Title
Comparison of Permeation of 2-Butoxyethanol Through Single and Multiple Layers of Disposable Nitrile Gloves

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Comparison of Permeation of 2-Butoxyethanol

Through Single and Multiple Layers of Disposable Nitrile Gloves

A thesis submitted in partial satisfaction

of the requirements for the degree Master of Science

in Environmental Health Sciences

by

Eun Jin Song

2017

ABSTRACT OF THE THESIS

Comparison of Permeation of 2-Butoxyethanol

Through Single, Double and Triple Layers of Disposable Nitrile Gloves

by

Eun Jin Song

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2017

Professor Shane S. Que Hee, Chair

The hypothesis was that multiple layers of disposable nitrile gloves would protect longer against 2-butoxyethanol (2-BE) than a single layer relative to standardized breakthrough time (SBRT) and steady state permeation rate (SSPR). Many industries such as aerospace, automotive, recycling, and waste disposal facilities utilize 2-BE. The resistance of disposable blue powder-free nitrile gloves (Kimberly-Clark) against 2-BE was tested in single, double, and triple layers. The American Society for Testing and Materials (ASTM) Method F739-12 for permeation resistance under continuous contact was used. For each run set, four 1-inch diameter permeation cells (three cells with 10 mL 2-BE as challenge and one air blank (1)) were used with 10 mL deionized water as the collection solvent in a water bath shaken at 72.3 ± 0.58 revolution/minute (4.82 ± 0.04 cm/second) at 35.0 ± 0.5 °C. 0.1 mL aliquots were sampled at 5, 10, 20, 30, 40, 50, 135, 240, 360, and 480 minutes. Capillary column gas chromatography-mass spectrometry (GC-MS) utilized mass to charge ratios 2-BE at m/z= 57 and 87, and 4-bromophenol (4-BP) internal

standard at m/z= 174 (1). The retention times for 2-BE and 4-BP were 4.8 min and 7.9 min. SBRT were found between 5 to 10 minutes for single, between 10 to 20 minutes for double, and between 30 to 40 minutes for triple layers, though thus not statistically different at $p \leq 0.050$. Single gloving had a rating of 'poor,' while double and triple gloving were 'good,' based on Kimberly Clark Professional permeation breakthrough time criteria. The other statistically different comparison was for the mass/area permeation at 30 minutes for the triple layer relative to a single layer. The average SSPR were 41.20 ± 8.81 $\mu g/cm^2/min$ for single gloving, 48.48 ± 55.57 $\mu g/cm^2/min$ for double gloving, and 5.39 ± 4.64 $\mu g/cm^2/min$ for triple gloving. Both single and double gloving had a rating of good, and triple gloving had a rating of very good based on Ansell permeation rate criteria for Chemical Resistant Gloves. Thus, multiple layers did tend to prolong SBRT, but only triple layers definitely lowered the SSPR.

The thesis of Eun Jin Song is approved.

Yifang Zhu

Wendie Robbins

S. Que Hee, Committee Chair

University of California, Los Angeles

2017

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1. INTRODUCTION

1.1 *Hypothesis and Aims*

The hypothesis was that multiple layers of disposable nitrile gloves would protect better against 2-BE than a single layer relative to SBRT and SSPR. The aims to this research were (1) to determine if disposable nitrile gloves were resistant to 2-BE, and (2) to determine if multiple glove layers provided more protection.

1.2 *Background*

1.2.1 *Glove Permeation*

Many chemicals can cause skin adverse effects like dermatitis due to contact and if the worn gloves are not resistant (1, 2). The standard test method for permeation resistance in the U.S. is American Society for Testing and Materials (ASTM) F739-12 entitled 'Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact.' The SBRT and the SSPR of a chemical through the protective barrier can be determined. The SBRT is the time at which the permeation rate reaches 0.1 $\mu g/cm^2/min$. The SSPR is the constant rate of permeation after breakthrough during the steady-state permeation period (9).

1.2.2 *Theory*

The permeation process through a glove also involves consideration of degradation and penetration. Degradation is the physical deterioration of the material due to contact with an agent. The material may get harder, stiffer, more brittle, softer, weaker, or may swell after chemical exposure (1). Penetration results when the chemical leaks through seams, pinholes and other imperfections in the material either already in the material or after degradation (6).

Permeation occurs when the chemical molecules adsorb onto the contact surface of the material, diffuse through the material, and then desorb at the opposite surface of the material (9).

Fick's First Law can be used to express diffusion of chemicals through the material of the glove as in equation 1-1.

$$J = D \times A \times (dc/ dl) \qquad (1\text{-}1)$$

where J is the permeant mass transfer rate (µg/min), c is the permeant concentration (µg/cm^3), l is the glove thickness (cm), A is the cross-sectional area exposed (cm^2) and D is the diffusion coefficient (cm^2/min). The permeation rate can be determined using a standard test method, such as ASTM Method F-739, European Permeation test EM 369, and the International Standard test ISO 6529 (1).

Equation 1-1 also can be expressed as the following:

$$J= D \times A \times (C_1- C_2)/ l \qquad (1\text{-}2)$$

where C_1 and C_2 are analyte concentration or masses in the challenge cell at times 1 and 2 and where D is independent of the concentration gradient and thickness (1).

The constant D can be calculated by extrapolating the mass or mass/area versus time permeation steady state region to zero mass at lag time, t_i:

$$D= l^2/ 6t_i \qquad (1\text{-}3)$$

Equation (1-3) is not obeyed in cases of significant swelling or shrinking of the material.

1.2.3 *Test Compound*

1.2.3.1 *Physical Properties*

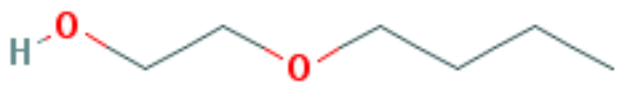
IUPAC Name: 2-butoxyethanol

CASRN: 111-76-2

Molecular Formula: $C_6H_{14}O_2$

Molecular Weight: 118.176 g/mol

2D Structure :



Physical Description: colorless liquid with a mild and a pleasant sweet ether-like odor.

