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Site-Specific Whole Glove Chemical Permeation

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This study explored chemical permeation of latex neoprene gloves by acetone. Twenty-three specific glove sites were monitored to determine the breakthrough time and the challenge liquid concentration at steady-state. In summation, the thinnest parts of the gloves, which are the backs, the palms, and the interstices between the fingers, exhibited the shortest breakthrough times and largest steady-state concentrations. The thickest parts of the gloves, the fingertips, exhibited the longest breakthrough times and least steady-state concentrations. The backs or palms are appropriate specimens to use for chemical permeation testing.

Introduction

Gloves for protecting the hands against hazardous liquids are manufactured from either latex or solvent/cement dipped materials.⁽¹⁾ A standard method for testing the resistance of such protective materials to permeation is used to estimate dermal exposure to potentially hazardous liquids.⁽²⁾ However, current chemical resistance standard methods evaluate only a part of the whole protective clothing. For example, for testing the material from which gloves are manufactured, a specimen is usually cut from the palm, back or gauntlet of a glove.^(2,3) Historically, whole glove chemical resistance was determined by monitoring a physical parameter, as weight, before and after testing. Using weight as an example, the whole glove was weighed, turned inside out, and filled with the challenge liquid. After a specified time, the glove was drained of the liquid, patted dry, then the weight remeasured.^(4,5) Recently, the chemical permeation

characteristics of whole gloves have been determined.⁽⁶⁾ However, in all these methods, specific sites on the glove are not monitored. This study explored chemical permeation at twenty-three specific glove sites; the breakthrough times and the challenge liquid concentrations at steady-state were evaluated.

Different glove sites were monitored since the thickness of the protective material varies, and permeation theory

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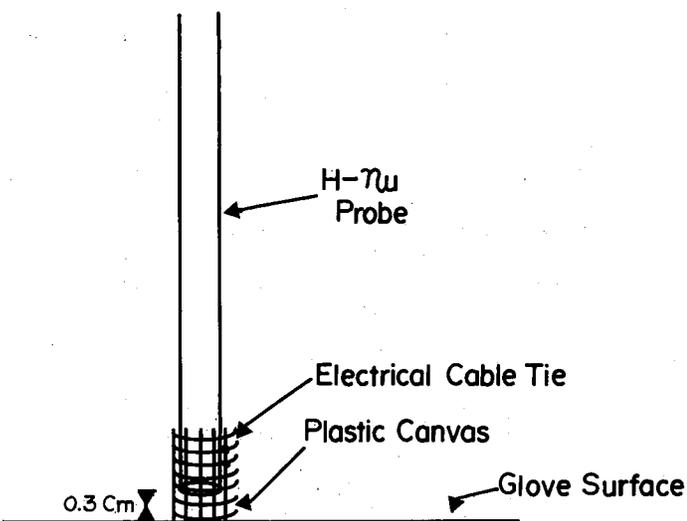


Figure 1 — Probe tip of photoionization detector.

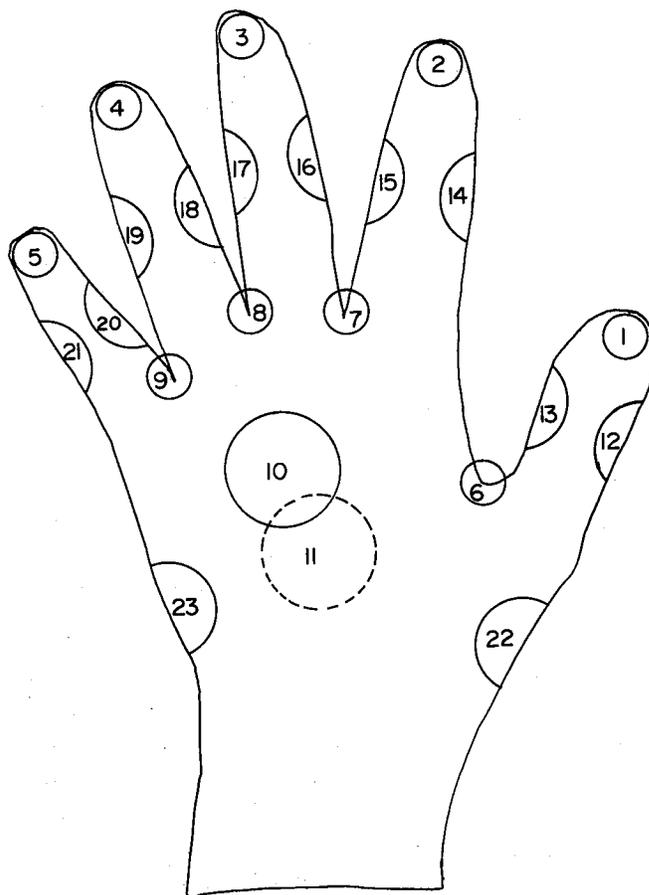


Figure 2 — Glove sites: 1-5 fingertips, 6-9 between fingers, 10 back, 11 palm, 12-21 sides of fingers, 22-23 sides of hands.

