40	0.055	21	6:32	—	34.35
3	0.43	0.058	21–25	6:37	—	34.27

Average permeation rate: 33.70 µg/cm²·min.

Average breakthrough time: 6 hr, 28 min.

Table A.5
Permeation of acetic acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.058	21-22	>7	—	—
2	0.43	0.058	21-25	>24	—	—
3	0.41	0.056	21-24	>8	—	—

Table A.6
Permeation of ethanol through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.057	23	3:25	—	2.38
2	0.41	0.056	20-25	4:05	—	1.77
3	0.41	0.054	23	2:40	—	3.68
4	0.41	0.058	23	3:44	—	2.90

Average permeation rate: 2.68 µg/cm²·min.

Average breakthrough time: 3 h, 28 min.

Table A.7
Permeation of ethanol through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.057	21-23	>6:30	—	—
2	0.41	0.055	22-24	>16	—	—
3	0.41	0.060	22	>8	—	—

Table A.8
Permeation of TCE through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.0559	21	5	High	—
2	0.41	0.0574	21	8	High	—
3	0.43	0.0569	22	6	High	—

Average breakthrough time: 6 min.

Table A.9
Permeation of TCE through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.46	0.0607	25	7	High	—
2	0.46	0.0613	24	7	High	—
3	0.41	0.0574	21	13	High	—

Average breakthrough time: 9 min.

Table A.10
Permeation of carbon tetrachloride through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0564	24	25	24	High
2	0.43	0.0576	24	47	106	High
3	0.43	0.0546	23	54	62	High

Average breakthrough time: 42 min.

Table A.11
Permeation of carbon tetrachloride through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.48	0.0675	24	69	32	High
2	0.43	0.0618	24	47	15	High
3	0.43	0.0574	23	54	45	High

Average breakthrough time: 57 min.

Table A.12
Permeation of 70% nitric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.0574	23	>7	—	—
2	0.41	0.0541	22	>7	—	—
3	0.41	0.0570	22	>7	—	—

Table A.13
Permeation of 70% nitric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.46	0.0637	21	>7	—	—
2	0.48	0.0655	21	>7	—	—
3	0.51	0.0662	19	>7	—	—

Table A.14
Permeation of 50% nitric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.46	0.0612	22	>6	—	—
2	0.46	0.0588	23	>6	—	—
3	0.41	0.0552	23	>6	—	—

Table A.15
Permeation of 50% nitric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.46	0.0654	23	>6	—	—
2	0.51	0.0709	23	>6	—	—
3	0.48	0.0671	23	>6	—	—

Table A.16
Permeation of hydrochloric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.41	0.0571	23	>6	—	—
2	0.51	0.0621	23	>6	—	—
3	0.48	0.0637	23	>6	—	—

Table A.17
Permeation of hydrochloric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.48	0.0659	23	>6	—	—
2	0.48	0.0692	23	>6	—	—
3	0.48	0.0658	23	>6	—	—

Table A.18
Permeation of sulfuric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.51	0.0666	23	>6	—	—
2	0.48	0.0658	23	>6	—	—
3	0.53	0.0704	21	>6	—	—

Table A.19
Permeation of sulfuric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.46	0.0611	23	1:30	—	Dissolved
2	0.48	0.0643	23	0:50	—	Dissolved
3	0.46	0.0591	22	2:50	—	Dissolved

Table A.20
Permeation of phosphoric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.46	0.0574	19	>7	—	—
2	0.43	0.0609	19	>7	—	—
3	0.46	0.0692	23	>6	—	—

Table A.21
Permeation of phosphoric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.48	0.0659	20-24	>6	—	—
2	0.41	0.0577	20-24	>6	—	—
3	0.41	0.0567	23	>6	—	—

Table A.22
Permeation of 10% chromic acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.53	0.0720	23	>6	—	—
2	0.60	0.0812	23	>6	—	—
3	0.48	0.0683	23	>6	—	—

Table A.23
Permeation of 10% chromic acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.40	0.0541	23	>6	—	—
2	0.46	0.0583	23	>6	—	—
3	0.41	0.0557	23	>6	—	—

Table A.24
Permeation of sodium hydroxide (5M) through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.45	0.0646	22	>6	—	—
2	0.53	0.0735	22	>6	—	—
3	0.58	0.0810	22	>6	—	—

Table A.25
Permeation of sodium hydroxide (5M) through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.38	0.0524	22	>6	—	—
2	0.43	0.0575	22	>6	—	—
3	0.38	0.0529	22	>6	—	—

Table A.26
Permeation of lactic acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.51	0.0697	22	>6	—	—
2	0.59	0.0807	21	>6	—	—
3	0.59	0.0817	21	>6	—	—