Density: 0.902 g/mL at 20 °C (16)

Flash Point: 141 °F (61 °C), closed cup (17)

Boiling Point: 340 °F (171 °C) at 743 mm Hg (17)

Solubility: greater than or equal to 100 mg/mL at 72 °F (17)

Vapor Pressure: 0.88 mm Hg at 25 °C

1.2.3.2 *Uses*

2-BE is used in flame retardants, functional fluids (open systems), intermediates, paint additives and coating additives, processing aids, specific to petroleum production, and solvents for cleaning or degreasing. The consumer uses include for antifreeze, de-icing products, cleaning, furnishing care, electrical products, inks, toners, colorants, lubricants, greases, paints, and coatings. Worldwide, 2-BE use is 41% as solvent for protective coatings; 18% as solvent for metal cleaners and liquid household cleaners; 9% for synthesis of 2-BE acetate; 1% for synthesis of di(2-BE) phthalate; and 31% for other solvent uses. The U.S. produced 2002 >100 million to 500 million pounds (8).

1.2.3.3 *Toxic Effects*

In general, health effects associated with exposure to 2-BE have been identified from studies in animals. It has moderately acute toxicity and is readily absorbed via inhalation, ingestion, or dermal exposure. It is an eye and skin irritant, but not a skin sensitizer. Acute dermal toxicity for rabbit has LD_{50}= 100 - 610 mg/kg, and guinea-pig has LD_{50}= 210 - 3000 mg/kg (10). The pharmacokinetic models of Corley et al. (11) and Johanson & Boman (12) consider dermal absorption from the vapor phase to account for approximately 21 - 75% of the total uptake. Pathways for the metabolism of 2-BE are similar in rodents and humans; the principal metabolite is 2-butoxyacetic acid produced by phase I processes (4). The U.S. Department of Health and Human Services, the International Agency for Research on Cancer, and U.S. Environmental Protection Agency have not classified 2-BE and 2-BE acetate as to their human carcinogenicity (15). No information on the carcinogenicity of 2-BE in experimental animals was found in the available literature; additionally, no epidemiologic studies or case reports examining the relationship between exposure to 2-BE and cancer in humans were found in the literature (14). In vivo mutagenicity tests have yielded uniformly negative results for 2-BE. These assays have included three bone marrow micronucleus tests utilizing intraperitoneal injection in rats and mice (13). The negative results from in vivo studies are sufficiently reassuring to allow the conclusion that 2-BE is not mutagenic (4). According to the Globally Harmonized System (GHS), its classification regarding skin hazard is H311: Toxic in contact with skin [Danger- Acute toxicity, dermal - Category 3] and H315: Causes skin irritation [Warning- Skin corrosion/irritation - Category 2].

2. EXPERIMENTAL

2.1 *Apparatus*

The moderately polar HP-5MS capillary column dimensions were 60.0 m x 320 µm inner diameter x 1.00 µm film thickness. The GC (Agilent 6890N) column temperature started at 120 °C for 2 minutes and ramped at 40 °C/min, to 280 °C and kept at 280 °C for 4 minutes at a helium carrier flow rate of 2.0 mL/min. The temperatures for the inlet ion source and MS (Agilent 5973) quadrupole were 230 °C and 150 °C, respectively. The selected ion monitoring (SIM) mode was used to enhance sensitivity and selectivity for the compounds of interest at m/z 57 ± 0.1 and 87 ± 0.1 for 2-BE and 172 ± 0.1 for 4-BP (1). The total ion current m/z range was 50 to 550. The shaking water bath temperature was 35.0 ± 0.5 °C; micrometer gauge (Marathon, catalog No. CO 030025) to measure thicknesses of each glove specimen; desiccators containing a saturated solution of sodium dichromate to generate a relative humidity of 65.2 ± 0.8%) was used to condition the gloves for at least 24 hours before/after permeation runs for measurement of thickness and mass (1); the permeation test cell (ASTM type I-PTC-600, Pesce Lab Sales, Immersible closed loop chamber) that has a two-chambered cell for contacting the specimen with the chemical on the specimen's outside surface and with a collection medium on the inside surface (Figure 1) (9); a 10-µL syringe (Hamilton Company) was used for injecting samples to GC; analytical balance (Mettler AE 260, DeltaRange®) to measure the glove mass before/after tests; 16-ft-lb torque wrench to tighten/loosen the bolts of the two-chambered cell; variable size pipettes with long tips to transfer collection solution aliquots; 25-mL graduated cylinders to collect the rest of the collection side volume from the collection side of cell; and 1-mL vials to store 0.1 mL of each collection side sample.

Figure 1: Complete test cell setup in shaking water bath

2.2 *Chemicals*

H_2O (deionized water), 2-BE (EASTMAN) (100 ng/µL), 4-BP (ALDRICH), acetone, and liquid neutral detergent.

2.3 *Procedure*

The permeation test method used was the ASTM Standard Test Method F739-12 under conditions of continuous contact (9). The permeation of 2-BE through blue disposable gloves (Kimberly-Clark Global Sales, LLC, Roswell, GA 30076 USA) was obtained by measuring the mass permeated over specific periods of time. The following steps were performed:

1. Drew and cut out circular pieces of gloves (diameter= 4.8 cm).
2. Preconditioned the gloves in a desiccator for at least 24 hours prior to the test.
3. Weighed the specimen (either single, double, or triple layer) on the analytical balance.
4. Measured thickness by using the micrometer screw gauge.

5. Placed specimen between two test-cell chambers, and tightened with 16-ft-lb torque wrench.
6. Assembled test cells in the calibrated constant temperature water bath shaker for 30 minutes at 35.0 ± 0.5 °C.
7. Placed into the collection sides a volume of 10 mL of deionized water and then 10 mL of 2-BE into each of three cells, with just air for the fourth cell (blank). The shaker was then started at 72.3 ± 0.58 revolution/minute.
8. Removed from each cell a volume of 0.1 mL of sample from collection side at 5, 10, 20, 30, 40, 50, 135, 240, 360, and 480 minutes.
9. Stored samples in the 0 °C freezer until measurement.

