Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

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To cite this article: Jimmy L. Perkins & Kim C. Rainey (1997) The Effect of Glove Flexure on Permeation Parameters, Applied Occupational and Environmental Hygiene, 12:3, 206-210, DOI: 10.1080/1047322X.1997.10389489

To link to this article: https://doi.org/10.1080/1047322X.1997.10389489

The Effect of Glove Flexure on Permeation Parameters

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Selection of gloves and other articles of chemical protective clothing (CPC) based on their performance against chemical permeation is the most common approach to the control of skin permeation of toxicants. However, there are several factors that can affect the efficacy of CPC which are not considered in the typical permeation test. These include temperature variations, intermittent use and reuse, thickness variations, and tool use. In this article the effects of hand flexure on permeation parameters are reported. Polyvinylchloride (PVC) or neoprene gloves were exposed to heptane or acetone and a human hand provided the flexing motion at average rates of about 30 or 50 flexes per minute for periods of up to 2 hours. A static or no flex condition was also tested as baseline. Permeation was assayed through weight loss by weighing together the test system (gloves and test cell) at periodic intervals. Results showed an effect of flex on permeation parameters for both polymers. While there was a statistically significant difference in both of the flex results (low or high) versus the no flex condition, there was no difference in the two flex levels. However, for the PVC system there was a clear trend of increasing permeation from no to low to high flex results. It is concluded that glove flexing does affect permeation behavior; however, the flexing conditions used in this experiment probably represent a near worst-case scenario for these effects. PERKINS, J.L.; RAINEY, K.C.: THE EFFECT OF GLOVE FLEXURE ON PERMEATION PARAMETERS. APPL. OCCUP. ENVIRON. HYG. 12(3):206–210; 1997. © 1997 AIH.

Generally, gloves and other articles of chemical protective clothing (CPC) are selected based on their permeation performance. There are a number of other factors that can be considered in the selection process, but often data are not available.[1] These factors include cut and tear resistance, heat stress, sizing, worker acceptability, manufacturer's quality control, dexterity, and tactility.

It is also important to note that there are a number of factors that affect the permeation process which are not part of the usual permeation test methods.[2,3] These test methods examine permeation under steady-state conditions and under relatively constant conditions of temperature, humidity, and other environmental factors. However, conditions in actual field use are very unlikely to be similar to those found in the laboratory. Thus, laboratory permeation tests only serve as an index of glove performance. Factors that can affect the permeation of a substance through a glove include temperature,[4] garment thickness,[5] frequency of use in the field,[6–8] and the use of tools.[9] In this study, the question of whether simple flexing of a glove could have an effect on permeation was examined.

Materials and Methods

The overall method represents a modification of ASTM F 1407-92. In the 1407 method a small aluminum test cell is used to hold a sample of the CPC. Permeation is assayed using a balance to periodically weigh the entire test system. A seal must be formed between the test specimen and the two faces of the aluminum cell. In the current method, permeation through the entire glove was measured by immersing a gloved hand into a large glass jar and sealing the glove cuff to the jar at its rim. The hand, but not the glove, was removed for periodic weighing of the system. Further details follow. All experiments were performed under a hood.

Materials

GLOVES AND PERMEANTS. Pioneer neoprene gloves (style N54, unsupported, 30 mil or 0.076 cm thickness) and Pioneer polyvinylchloride (PVC) gloves (style V20, unsupported, 20 mil or 0.051 cm thickness) were used. The neoprene gloves were tested against acetone and the PVC gloves against heptane. These chemical and glove combinations were chosen to achieve a breakthrough time that would yield a reasonable test period.

TEST CELL. A special test cell was designed from a 1-gallon, wide-mouth jar. The cell allowed a gloved human hand to be submerged into the acetone or heptane within the jar. Thus, flexing of the hand could occur. The test cell contained 2 L of the solvent.