points out that breakthrough time, permeation rate and liquid chemical concentration are all dependent upon material thickness.⁽⁷⁾ The thinnest parts of the glove, the interstices between the fingers, are expected to exhibit the shortest breakthrough times; whereas the thickest parts, the glove gauntlet and the fingertips, are expected to exhibit the longest breakthrough times. The glove's gauntlets were not evaluated since these sites were used to tie off or seal the liquid in the gloves.

Experimental

Five unsupported latex neoprene gloves of one lot were evaluated against the challenge liquid, acetone. This same material/chemical system has been used to validate the ASTM standard method F739-81, Chemical Resistance to Permeation.⁽³⁾ A photoionization detector (H-NU System P-101) equipped with a recorder was used to measure acetone concentration. Detector response was determined to be under five seconds. The photoionization detector and recorder were calibrated as a unit using a vapor pressure saturator.⁽⁸⁾ The lower quantitative limit was set as 1 ppm. The probe tip on the photoionization detector was fitted with a plastic screen shroud (Figure 1), which kept the tip at a constant distance (0.3 cm) from the glove surface. Allowing the tip to rest on the glove surface would have cut off the air flow through the detector probe tip. The flowrate through the detector probe, 50 mL/min, was experimentally verified

by a bubble meter. Twenty-three different sites over the entire glove (Figure 2) were selected for evaluation.

Several preliminary runs established an approximate breakthrough time for each site which was used to develop a sampling strategy. The sites which had the quickest preliminary breakthrough times were surveyed first, *etc.* The total time to monitor all sites was approximately 90 seconds. Therefore, breakthrough times may be in error by 90 seconds. However, since the sites were monitored systematically, *i.e.*, by increasing breakthrough times, the error should be minimal.

All experiments were conducted in a laboratory hood with a face velocity of greater than 100 feet per minute. The thickness of each glove site was measured to ± 0.01 mm using a dial guage. The mean of ten readings for each site was recorded as the mean site thickness. Each glove was turned inside out and filled with approximately 100 mL of acetone. The neck of the glove was then tied off with an electrical cable tie. The tied glove neck was evaluated for a tight seal with the H-NU probe, then the probe was moved to monitor the glove sites. The sites were noted on the recorder chart. A typical trace is shown in Figure 3.

Breakthrough time was calculated from the recording's trace with a constant recorder chart speed of 2.0 cm/min. The mean acetone concentration under steady-state equilibrium at each of the specific sites was calculated by averaging four concentrations at different time intervals greater than