After each run:

1. Poured each collection side into a graduated cylinder.
2. Discarded the liquid in the challenge side.
3. Disassembled the test-cell chamber using the torque wrench.
4. Transferred specimens into plastic beaker to dry in the fume hood overnight.
5. Weighed the specimen and measured its thickness and its diameter.
6. Placed specimen into a plastic petri dish, then stored in desiccator at relative humidity of 65.2 ± 0.8%.
7. Submerged the test-cell chambers, PTFE gasket, bolts and nuts into tap water with liquid detergent overnight.
8. Rinsed at least three times with distilled water, then cleaned and dried finally with acetone.

The 0.1 mL samples were thawed to room temperature before capillary gas chromatography-selective ion mass spectrometry analysis by the internal standards method using 4-BP at a concentration of 0.1 μg/μL in each sample and an injection volume of 2.0 μL. The standard curve was generated with 2-BE concentrations of 0, 0.1, 0.5, 1.0, 5.0, 10.0, 100.0 ng/μL in deionized water (2-BE of density 0.9015 g/mL at 20 °C was generated by preparing 11.1 μL of 2-BE in 100 mL total solution with deionized water) for the lower range, and 0, 100, 200, 300, and 400 ng/μL for the upper range.

After determining the concentration in each sample, the mass on the collection side was determined at each time point by multiplying the interpolated concentration by the collection side volume at each time point, correcting for the volumes of previous samples already taken. Then, the permeation curves for each layer of the glove were generated by plotting mass of 2-BE or mass/exposed surface area in the collection side versus challenge time.

3. RESULTS

3.1 *GC-MS*

The retention times for the 2-BE and the 4-BP were 4.8 min and 7.9 min, respectively. The total run time for each injection was 10 minutes. For glove exposure area (diameter= 2.3 cm) and permeation rate 0.1 $\mu g/cm^2/min$, the minimum concentration to find standardized breakthrough time was calculated to be 0.2075 ng/µL.

The regression equation for the low standards (0, 0.1, 0.5, 1, 5, 10, 50, and 100 ng/µL) was $y= 0.0553x + 0.0126$ ($R^2= 0.9904$, $p\leq 0.050$). The lower quantifiable limit was 0.1 ng/µL. The regression equation for the high standards range (100, 200, 300, and 400 ng/µL) was $y= 0.7058x - 40.9$ ($R^2= 0.9985$, $p\leq 0.050$).

3.2 *Permeation*

3.2.1 *Permeation Curves*

The mass/area versus time data for each single, double, and triple gloving data are shown in Tables 1 through 3. Also, the permeation curves of each test cell are shown in Figures 2 through 10. The figures show that there is a much variation within each gloving classification relative to the permeation curve shape.

3.2.2 *Permeation Parameters*

The permeation parameters of 2-BE are indicated in Table 4. The averaged SBRT were 4.17 ± 2.89 minutes for single gloving, 12.50 ± 4.33 minutes for double gloving, and 20.83 ± 16.65 minutes for triple gloving. From the Table 6 classification, the single gloving has ‘poor,’ both double and triple gloving have ‘good’ ratings. On the other hand, the Student t-test indicated that SBRT between double to single, triple to single, and triple to double were not statistically different at $p \leq 0.050$. The Student t-test indicated that there was a significantly different average permeated mass/area at 30 minutes and SSPR only between triple and single gloving (Table 5).

Table 1: Mass/area permeated of 2-BE through single layer of Kimberly-Clark disposable blue nitrile glove

Permeation Time (Minutes)	Mass/Area Permeated ($\mu g/cm^2$)		
	Cell 7	Cell 8	Cell 9
5	8	0	46
10	128	133	484
20	606	607	1083
30	820	944	1349
Average Mass/Area at 10 minutes	248.33 ± 204.11		
Average Mass/Area at 30 minutes	1038 ± 277		

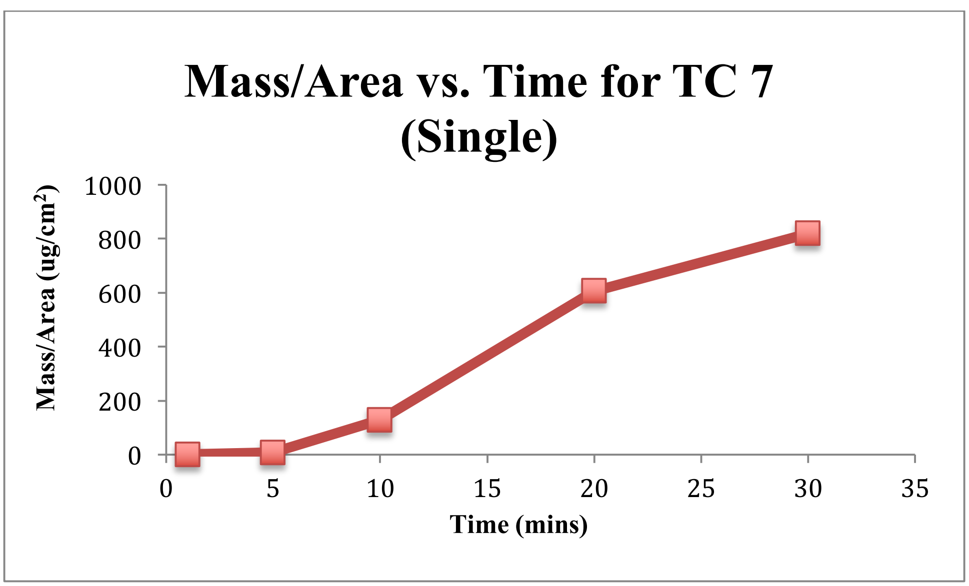


Figure 2: Permeation curve (mass/area vs. time) for test cell 7 (single)