The actual gloved hand was composed of several layers. These are shown in Figure 1. On the outside was the test glove. Inside this was a Normark® stainless steel/synthetic woven mesh glove. The purpose of this glove was to provide space for air movement and prevent stagnation. Next closest to the hand was a North Silvershield® glove, which was used to protect the employee's hand from permeation of the acetone or heptane. Attached to each finger of the Silvershield glove was a 6-inch (15-cm) length of 1-mm inside diameter flexible tube. These five tubes were joined to a central tube leading to a pump. The pump supplied air at a rate of 15 L/min. The ends of the tubes were open at the fingertips; thus air flowed through the tubes and then out through the glove cuff. This minimized the accumulation of permeated solvent. Accumulation of permeated solvent would impede the overall permeation process and thus add an additional uncontrolled variable to the experiment. Finally, closest to the hand was an Edmont

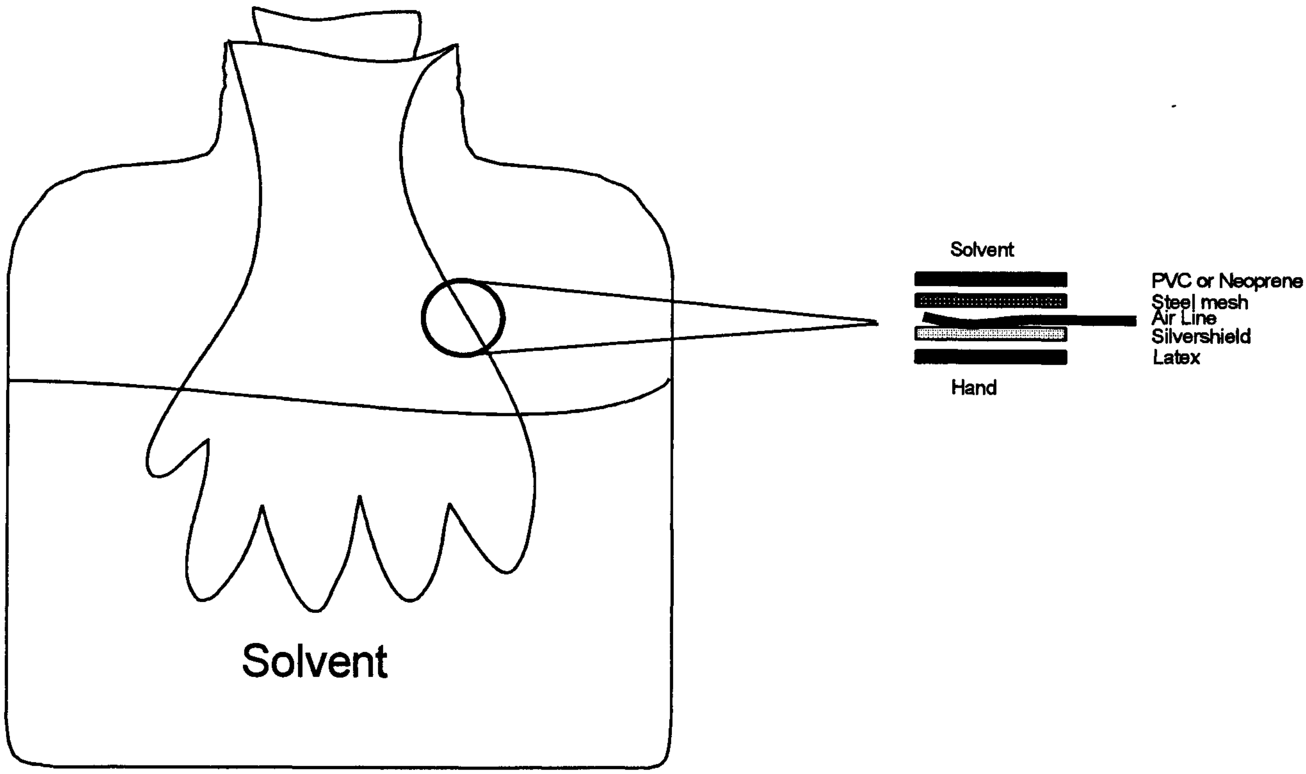

FIGURE 1. Depiction of the test system and detail of glove layering showing location of air lines.

surgeon's rubber latex exam glove. The purpose of this glove was to prevent perspiration from entering the system.

