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16. Abstract (Limit: 200 words) A study was conducted to evaluate protective clothing garment materials used by emergency response personnel and determine their effectiveness when combating ammonia (7664417) or ethylene-oxide (75218) in gaseous form. Data were collected using an automated permeation test system for 13 garment materials representing 11 types of total encapsulating suit materials and two glove materials. For this study neat (100 percent) and 2000 parts per million (0.2 percent) gas were chosen as challenge concentrations. A closed loop test system was chosen for the study using an infrared detector. Breakthrough times and steady state permeation rates were determined. The results indicated suitable garment materials were found to protect workers against 100 percent anhydrous ammonia for an extended time period and there was also a large selection of materials for 0.2 percent ammonia. Surgical latex was not recommended for protection against ammonia. Zippers, seams and other incidental clothing parts were not included in this study. While several materials offered reasonable working time protection against 100 percent ethylene-oxide, only two of the 13 materials were useful for extended time periods. Surgical latex was not recommended. The semiautomated test system used expedited chemical permeation resistance testing and proved to be effective in securing the needed data.

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This study evaluated chemical protective clothing garment materials for use by emergency response personnel confronted by ammonia or ethylene oxide in the gas phase. An automated permeation test system was used to collect these data. Three test specimens were evaluated concurrently versus a challange gas. Thirteen total encapsulating suit materials and two glove materials were tested.

AMMONIA AND ETHYLENE OXIDE PERMEATION THROUGH SELECTED PROTECTIVE CLOTHING

by

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INTRODUCTION

Chemical protective clothing has been called the last line of defense; that is, if there is failure the wearer will be at risk. Chemical permeation test systems to evaluate chemical protective clothing have been studied recently.[1,2] An excellent test system having good chemical sensitivity and selectivity is a closed loop system employing an infrared detector.[3] In a closed loop system, the collection medium is not replaced as in an open loop system, but is continuously recirculated. A closed loop system is more sensitive than an open loop system; i.e., should allow earlier detection of breakthrough time, providing all other factors remain the same. Typically, an infrared instrument such as a Miran-1A (non destructive inline system) is used as the detector for a closed loop system. This test system has been employed for evaluation of total encapsulating suit materials against methyl isocyanate, a toxic volatile chemical.[4] However, the system was manual, requiring constant monitoring, and was time consuming. But with the advance of computer technology, this type of testing can be successfully automated. Such a system employing data collection hardware has been specifically designed for our laboratory to accelerate chemical permeation testing and to minimize human intervention. The objective of this study was to evaluate the semi-automated chemical permeation test system by testihg three specimens simultaneously against a gaseous challenge.

In this study neat (100%) and 2000 ppm (0.2%) gas were chosen as challenge concentrations. These concentrations were chosen because they probably represent a "worst case" or an emergency situation, such as an unplanned discharge of chemicals in a confined space. The challenge gases, ammonia and ethylene oxide, were selected for study. They are important in industry, and they have acceptable infrared analytical sensitivity. Ammonia gas has an ACGIH threshold limit value time weighted average (TLV - TWA) of 25 ppm (18 mg/m^3) and a short term exposure limit (STEL) of 35 ppm (27 mg/m^3).[5] The current OSHA permissible exposure limit (PE) for ammonia is 50 ppm averaged over an eight hour shift. NIOSH recommends a ceiling limit of 50 ppm averaged over a five minute period.[6] At room temperature, ammonia is a gas with a lower explosive limit (LEL) of 16% and an upper explosive limit (UEL) of 25%. Ammonia is widely used in the chemical industry as a starting material; e.g. explosives manufacture, plastics, and fibers manufacture and as a refrigerant.[7]