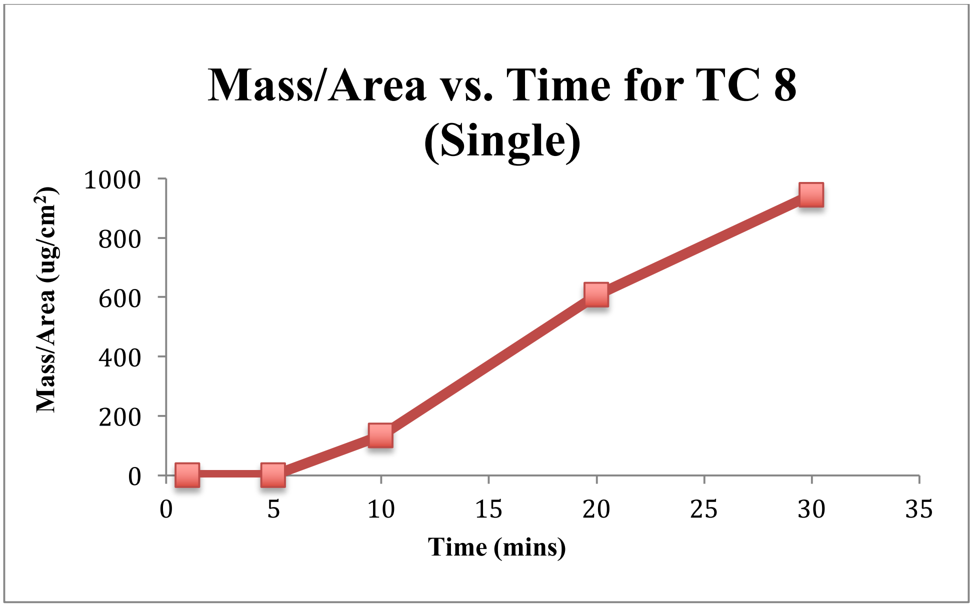


Figure 3: Permeation curve (mass/area vs. time) for test cell 8 (single)

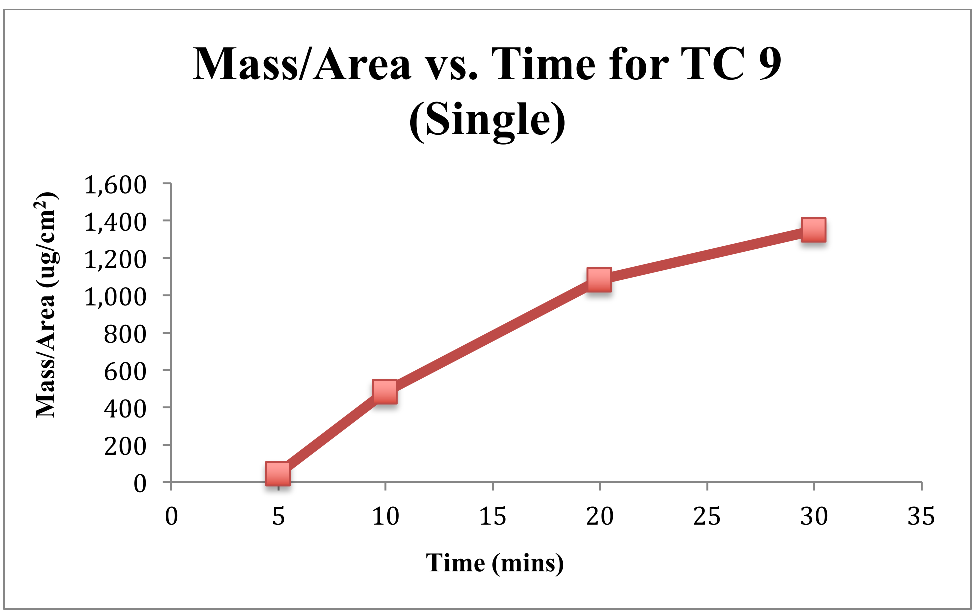


Figure 4: Permeation curve (mass/area vs. time) for test cell 9 (single)

Table 2: Mass/area permeated of 2-BE through double layer of Kimberly-Clark disposable blue nitrile glove

Permeation Time (Minutes)	Mass/Area Permeated (μg/cm^2)		
	Cell 1	Cell 2	Cell 3
5	2	0	0
10	0	2	0
20	55	435	9
30	28	406	1134
40	108	688	1165
50	281	-	1057
135	-	-	1201
Averaged Mass/Area at 10 minutes	0.667 ± 1.155		
Averaged Mass/Area at 30 minutes	523 ± 562		

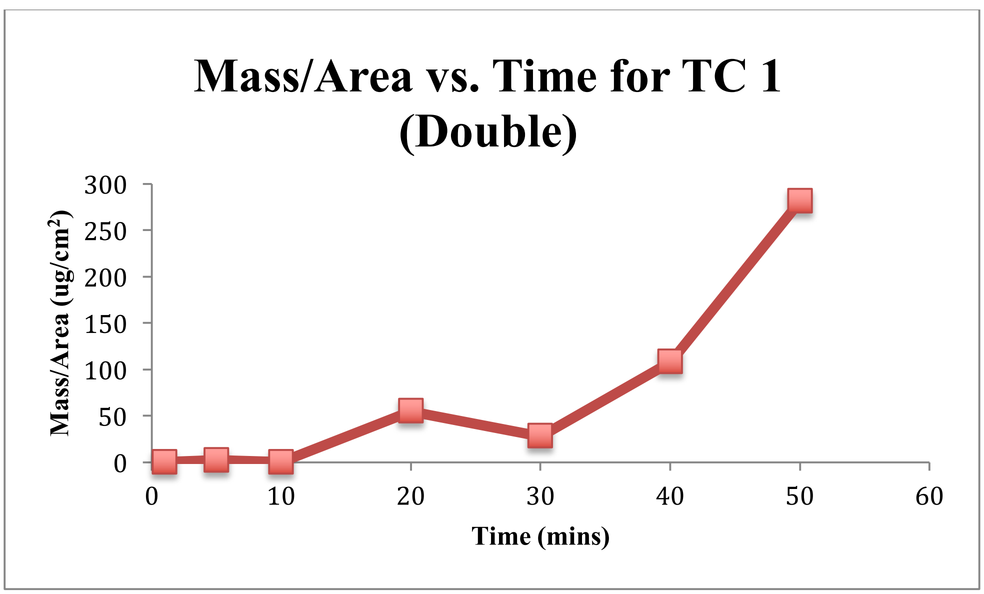


Figure 5: Permeation curve (mass/area vs. time) for test cell 1 (double)