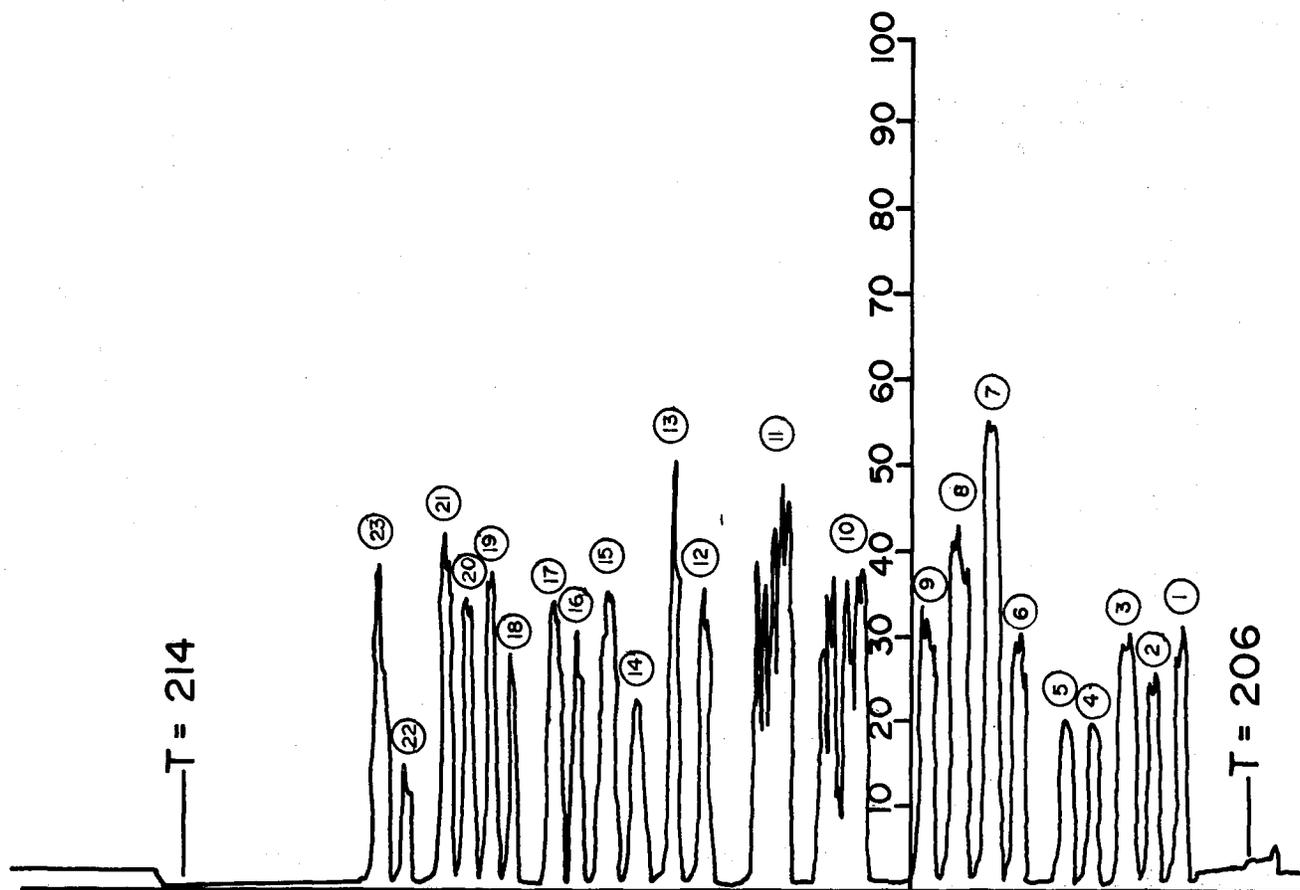


Figure 3 — Typical trace from chart recorder.

TABLE I
Mean Thickness (mm) Per Glove Site

Site	Glove Number				
	1	2	3	4	5
1	0.486 ^A	0.486	0.468	0.508	0.482
2	0.512	0.526	0.489	0.532	0.494
3	0.514	0.518	0.466	0.528	0.496
4	0.496	0.470	0.464	0.530	0.486
5	0.484	0.478	0.504	0.502	0.484
6	0.410	0.486	0.420	0.370	0.380
7	0.435	0.430	0.446	0.390	0.385
8	0.390	0.400	0.405	0.375	0.420
9	0.420	0.420	0.420	0.410	0.350
10	0.485	0.425	0.460	0.475	0.405
11	0.385	0.420	0.470	0.420	0.400
12	0.415	0.425	0.480	0.440	0.435
13	0.400	0.450	0.500	0.455	0.450
14	0.415	0.430	0.400	0.425	0.405
15	0.430	0.405	0.480	0.423	0.390
16	0.430	0.455	0.500	0.460	0.410
17	0.450	0.470	0.520	0.435	0.445
18	0.420	0.430	0.495	0.430	0.410
19	0.440	0.460	0.540	0.440	0.430
20	0.425	0.440	0.498	0.445	0.410
21	0.425	0.465	0.530	0.438	0.440
22	0.455	0.480	0.505	0.480	0.485
23	0.460	0.485	0.510	0.455	0.440

^AEach value is an average of ten readings.

TABLE II
Site-Specific Breakthrough Time (min)

Site	Glove Number				
	1	2	3	4	5
1	14.8	28.2	26.8	22.9	18.0
2	8.8	28.4	26.9	23.0	18.1
3	9.3	28.6	28.1	23.2	18.3
4	9.7	28.7	28.3	18.6	18.9
5	9.9	28.9	28.4	23.4	18.7
6	7.2	12.0	15.6	11.5	10.3
7	11.3	16.4	15.8	11.8	10.6
8	11.4	16.9	15.5	11.9	10.7
9	8.2	17.1	17.2	14.8	11.1
10	12.1	17.0	10.3	13.5	8.8
11	17.3	14.0	18.6	15.4	11.4
12	17.8	19.5	23.1	20.4	15.7
13	18.3	31.2	23.6	16.3	15.9
14	19.0	14.8	23.7	20.8	20.8
15	19.3	20.0	23.9	20.9	16.2
16	19.8	20.3	19.4	21.0	16.6
17	20.8	20.5	24.2	16.8	16.7
18	21.8	20.7	20.0	17.3	16.9
19	22.5	20.9	24.5	17.5	17.0
20	23.4	21.1	20.4	17.6	17.1
21	23.6	21.4	24.9	17.7	17.3
22	14.1	22.0	20.7	18.0	17.4
23	14.5	22.2	25.3	18.2	17.5