Ethylene oxide has an ACGIH threshold limit value time weighted average of 1 ppm (2 mg/m^3), and is listed as a suspected human carcinogen.[5] The current OSHA permissible exposure limit (PEL) is 1 ppm averaged over an eight hour work shift. NIOSH recommends it be controlled and handled as a potential human carcinogen. The NIOSH recommended exposure limit (REL) is 5 ppm as a ceiling concentration in any ten minute sampling period and not to be achieved for more than ten minutes during any work day. Also, NIOSH recommends ethylene oxide exposure be less than 0.1 ppm (0.18 mg/m^3) as a TWA for up to an eight hour workshift, 40-hour work week.[8] At room temperature, ethylene oxide is a gas. The lower explosive limit (LEL) is 3% and the upper explosive limit (UEL) is 100%. Ethylene oxide is a widely used sterilization agent.[8]

This study does not evaluate the integrity of the entire encapsulating suit; rather, it evaluates only the garment material. In an actual emergency, the chemical resistance of facepieces, seams, and closures, as well as other components of the total encapsulating suit, must be evaluated. Often, gloves, boots, and o-rings are different from the garment material. Also, the facepiece and positive pressure vent valves are different materials from the garment and could present added leakage potential, which must be considered. These different materials must be evaluated for their risk potential to the contacted chemical, and their chemical resistance if there is appreciable contact risk.

EXPERIMENTAL MATERIALS

The air used was house air which was passed through a dryer/sorbent system to remove contaminants.

Ammonia gas, anhydrous grade 99.99% purity and ethylene oxide 99.9% purity were purchased from Matheson Gas Products.

The cell was a glass 1-inch (2.54 cm) diameter chemical permeation cell available from AMK Glass Co., 610 South 3rd Avenue, Vineland, NJ 08360. It is completely described in reference 9.

The Miran 1A General Purpose Infrared Gas Analyzer is a single-beam, variable filter spectrometer capable of scanning the infrared spectral range between

2.5 and 14.5 μm. The instrument is equipped with a gas cell having variable path length between 0.75 and 20.25 meters. A stainless steel pump, Model MB-41, manufactured by Metal Bellows Corporation producing a flowrate of approximately 8 sLpm was used to circulate air through the closed system. All tubing was Teflon®; all connectors were stainless steel or Teflon®.

The specimens tested are listed in data Table I through IV and represent a wide variety of garment materials used to fabricate total encapsulating suits.

The computer hardware included:

Computer

Hewlett Packard, Model 216 -- 1 Mbyte RAM, with 3-1/2 inch dual floppy disk drive, data acquisition system, and plotter.

EXPERIMENTAL DESIGN

The NIOSH developed software is a menu driven program written in HP Basic 5.1 capable of data storage, retrieval, and analysis. The software was written so that calibration data could be entered, then used to convert the detector's voltage reading into concentration.

Breakthrough time was selected as that positive voltage exceeding the limit of detection by twice the background. Steady state permeation rate was determined from the linear portion of the voltage (concentration) versus time computer generated graph.

The actual system consisted of three separate cell-detector sub-systems (loops) which were monitored by the computer (Figure 1). Each sub-system was a closed loop, with one infrared detector to monitor the collection side of the permeation cell. The challenge side of the cell was connected to a mixing manifold. The mixing manifold was in turn connected to a compressed gas cylinder (challenge agent) and house air. The house air was metered through a TYLAN® mass flow controller into the mixing manifold. The compressed gas was metered by a calibrated rotameter.

The challenge side of the cell was an open loop, and was common to all cells. The challenge gas was replaced continuously at 3 to 5 liters per minute flowrate. Compressed gas alone was used to obtain 100%, or neat, gas challenge concentration. For the 2000 ppm concentration, the compressed gas was diluted with clean house air. The system was calibrated bimonthly, but a two point calibration check was made daily. These points must lie within the 95% confidence interval; if not, a complete recalibration was conducted. The three detectors ran simultaneously. A data point was collected and stored every minute. Thus, the bias due to sampling is ± 1 minute. The system could operate for up to 72 hours before memory capacity was exceeded. The following IR conditions were used throughout the experiments:

ethylene oxide

0 - 1.0 Absorbance scale

1 mm slit width

1 sec response time

20.25 m pathlength

3.3μm wavelength

Ammonia

0 - 1.0 Absorbance scale

1 mm slit width

1 sec response time

20.25 m pathlength

10.9 μm wavelength

The ethylene oxide lower limit of detection for this system was 0.59 ppm (1.06 mg/m^3). The ammonia lower limit of detection for the same system was 1.18 ppm (0.82 mg/m^3).