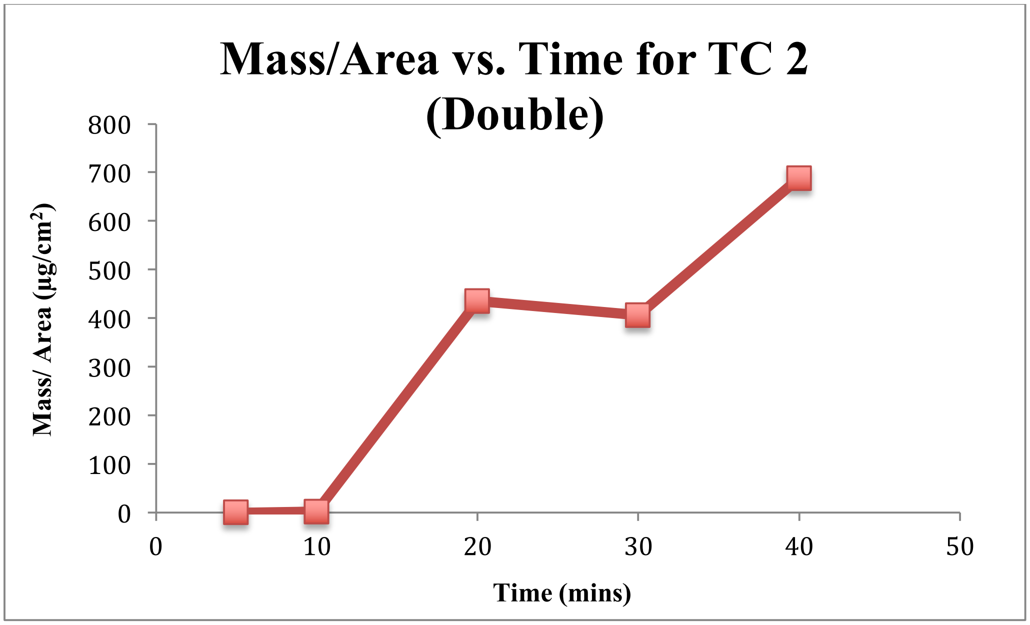


Figure 6: Permeation curve (mass/area vs. time) for test cell 2 (double)

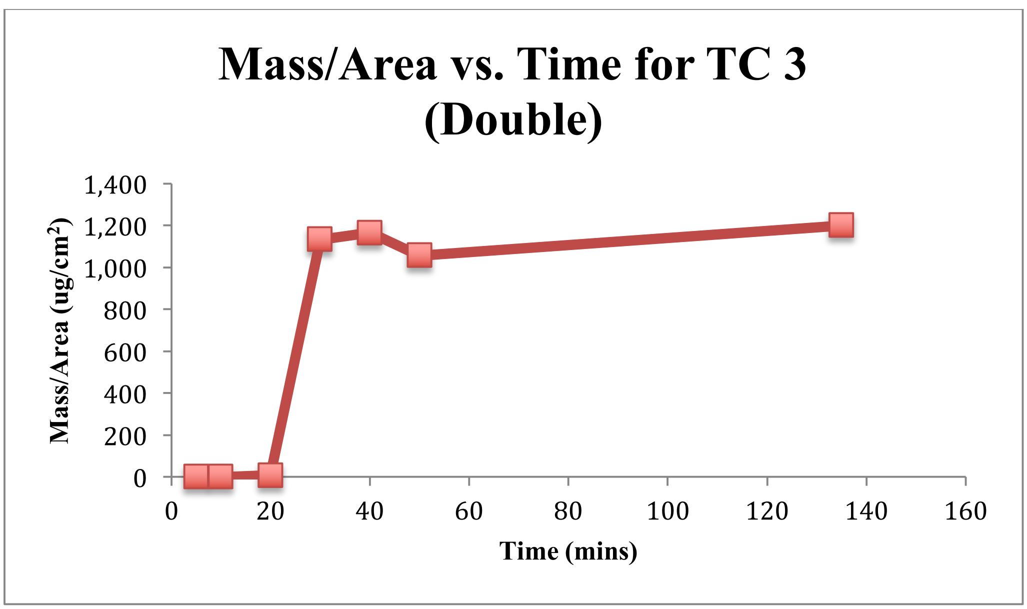


Figure 7: Permeation curve (mass/area vs. time) for test cell 3 (double)

Table 3: Mass/area permeated of 2-BE through triple layer of Kimberly-Clark disposable blue nitrile glove

Permeation Time (Minutes)	Mass/Area Permeated ($\mu g/cm^2$)		
	Cell 4	Cell 5	Cell 6
5	0	26	0
10	0	75	0
20	0	99	0
30	7	192	79
40	6	231	195
50	8	306	972
135	-	-	1392
Average Mass/Area at 10 minutes	25 ± 43.30		
Average Mass/Area at 30 minutes	92.7 ± 93.3		

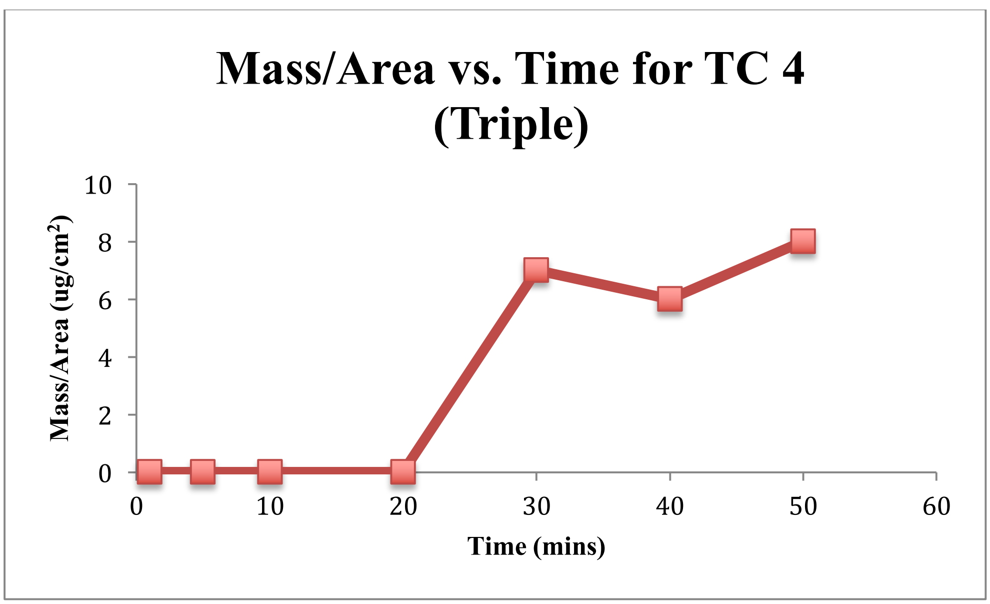


Figure 8: Permeation curve (mass/area vs. time) for test cell 4 (triple)