Table A.27
Permeation of lactic acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.41	0.0564	23	>6	—	—
2	0.45	0.0623	23	>6	—	—
3	0.43	0.0699	23	>6	—	—

Table A.28
Permeation of sewing machine oil through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (μg/cm ² ·min)	Steady-state permeation rate (μg/cm ² ·min)
1	0.53	0.0682	23	>6	—	—
2	0.52	0.0694	23	>6	—	—
3	0.53	0.0682	22	>6	—	—

Table A.29
Permeation of sewing machine oil through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.51	0.0710	23	>6	—	—
2	0.62	0.0821	22	>6	—	—
3	0.62	0.0839	22	>6	—	—

Table A.30
Permeation of RPM Handy Oil through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0573	21	>6	—	—
2	0.38	0.0528	21	>6	—	—
3	0.43	0.0573	21	>6	—	—

Table A.31
Permeation of RPM Handy Oil through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.55	0.0758	21	>6	—	—
2	0.57	0.0776	21	>6	—	—
3	0.61	0.0835	21	>6	—	—

Table A.32
Permeation of 10% ammonium hydrofluoride through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.51	0.0696	24	>16	—	—
2	0.48	0.0673	22	> 6	—	—
3	0.51	0.0706	23	>16	—	—

Table A.33
Permeation of 10% ammonium hydrofluoride through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.51	0.0696	24	>16	—	—
2	0.48	0.0673	22	> 6	—	—
3	0.51	0.0706	23	>16	—	—

Table A.34
Permeation of 50% hydrofluoric acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0585	21	>6	—	—
2	0.43	0.0603	23	>6	—	—
3	0.41	0.0568	23	>6	—	—

Table A.35
Permeation of 50% hydrofluoric acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.52	0.0714	22	>6	—	—
2	0.51	0.0701	22	>6	—	—
3	0.41	0.0568	23	>6	—	—

Table A.36
Permeation of 90% cutting oil/10% TCE through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.44	0.0604	20	1:20	0.31	9
2	0.38	0.0517	24	0:52	0.43	14
3	0.37	0.0502	22	0:53	0.31	12

Table A.37
Permeation of 90% cutting oil/10% TCE through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.51	0.0700	20	>23	—	—
2	0.41	0.0620	20	>8	—	—
3	0.44	0.0620	23	>8	—	—

Table A.38
Permeation of kerosene through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h:min)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0584	22	5:15	0.02	0.24
2	0.43	0.0585	—	4:25	0.04	0.14
3	0.48	0.0634	22	5:51	0.05	—

Table A.39
Permeation of kerosene through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0590	22	> 6	—	—
2	0.43	0.0604	—	>16	—	—
3	0.46	0.0632	—	>16	—	—

Table A.40
Permeation of trichloroacetic acid through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.38	0.0507	21-23	>6	—	—
2	0.51	0.0664	21	>6	—	—
3	0.45	0.0612	21	>6	—	—

Table A.41
Permeation of trichloroacetic acid through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.48	0.0643	24	>18	—	—
2	0.46	0.0642	23	> 6	—	—
3	0.43	0.0606	21	> 6	—	—

Table A.42
Permeation of 90% ethylene glycol/10% nitric acid through neoprene (nitric acid data).

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.48	0.0676	20	>6	—	—
2	0.37	0.0520	22	>6	—	—
3	0.48	0.0660	20	>6	—	—

Table A.43
Permeation of 90% ethylene glycol/10% nitric acid through hypalon (nitric acid data).

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.47	0.0662	23	>15	—	—
2	0.48	0.0660	20	> 6	—	—
3	0.41	0.0565	23	>16	—	—

Table A.44
Permeation of 90% ethylene glycol/10% nitric acid mixture through neoprene (ethylene glycol data).

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.43	0.0578	22	>6	—	—
2	0.41	0.0560	22	>6	—	—
3	0.45	0.0618	24	>6	—	—

Table A.45
Permeation of 90% ethylene glycol/10% nitric acid mixture through hypalon
(ethylene glycol data).

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.0556	24	>6	—	—
2	0.41	0.0565	24	>6	—	—
3	0.41	0.0558	24	>6	—	—

Table A.46
Permeation of DMSO through neoprene.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.46	0.0613	24	> 6	—	—
2	0.38	0.0518	25	>10	—	—
3	0.48	0.0611	23	> 6	—	—

Table A.47
Permeation of DMSO through hypalon.

Run no.	Thickness (mm)	Weight/area (g/cm ²)	Temperature (°C)	Breakthrough time (h)	Permeation rate at breakthrough (µg/cm ² ·min)	Steady-state permeation rate (µg/cm ² ·min)
1	0.41	0.0557	24	>14	—	—
2	0.43	0.0593	24	>12	—	—
3	0.48	0.0657	24	>17	—	—

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