TABLE III
Site-Specific Normalized Breakthrough (min/mm²)

Site	Glove Number				
	1	2	3	4	5
1	62.66	119.39	122.36	88.74	77.48
2	33.57	102.65	112.50	81.27	74.17
3	35.20	106.59	129.40	83.22	74.39
4	39.43	129.92	131.45	66.22	80.02
5	42.26	126.49	111.80	92.86	79.83
6	42.83	68.03	113.95	79.64	75.24
7	59.72	88.70	79.43	77.58	71.51
8	74.95	105.63	94.50	84.62	60.66
9	46.48	96.94	97.51	88.00	90.61
10	51.44	94.12	48.68	59.83	53.65
11	116.71	79.37	84.20	87.30	71.25
12	103.35	107.96	100.26	105.37	82.97
13	114.37	154.07	94.40	78.73	78.52
14	110.32	80.04	148.13	115.16	126.81
15	104.38	121.93	103.73	116.81	106.51
16	107.08	98.06	77.60	99.24	98.75
17	102.72	92.80	89.50	88.78	84.33
18	123.58	111.95	81.62	93.56	100.54
19	116.22	98.77	84.02	90.39	91.94
20	129.55	108.99	82.26	88.88	101.73
21	130.66	97.31	88.64	92.26	89.36
22	68.11	95.49	81.17	78.13	73.97
23	68.53	94.38	97.27	87.91	90.39

34 minutes. Steady-state equilibrium was achieved in all instances after 30 minutes of exposure.

Results

Table I lists the mean glove thickness of each of the numbered specific glove sites illustrated in Figure 2. An analysis of variance (ANOVA) was performed using a Tektronix microcomputer with an ANOVA Tektronix software package. The analysis confirmed what was intuitively obvious. The sites are not the same thickness. The thickest sites (1-5) are the fingertips; the thinnest sites (6-9) are between the fingers. Specific site breakthrough times were statistically different (Table II). Site-specific normalized breakthrough times (min/mm²) are shown in Table III. Breakthrough times must be normalized to eliminate the statistical difference which is due solely to varying material thickness. Since breakthrough times are directly proportional to the square of the material thickness, normalization breakthrough times (min/mm²) were calculated.⁽⁹⁾ An analysis of variance revealed that site-specific normalized breakthrough times were equivalent. Table IV contains the calculations of mean site-specific breakthrough times, which were obtained by multiplying the mean site-specific normalized breakthrough times (mean of specific sites — Table III) by the site mean thicknesses. The calculated mean breakthrough times fall into three broad ranges:

1. The < 16-minute range, at the thinnest sites. These sites are the interstices between the fingers (sites 6 through 9), the back (site 10), and the palm (site 11).

TABLE IV
Calculated Mean Breakthrough Time
Mean Normalized Breakthrough Time × Mean Thickness²

Site	Mean Normalized Breakthrough (min/mm ²)	Mean Thickness (mm)	Calculated Breakthrough (min)
1	94.13	× 0.486 ²	= 22.2
2	80.83	× 0.511 ²	= 21.1
3	85.76	× 0.507 ²	= 22.0
4	89.41	× 0.489 ²	= 21.4
5	90.65	× 0.490 ²	= 21.8
6	75.94	× 0.390 ²	= 11.6
7	75.39	× 0.417 ²	= 13.1
8	84.07	× 0.398 ²	= 13.3
9	83.91	× 0.404 ²	= 13.7
10	61.54	× 0.450 ²	= 12.5
11	87.77	× 0.419 ²	= 15.4
12	99.96	× 0.439 ²	= 19.3
13	104.02	× 0.451 ²	= 21.2
14	116.09	× 0.415 ²	= 20.0
15	110.67	× 0.426 ²	= 20.1
16	96.15	× 0.451 ²	= 19.6
17	91.63	× 0.464 ²	= 19.7
18	102.25	× 0.437 ²	= 19.5
19	96.29	× 0.462 ²	= 20.6
20	102.28	× 0.441 ²	= 19.9
21	99.65	× 0.448 ²	= 20.0
22	79.37	× 0.481 ²	= 18.4
23	87.70	× 0.480 ²	= 20.2