All experiments were conducted at room temperature (24°C ± 3°C).

RESULTS

Chemical permeation test results; i.e., breakthrough times and steady state permeation rates are listed as Tables I through IV. Thirteen garment materials representing eleven types of total encapsulating suit materials and two glove materials were used. Table I contains the chemical permeation data for 100% (neat) anhydrous ammonia; Table II, the data for 0.2% ammonia (2000 ppm) ethylene oxide. The mean breakthrough times and standard deviation were rounded off to the nearest minute. Tables I, II, III, and IV were combined and modified into two separate tables. Tables V and VI group breakthrough times into three intervals: Greater than 240 minutes, 60 to 340 minutes, and less than 60 minutes. Also within a group, materials are arranged by decreasing mean breakthrough time.

It can be seen from this data that there are suitable garment materials to protect workers against 100% anhydrous ammonia for an extended time; and there is also a large selection of materials for 0.2% ammonia. However, it must be remembered that this report does not address seams, zippers, etc., which would have to be evaluated separately. Surgical latex is not recommended for use in protection against ammonia.

Many materials afforded protection for a reasonable working time (60 to 240 minutes) against 100% ethylene oxide. For extended exposure, only two of thirteen materials are suitable. At the lower concentration, 0.2% ethylene oxide, most material afforded protection for 4 hours. Surgical latex is not recommended for protection against ethylene oxide.

DISCUSSION

Chemical permeation is a three step process: sorption on the outer surface, diffusion and solution through the matrix, and desorption from the inner surface. Chemical permeation is a concentration dependant phenomenon; that is, the experimentally observed parameters, breakthrough time, and steady state rate should vary with concentration. Breakthrough time should vary inversely with concentration. The breakthrough time becomes shorter as concentration is increased. This is empirical rather than theoretical. The steady state rate theoretically should vary directly with concentration. The steady state rate becomes larger as concentration is increased. The data demonstrates this qualitatively; the breakthrough times for 100% challenge agent concentration should be shorter than for 0.2% challenge concentration. Also, the steady state permeation rate using a 100% challenge concentration should be larger than that using a 0.2% challenge concentration.

Breakthrough time standard deviation and steady state permeation standard deviation demonstrates the variability observed. However, the variation is believed to be due to specimen variations rather than variation in the test system.[(2)] Chemical permeation data variation has been observed by other researchers using liquid challanges.

The test system was calibrated periodically. Large variation of individual challange gas calibration points (concentration versus IR voltage) were absent. Further, standard curves generated by these calibration points did not exhibit large variation. Variation of experimentally obtained data cannot be explained, based on test system variation.

Test specimens were not rigorously inspected for pinholes. Specimens were placed over a 60 watt light. This would not reveal very small pinholes. Pinholes would cause chemical penetration. Chemical penetration would be observed in chemical permeation experiments, as rapid breakthrough and increasing concentration of permeant gas. This behavior was not observed, so chemical penetration is not a significant factor. However, other experiments in progress have revealed chemical protective clothing may have a fractured surface which is pitted and cratered, much like the surface of the moon. Further, thicknesses have been measured on such fractured materials and were found to be amazingly consistent. There were not high and low areas which yielded large thickness variations. These surface fractures may be responsible for the observed variation in experimental data.[11] Ongoing research in this area should resolve this issue.

CONCLUSION

A semi-automated test system can expedite chemical permeation resistance testing. One material can be routinely tested in triplicate versus a gaseous challenge. Two materials can be tested in triplicate to maximize data collection. This test system was used to obtain chemical permeation data; i.e., breakthrough time and steady state permeation rate for ethylene oxide and ammonia gas under IDLH conditions.

The system is an effective, efficient method to generate chemical permeation data for gas challange agents. The test system is suitable for gas challange concentrations in the IDLH range and near the AGGIH TLVs.