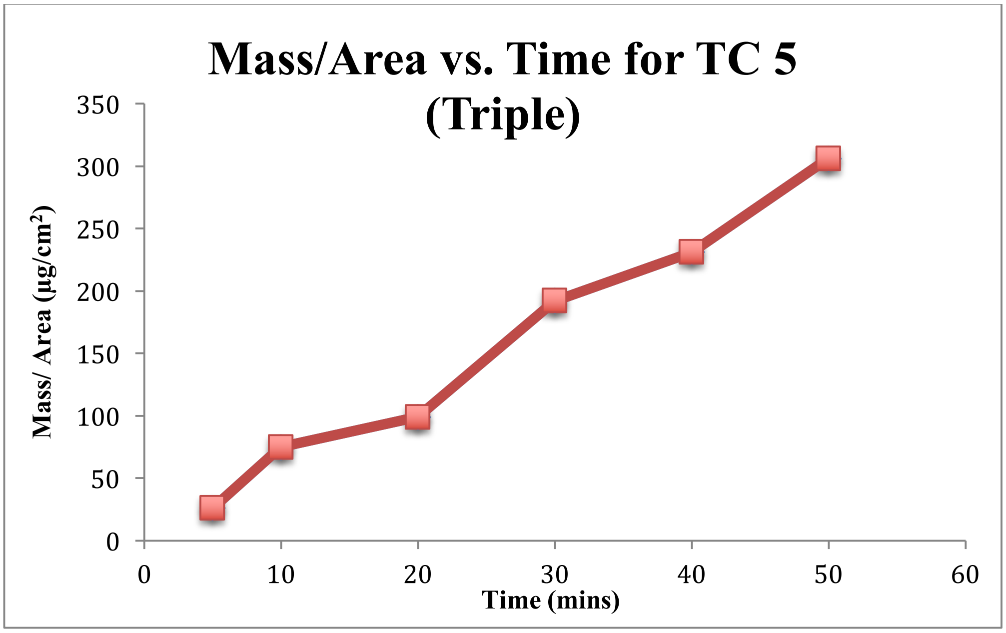


Figure 9: Permeation curve (mass/area vs. time) for test cell 5 (triple)

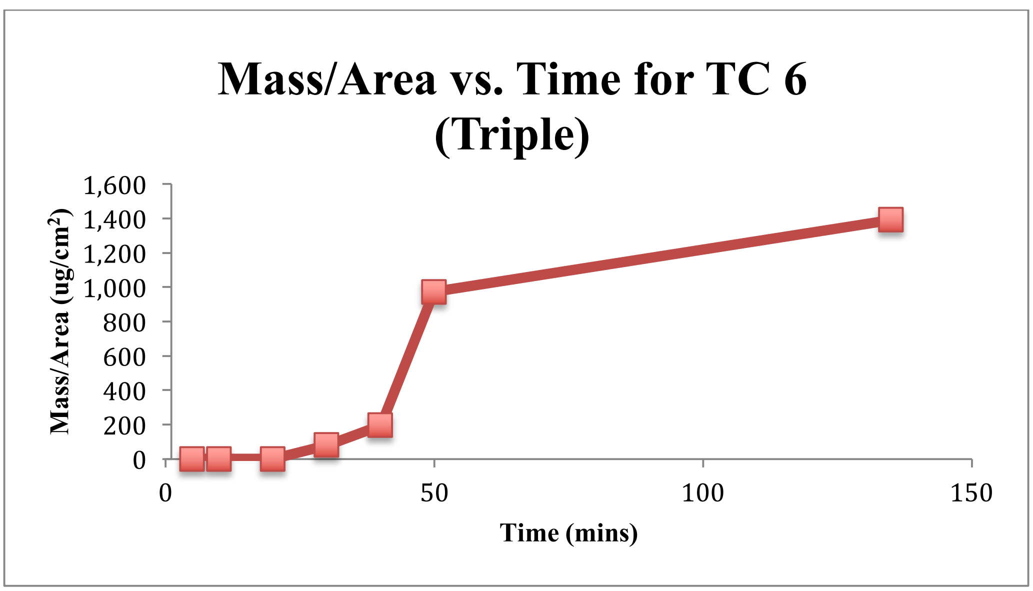


Figure 10: Permeation curve (mass/area vs. time) for test cell 6 (triple)

The averaged SSPR were 41.20 ± 8.81 μg/cm^2/min for single gloving, 48.48 ± 55.57 μg/cm^2/min for double gloving, and 5.39 ± 4.64 μg/cm^2/min for triple gloving. From the Table 7 classification, both single and double gloving was "good," and triple gloving has "very good" ratings. From the Student t-test, the triple SSPR was significantly different at $p \leq 0.050$ from the single SSPR. Other comparisons were not statistically significant at $p \leq 0.050$ except for the average mass/area permeated at 30 minutes for the same pairing.

The lag time (t_l) measured by extrapolation of the linear steady state section of the permeation curve to the horizontal time axis where mass/area (y-axis) was zero, allowed the calculation of the diffusion coefficient (D) from equation 1-3 (1).