Methods

SEAL. The four-layered, gloved hand was inserted into the 1-gallon test cell. One inch (2.54 cm) of the PVC glove or 1.5 inches of the neoprene glove was then folded back around the lip of the test cell opening. Several layers of Teflon® tape were placed on the folded-back portion and then a threaded metal band was screwed over the folded-back portion, resulting in a tight seal. This procedure secured the test glove and restricted solvent from escaping the test cell by means other than permeation through the PVC or neoprene glove.

AIR SUPPLY. Purge air was supplied to the glove system at a rate of 15 L/min through the tubing attached to the Silvershield glove. It was calculated that this flow of air would keep the permeant's concentration below 2 percent of its saturated concentration (240,000 ppm for acetone and 53,000 ppm for heptane at 25°C). These calculations were based on the expected steady-state permeation rates and ideal mixing conditions. The air was supplied via flexible Tygon® tubing.

TEMPERATURE CONTROL. The temperature was controlled in the range of 24° to 26°C. A thermometer was placed within the liquid solvent. If the temperature reached 25.5°C, the system was cooled by placing the test cell on a frozen Freezerbrick® without interrupting the test until the temperature was reduced to 24°C.

PROCEDURE. Three types of tests were run: a static test with no flexing, a 1-minute flex, and a 5-minute flex. In the static test a latex-gloved hand was inserted into the glove system. Once the glove system was submerged in the solvent, the latex-gloved hand was removed for the remainder of the test, but the remaining glove assembly was fully extended. The purge air flowed during these static tests. Once the latex-covered hand was withdrawn from the system, the system was placed on the balance and allowed to stabilize for 15 seconds. At that point the first reading was made. The system remained on the balance for the remainder of these tests and readings were made every minute.

For the 1-minute flex the latex-covered hand was placed into the system and flexing occurred every second for 1 minute, or 60 flexes. To weigh the system, the Tygon tubing trunk line was detached near the top of the glove, the system was placed on the balance, the balance was allowed to stabilize, and the weight was recorded. The purge air flow was off for only about 15 seconds. The tubing was then reattached to the system and the system removed from the balance, but flexing did not begin nor was the hand inserted until 1 minute had elapsed from the time the flexing ended. This process was repeated for a total of 1 hour for the PVC–heptane and 2 hours for the neoprene–acetone combination.

For the 5-minute flex the process was similar to that of the 1-minute flex except that the flexing period was extended to 5 minutes. Also for the PVC runs, which lasted 1 hour, the rest and weighing period was 1 minute, but for the acetone–neoprene 2-hour runs, the rest and weighing period was 2 minutes. All tests were run in triplicate.

An A & D electronic balance (capacity 3100 g, readability 0.01 g) was used to weigh the system. Calibration was checked

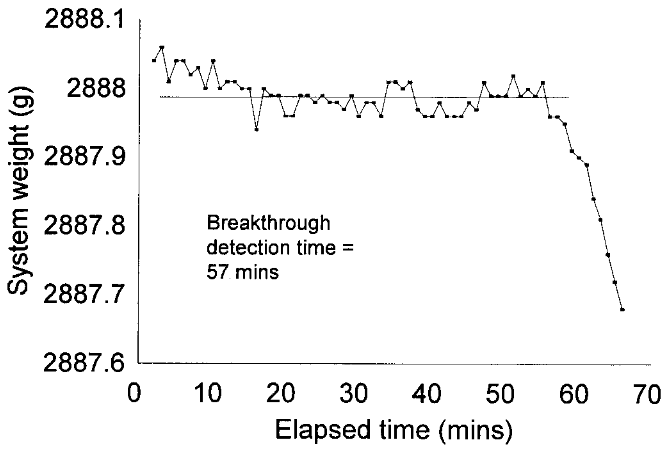

FIGURE 2. Elapsed time versus system weight for a replicate of the static acetone–neoprene test. Only 70 of the 120 minutes are shown to clearly indicate how breakthrough detection time was determined.

TABLE 1. Steady-State Permeation Rates and Breakthrough Detection Times

Combination	Action	SSPR	BT
PVC–heptane	Static	118	13
		74	11
		103	9
	Flex (1 minute)	133	8
		133	5
		133	5
	Flex (5 minutes)	162	6
		147	6
		147	7
Neoprene–acetone	Static	130	57
		130	55
		110	60
	Flex (1 minute)	151	46
		171	45
		161	43
	Flex (5 minutes)	151	43
		171	49
		161	41

SSPR = steady-state permeation rate ($\mu g/min/cm^2$); BT = breakthrough detection time (minutes).

prior to and after each test run by weighing a 1-g standard. The system consisted of the test cell, the solvent, the thermometer, the test glove, the metal band, the steel mesh glove, the tubing, and the Silvershield glove.