TABLE V
Mean Site-Specific Steady-State Concentration (ppm)

Site	Glove Number				
	1	2	3	4	5
1	551 ^A	615	585	711	816
2	420	691	625	812	735
3	253	715	661	695	585
4	279	551	601	775	525
5	259	404	561	705	625
6	775	701	1103	1032	1053
7	852	731	886	1012	1077
8	856	685	912	1087	1057
9	761	711	916	1016	1002
10	621	806	856	986	962
11	822	731	571	821	892
12	455	581	771	896	816
13	645	551	675	765	755
14	394	761	852	745	852
15	585	665	741	761	745
16	390	681	731	882	775
17	460	761	701	755	721
18	249	751	775	785	711
19	494	681	802	771	645
20	370	775	701	755	685
21	540	771	816	912	775
22	394	314	916	822	731
23	561	534	611	745	601

^AEach value is an average of four readings.

TABLE VI
Whole Glove Normalized Steady-State Concentration × Steady-State Concentration × Thickness (ppm × mm)

Site	Glove Number				
	1	2	3	4	5
1	268	299	274	361	393
2	215	363	306	432	363
3	130	370	308	367	290
4	147	259	279	411	255
5	125	193	283	354	302
6	318	294	408	392	390
7	371	314	395	395	415
8	334	274	369	408	444
9	320	299	385	417	351
10	301	343	394	468	390
11	316	307	268	345	357
12	188	247	370	394	355
13	258	248	337	348	340
14	163	327	341	317	345
15	252	269	356	322	290
16	168	310	365	406	318
17	207	358	364	328	321
18	105	323	384	338	291
19	218	313	433	339	277
20	157	341	349	336	281
21	229	358	432	399	341
22	179	151	463	395	354
23	258	259	312	339	264

- The 16- to 21-minute range, at sites of intermediate thickness. These specific sites (12 through 23) are the sides of the fingers and glove.
- The > 21-minute range, at the thickest sites. These sites (1 to 5) are the fingertips.

Site-specific steady-state permeation rates were not calculated; however, site-specific steady-state concentrations were experimentally measured (Table V). An analysis of variance proved that the steady-state concentrations were not equivalent. A normalized steady-state concentration, ppm × mm, was calculated. Since steady-state permeation rate or steady-state concentration is inversely proportional to thickness, the mean site-specific steady-state concentration (Table V) was multiplied by the mean thickness (Table I) and is shown in Table VI. Only two ranges are apparent: > 800 ppm mean steady-state concentration at the interstices between the fingers (sites 6-9) and the back (site 10) of the glove, and 500 to 800 ppm at all other sites. The thinnest specific sites had the largest mean steady-state concentration (Table VII).

Discussion and Conclusion

In order to afford the worker some measure of protection, gloves are removed before an unacceptable concentration of liquid chemical has permeated through the garment material. Permeation can be determined on patches (pieces) of

TABLE VII
Calculated Mean Steady-State Concentration. Mean
Normalized Steady-State Concentration ÷ Mean Thickness

Site	Normalized Steady-State Concentration (ppm - mm)	Mean Site Thickness (mm)	Calculated Mean Steady-State Concentration (ppm)
1	319.0	0.486	656.4
2	335.8	0.511	657.1
3	293.0	0.507	577.9
4	270.2	0.489	552.5
5	251.4	0.490	513.1
6	360.4	0.390	924.1
7	378.0	0.417	906.5
8	365.8	0.398	919.1
9	354.4	0.404	877.2
10	379.2	0.450	842.7
11	318.6	0.419	760.4
12	310.8	0.439	708.0
13	306.2	0.451	678.9
14	298.6	0.415	719.5
15	297.8	0.426	699.1
16	313.4	0.451	694.9
17	315.6	0.464	680.2
18	288.2	0.437	659.5
19	316.0	0.462	684.0
20	292.8	0.441	664.0
21	351.8	0.448	785.3
22	308.4	0.481	641.2
23	286.4	0.480	596.7

glove material or the whole glove. A whole glove test method requires appreciable time to perform the test, then time to analyze the data. An expediency uses a piece or patch of garment material from an area which is an acceptable surrogate for the whole. The surrogate sites, therefore, should have a short breakthrough time and large steady-state con-

centration as compared to the rest of the sites. Additionally, the specimen must be flat and have a sufficient diameter to fit into a test cell. The glove's palm and back met these criteria.

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