Table 4: Permeation parameters of 2-BE through disposable blue nitrile gloves

Test Cell	SBRT (mins)	SSPR (μg/cm^2/min)	Thickness, mm	t_l (lag time, min)	D*10^{-6} (cm^2/min)
4 (Triple)	20 to 30	0.27± 0.54	0.3560	19.48	10.84
5 (Triple)	<5	6.60± 15.59	0.3610	3.64	59.67
6 (Triple)	30 to 40	9.30± 16.29	0.3780	30.34	7.849
Average	20.83± 16.65	5.39± 4.64	0.3650	17.82± 13.43	26.12± 29.09
1 (Double)	10 to 20	12.65± 37.97	0.2230	29.01	2.857
2 (Double)	5 to 10	20.29± 372.15	0.2490	6.14	16.83
3 (Double)	10 to 20	112.50	0.2500	19.92	5.229
Average	12.50± 4.33	48.48± 55.57	0.2407	18.36± 11.52	8.305± 7.477
7 (Single)	<5	34.33± 478.43	0.1280	4.87	5.607
8 (Single)	5 to 10	40.55± 55.93	0.1600	6.16	6.926
9 (Single)	<5	51.71± 157.75	0.1270	1.93	13.93
Average	4.17± 2.89	41.20± 8.81	0.1383	4.32± 2.17	8.821± 4.473

Table 5: Student t-test between single, double, and triple gloving on SBRT, SSPR, t_l, and D

	SBRT (mins)	SSPR ($\mu g/cm^2/min$)	t_l (lag time, min)	$D*10^{-6}$ (cm^2/min)	Average mass/area at 10 minutes	Average mass/area at 30 minutes
Double to Single	$p > 0.500$	$p > 0.500$	$0.100 < p < 0.200$	$p > 0.500$	$0.100 < p < 0.200$	$0.200 < p < 0.400$
Triple to Single	$0.100 < p < 0.200$	$0.001 < p < 0.005$	$0.100 < p < 0.200$	$0.200 < p < 0.400$	$0.100 < p < 0.200$	$0.005 < p < 0.010$
Triple to Double	$0.400 < p < 0.500$	$0.200 < p < 0.400$	$p > 0.500$	$0.200 < p < 0.400$	$0.200 < p < 0.400$	$0.200 < p < 0.400$

Table 6: Kimberly-Clark Professional permeation breakthrough time criteria for chemical resistance rating of disposable nitrile gloves (1)

Rating	Permeation breakthrough time (minutes)
Excellent (E)	60-480
Good (G)	10-59
Poor (P)	1-9
Not Recommended (NR)	< 1

Table 7: Ansell permeation rate criteria for Chemical Resistant Gloves (1)

Rating	Permeation Rate ($\mu g/cm^2/min$)
Excellent (E)	< 0.9
Very Good	0.9 - 9
Good	9 - 90
Fair	90 - 900
Poor	900 - 9,000
Not Recommended (NR)	> 9,000

3.3 *Thickness*

The thickness measurements are indicated in Table 8. After reconditioning of the specimen materials at least 24 hours in desiccators, the percent difference between before and after challenge was 3.9% for single, 10.9% for double, and 11.5% for triple. In order to measure statistical significance before and after challenging, Student t-tests were performed, and the results are indicated in Table 9. For the single layer with percent difference of 3.9% with p-value greater than 0.500, there was no significant difference in thickness. On the other hand, double and triple thicknesses were significantly different, and specimens swelled based on ≥10% percent difference.

Table 8: Thickness measurements on each single, double, and triple layers

	Before Challenge (mm)	**After Challenge (mm)**	**% Difference**
Single			
Cell 7	0.1280	0.1400	9.375
Cell 8	0.1600	0.1720	7.500
Cell 9	0.1270	0.1190	-6.299
Blank	0.1230	0.1220	-0.813
Average*	**0.1383**	**0.1437**	**3.855**
SD	**0.0188**	**0.0267**	
Double			
Cell 1	0.2230	0.2550	14.35
Cell 2	0.2490	0.2640	6.024
Cell 3	0.2500	0.2820	12.80
Blank	0.2530	0.2580	1.976
Average*	**0.2407**	**0.2670**	**10.94**
SD	**0.0153**	**0.0137**	
Triple			
Cell 4	0.3560	0.4290	20.51
Cell 5	0.3610	0.3990	10.53
Cell 6	0.3780	0.3930	3.968
Blank	0.3680	0.3700	0.543
Average*	**0.3650**	**0.4070**	**11.51**
SD	**0.0115**	**0.0193**	

*average without blank

Table 9: Student t-test for each single, double, and triple changes in thickness

Glove layer	p-value
Single	$0.500 < p$
Double	$0.050 < p < 0.100$
Triple	$0.025 < p < 0.050$

3.4 *Weight*

The weight measurements are indicated in Table 10. After reconditioning of the specimen materials at least 24 hours in desiccators, the percent difference between before and after challenge was 8.5% for single, 11.8% for double, and 14.3% for triple. This percent difference might be due to permeate retention within the specimen (high boiling point, non-volatile). In order to measure significance difference in weight before and after challenging, the Student t-test was performed and the results are indicated in Table 11. However, none of the changes were significantly different.

Table 10: Weight measurements on each single, double, and triple layers

	Before Challenge (mm)	**After Challenge (mm)**	**% Difference**
Single			
Cell 7	0.2180	0.2358	8.165
Cell 8	0.2257	0.2532	12.18
Cell 9	0.1847	0.1928	4.385
Blank	0.1839	0.1839	0.000
Average*	**0.2095**	**0.2273**	**8.498**
SD	**0.0218**	**0.0311**	
Double			
Cell 1	0.4119	0.4518	9.687
Cell 2	0.2436	0.2809	15.31
Cell 3	0.2536	0.2839	11.95
Blank	0.2484	0.2484	0.000
Average*	**0.3030**	**0.3389**	**11.82**
SD	**0.0944**	**0.0978**	
Triple			
Cell 4	0.6505	0.7311	12.39
Cell 5	0.4480	0.5341	19.22
Cell 6	0.4319	0.4846	12.20
Blank	0.3864	0.3864	0.000
Average*	**0.5101**	**0.5833**	**14.34**
SD	**0.1218**	**0.1304**	

*average without blank

Table 11: Student t-test for each single, double, and triple changes in weight

Glove layer	p-value
Single	$0.400 < p < 0.500$
Double	$0.500 < p$
Triple	$0.500 < p$

4. DISCUSSION

The hypothesis was that multiple layers of disposable nitrile gloves would protect longer against 2-BE than a single layer relative to SBRT and SSPR. From Table 5, the only significant difference between glove layers at $p \leq 0.050$ was triple to single gloving on SSPR and average mass/area permeated at 30 minutes whereas all other permeation parameters showed no statistical difference at $p \leq 0.050$ in SBRT, lag time (t_i) and diffusion coefficient (D). The relationship between mass/area and time was exponential rather than linear.