Data Reduction

Breakthrough detection time was determined visually by examining a graph of weight versus time. Figure 2, a replicate of the static neoprene–acetone test, is shown as an example. A best-fit line was drawn approximately through the early data points, and the first point after which the weight values dropped below this line and continued on a downward trend was considered to be the breakthrough detection time. Before this time, fluctuations represent the random error or noise in the test.

The steady-state permeation rate was determined from the slope of the weight versus time line. In Figure 2 the entire test is not shown; however, the last 5 minutes of the curve indicate, to the eye, that the test is beginning to approach steady state. However, one cannot be sure of this by visual examination alone, as subtle changes in slope may be occurring. In this replicate it was at least 25 more minutes before steady state occurred. (Note that these additional minutes are not shown in order to preserve the scale that demonstrates the noise.) Thus a regression analysis was performed to determine that the curve had become linear. The number of data points used in the regression analysis varied depending on how often weight readings were taken (i.e., the total time period used in the regression remained about constant). In the case of the static test, approximately 20 to 25 values were used. In the case of the 1-minute flex tests, the number of values varied from approximately 10 to 14, whereas for the 5-minute flex test the number of values varied from three to six. In all cases the correlation coefficients were 0.999.

The steady-state permeation rate (SSPR) calculations require knowledge of the slope from the above regressions and the exposed glove area. The latter was determined as follows. First the entire glove was weighed. A 1 × 3-inch (2.5 × 7.5-cm) strip of the glove was then carefully cut away. This strip was weighed and the polymer weight per surface area was calculated. This surface density was applied to the entire glove weight to yield the glove surface area. The area of the cuff that was not exposed (see earlier description) was then subtracted. This yielded the exposed area. Although some of this area was not exposed to liquid, it was assumed that the vapor in the cell would have reached saturation very rapidly. Previous work has shown that saturated vapor permeation and liquid permeation are equivalent.[10] Therefore it was assumed that all glove areas in the cell had equal exposure.

Results and Discussion

The results of all tests are shown in Table 1. Although the method used in these experiments is not an American Society for Testing and Materials standard method, it is based on the weight loss method (F 1407-92).[3] While results derived from method 1407 for the combinations tested here could not be found, some results are available for method F 739-91.[2] The neoprene model was tested against acetone by Nelson *et al.*[11] They found a breakthrough detection time of 32 minutes and an SSPR of 170 $\mu g/cm^2/min$. These results compare favorably to static results reported here (55 to 60 minutes and 110 to 130 $\mu g/cm^2/min$ in the static tests), particularly since the gloves they used were thinner (0.7 versus 0.76 cm). Also, because their work was completed in 1981, recipe changes may have been made to the product since then. No other results could be found for the combinations used in these tests.[13]

In a typical test the initial system weight was about 2700 to 2800 g. Those tests involving heptane lost about 3 to 4 g for the 1-hour test, while for acetone the loss was about 6 to 9 g for the 2-hour test. Measurements were made to the nearest 0.01 g so that the results were not affected by the readability, reproducibility, or capacity of the balance.

A later study showed that most of the solvent loss could be accounted for by collecting the permeant inside the glove.[12] In that study, using the same experimental setup, a glove made from charcoal cloth was inserted next to the exposed glove. The charcoal cloth glove was used to adsorb vapor that permeated the exposed glove. Thus any difference in the weight loss from the system and the vapor mass found on the charcoal cloth could be due to ineffectiveness of the seal at the top of the cell or to vapor permeating the exposed glove but not being captured by the charcoal. In three replicates an average of 9 percent of the weight loss could not be accounted for by the charcoal assay. Therefore the stated SSPRs may be about 9 percent too high. This also may account for some of the difference in these data versus those of Nelson *et al.*[11]

It can be seen that for PVC–heptane there is a general trend toward decreasing breakthrough time and increasing steady-state permeation rate with flex. For the neoprene–acetone combination it appears that flex had an effect versus static, but there appears to be no difference in the 1-minute and 5-minute flex runs. An analysis of variance indicated that there was a statistically significant difference between the flex runs and the static run. However, there was no significant difference between the 1-minute and 5-minute flex runs for either combination.