When these data were compared to those of the Kimberly-Clark single purple unsupported, unlined, powderless nitrile glove of SSPR for 2-BE of 1.27 ± 0.11 µg/cm^2/min (18), the SSPR of the single blue nitrile glove from the present study was 41.20 ± 8.81 µg/cm^2/min. Based on the Ansell classification of the SSPR for all glove materials, the purple nitrile glove has a better rating than blue nitrile glove. This is unexpected because the blue glove is thicker than purple glove (1).

The SBRT for the single purple glove layer was less than 20 minutes, but that for the single blue glove was less than 5 minutes. Based on the Showa Glove Company Glove Selection Guide Chart, chemically protected gloves such as N-DEX Plus 8005, Nitri-Solve 727 nitrile gloves, and Neoprene 6780 gloves have “excellent” ratings with breakthrough times of longer than 480 minutes against 2-BE (19).

The comparisons for SBRT, SSPR (except the comparison between triple to single), average mass/area permeated at 10 and 30 minutes (except the comparison between triple to single), lag time (t_i), and diffusion coefficient (D) for single, double, and triple gloving were not significantly different at $p \leq 0.050$. Therefore, multiple layers of disposable nitrile gloves are not appreciably more protective against 2-BE except for triple gloving for SSPR and average mass/area permeated at 30 minutes.

GC-MS proved to be accurate and precise in the analyses for 2-BE and 4-BP. The major type of permeation curve is Nelson type A (20).

The limitation of equation 1-3 is that in cases of significant swelling or shrinking of the material, equation 1-3 is no longer valid to calculate the D value (1). Another limitation of the data was that the ASTM method does not simulate vigorous hand motions, and so produces permeation parameter data that do not account for this variable (1).

5. SUGGESTIONS FOR FUTURE WORK

This research investigation will help advance the science of Industrial/Occupational Hygiene through knowing the duration that workers can use disposable nitrile gloves working with 2-BE. Therefore, different brands of gloves or chemically protective gloves should be used for their resistance to 2-BE or other chemicals. In this way, workers will not worry about their potential for dermatitis and skin absorption during that work period. Also, this would help industries, as well as employees reduce their costs and concerns dealing with dermatitis if the same was true for other chemicals.

Doing more than three replicates might increase the power of the experiment. Therefore, sample size calculations should be done (21).

6. REFERENCES

1. Banaee, Sean: Permeation of Limonene through Disposable Nitrile Gloves in the Robot Hand Whole Glove and ASTM Closed Loop Models, D.P.H. Dissertation, UCLA, 2015, 169 pages; 3689387.
2. National Institute for Occupational Safety and Health: Recommendations for Chemical Protective Clothing Database, Education and Information Division, Atlanta, GA, 2011.
3. Phalen; R.N. and Wong; V.W.: Chemical Resistance of Disposable Nitrile Gloves Exposed to Simulated Movement, Journal of Occupational And Environmental Hygiene, 9: 630-639, 2012.
4. World Health Organization/International Programme on Chemical Safety. Concise International Chemical Assessment Document No. 10. 2-Butoxyethanol p.4 (1998).
5. Anna; D.H.: Chemical protective clothing, AIHA Press, Fairfax, VA, 2003.
6. CCOHS (Canadian Centre for Occupational Health and Safety) Chemical Protective Clothing - Glove Selection.
7. Keh-Ping Chao, Ven-Shing Wang, and Pak-Hing Lee: Modeling Organic Solvents Permeation Through Protective Gloves, Journal Of Occupational And Environmental Hygiene, 1: 57-61, 2004.
8. U.S. National Library of Medicine, PubChem, 2-Butoxyethanol, Compound Summary for CID 8133, 2012 <https://pubchem.ncbi.nlm.nih.gov/compound/2-Butoxyethanol#section=Top>.
9. ASTM F739-12: Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact, ASTM International, West Conshohocken, PA, 2012.

10. Organization for Economic Co-operation and Development (OECD) Screening Information Dataset (SIDS), 2-Butoxyethanol, 1997 <http://www.inchem.org/documents/sids/sids/111762.pdf>.
11. Corley et al.: Physiologically Based Pharmacokinetics and the Dermal Absorption of 2-Butoxyethanol Vapor by Humans. Fundamental and Applied Toxicology, 39: 120-130, 1997.
12. Johanson, G and Boman, A.: Percutaneous absorption of 2-butoxyethanol vapour in human subjects. Br. J. Indust. Med., 48: 788-792, 1991.
13. Elliott, B. M., and Ashby, A.: Review of the genotoxicity of 2-butoxyethanol. Mutat. Res., 387: 89–96, 1997.
14. National Toxicology Program: NTP Technical Report on the Toxicology and Carcinogenesis Studies of 2-Butoxyethanol IN F344/N Rats and B6C3F$_1$ Mice, Research Triangle Park, NC, 2000 <https://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr484.pdf>.
15. Agency for Toxic Substances & Disease Registry: Toxic Substances Portal- 2-Butoxyethanol and 2-Butoxyethanol Acetate, Atlanta, GA, 2011 <https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=346&tid=61>.
16. U.S. National Library of Medicine, Hazardous Substances Data Bank (HSDB), 2-Butoxyethanol, Bethesda, MD.
17. National Toxicology Program (NTP), 2-Butoxyethanol, Research Triangle Park, NC.
18. Banaee, Sean and Shane S. Que Hee: Permeation of Ethoxy- and Butoxy- Ethanols Through Disposable Nitrile Gloves, Chemosphere, Submitted, 2017.
19. Guide to Chemical-Resistant Best Gloves, A Showa Glove Company, 2008 Edition < http://tchristy.com/wp-content/uploads/2015/11/CHEMREST-Guide_A772-SDS.pdf>.
20. Nelson, G.O. et al. American Industrial Hygiene Association Journal, 42: 217-225 (1981).

21. Sample Size and Power for Epidemiologic Studies, PennState Eberly College of Science, STAT 507, Epidemiological Research Methods, <https://onlinecourses.science.psu.edu/stat507/node/64>.