The results may raise a question as to whether small differences in the experimental conditions between the static versus flex tests might have affected results. However, there are two pieces of evidence to the contrary. First, for the PVC–heptane results, while there is no significant difference in 1-minute and 5-minute flex, there did appear to be a trend from static to 1-minute to 5-minute flex results. Second, during both static runs and the static periods of the flex tests (the 1- or 2-minute periods of weighing and rest), conditions were identical. During these periods the glove systems did not collapse and it appeared that air flow was good throughout the glove and should have prevented any impedance of permeation. Thus, it is suspected that the experimental effects seen are due to flex and not to the test system.

The increase in the number of flexes in the 5-minute versus the 1-minute tests may not have been enough to cause a significant difference in these two test results. For the PVC–heptane system there was 66 percent increase in flexing (1800 to 3000 flexes). For the neoprene–acetone system the increase in flexes was smaller, 41 percent (3600 to 5100 total flexes). On the other hand, the number of flexes conducted in the 5-minute period is extreme relative to actual use conditions. It is hard to imagine a job that would require this much movement. Thus these tests probably represent the extreme in terms of actual field conditions, but do demonstrate that flexing alone can have an effect on permeation results.

PVC is known to contain up to 50 percent plasticizer to make it flexible, and therefore it is subject to considerable change of properties during extreme permeation tests. During the PVC–heptane runs the gloves became stiff by the end of the 1-hour period. This is probably due to the loss of plasticizer from the PVC system. In two of the 5-minute flex runs (the first two listed in Table 1), a small amount of liquid was observed inside the glove at the end of the test. Holes were found in both of these gloves. This small amount of liquid would have remained in the system during the weighing procedure and thus would not have been counted as permeated solvent. Any evaporation from the drops prior to the end of the test was apparently small as the three SSPR results for this treatment (Table 1) are very similar. Whether the holes affected the results in a meaningful manner or not, the creation of holes in the high flex experiments indicates the importance of flex on glove efficacy.

The change in permeability with flex cannot be accounted for by flex-induced thickness changes alone. For example, the SSPR for the static PVC experiments is about 50 percent smaller than for the high flex experiments. A proportional decrease in thickness throughout the glove would account for this, but it is likely that the effect of flex occurred over only a small portion of the gloves. Thus the induced thickness changes would have had to have been great. Another possibility is that the flexing motion breaks molecular attractions between polymer chains, thus opening larger spaces for permeants. Finally, for PVC, the loss of plasticizer from the glove may be increased by the flexing action. This may be a result of broken polymer chain interactions that allow the permeant to more intimately contact and solubilize the plasticizer molecules.

Conclusions and Recommendations

It is concluded that physical movement as simple as glove flexure may have an effect on overall permeation results. While the results found here showed that flexing alone had a significant effect on permeation parameters, the effect is relatively small in the overall scheme of things. Other variables such as temperature, thickness variability, and intermittent use are probably more important than flexing alone. Nevertheless, flexing along with these other variables constitutes an important consideration for the industrial hygienist. Thus any attempt to ascertain the actual performance of CPC in the field seems justified.

Acknowledgments

The authors thank Mr. John Veros of Pioneer for donation of the gloves. Ms. Rainey was supported by a National Institute for Occupational Safety and Health training grant (5 T-42 CCT410429-02). The authors also thank Ms. Arlene Bulger, Ms. Casey Rollins, and Dr. Dennis Crouse of the University of Alabama at Birmingham Neonatology Laboratory for the use of the balance and hood. Special thanks to Ms. Juanita Settine for laboratory assistance, and to Ms. Brenda Wade and Ms. Sarah Chalkley for typing the manuscript and designing the tables. Dr. H. Kenneth Dillon generously provided critique of the experimental design and numerous helpful comments. Two anonymous reviewers were extremely critical and helpful.

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