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TABLE I

Permeation of 100% Ammonia Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate ($\mu g/cm^2/min$)	Mean Steady State Permeation Rate ± Standard Deviation
Wheeler	1	0.450		18		1.94	
Polyvinylchloride	2	0.450		20		1.83	
(PVC)	3	0.450		20		1.98	
	4	0.440		20		1.34	
	5	0.435	0.445 ± 0.007	20	19 ± 1	0.98	1.61 ± 0.44
Wheeler	1	0.274		>566			
Butyl	2	0.280		>566			
	3	0.278	0.277 ± 0.003	>566	>566	---	---
Fyrepel	1	0.214		45		0.76	
Viton®	2	0.212		50		0.21	
	3	0.211	0.212 ± 0.015	55	50 ± 5	0.30	0.42 ± 0.29
Dayton	1	0.187		2			
Surgical Latex	2	0.200		2		27.5	
	3	0.191	0.192 ± 0.007	2	2 ± 0	25.5	26.5 ± 1.4
ILC Dover	1	0.429		51		1.43	
Urethane	2	0.433		50		0.51	
	3	0.436	0.433 ± 0.035	59	53 ± 5	1.08	1.01 ± 0.47
ILC Dover	1	0.546		140		0.19	
Chloropel	2	0.546		171		0.34	0.32 ± 0.13
	3	0.540	0.544 ± 0.003	151	154 ± 16	0.44	
MSA Betex®	1	0.453		>850			
Butyl on Polyester	2	0.455		>850			
on Neoprene	3	0.455	0.454 ± 0.0001	>850	>850	---	---

TABLE I (Continued)

Permeation of 100% Ammonia through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate (µg/cm²/min)	Mean Steady State Permeation Rate ± Standard Deviation
MSA Vautex®	1	0.491		>400			
Viton on Nylon	2	0.497		>400			
on Neoprene	3	0.498	0.495 ± 0.023	>400	>400	---	---
Fairprene®	1	0.438		170		0.83	
Neoprene	2	0.447		150		0.55	
	3	0.436	0.440 ± 0.006	170	163 ± 11	0.48	0.62 ± 0.19
Saranex-Tyvek®	1	0.140		18		0.11	
	2	0.170		19		0.06	
	3	0.170	0.160 ± 0.017	30	21 ± 8	0.09	0.09 ± 0.03
Chem Fab	1	0.270		219		0.02	
Nonwoven Nomex	2	0.270		269		0.02	
on Teflon	3	0.279	0.273 ± 0.005	275	254 ± 30	0.04	0.03 ± 0.01
Pioneer	1	0.342		288		0.56	
Nitrile Glove	2	0.350		295		0.58	
A-15	3	0.344	0.345 ± 0.004	280	288 ± 7	0.84	0.66 ± 0.15
Chemron	1	0.299		30		0.22	
Chemrel®	2	0.288		30		0.20	
	3	0.283	0.290 ± 0.008	40	33 ± 6	0.15	0.19 ± 0.04

TABLE II

Permeation of 0.2% Ammonia Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate (μg/cm²/min)	Mean Steady State Permeation Rate ± Standard Deviation
Wheeler	1	0.429		19		0.91	
Polyvinylchloride	2	0.435		21		1.32	
(PVC)	3	0.438	0.434 ± 0.004	23	21 ± 2	0.92	1.05 ± 0.23
Wheeler	ND						
Butyl							
Fyrepel	1	0.221		68		0.14	
Viton®	2	0.222		75		0.34	
	3	0.223	0.222 ± 0.001	98	80 ± 16	0.38	0.17 ± 0.16
Dayton	1	0.222		5		8.77	
Surgical Latex	2	0.226		5		9.15	
	3	0.224	0.224 ± 0.002	5	5 ± 0.0	5.38	7.77 ± 2.07
ILC Dover	1	0.540		269		0.09	
Chloropel®	2	0.544		259		0.30	
	3	0.545	0.543 ± 0.003	291	273 ± 16	0.19	0.19 ± 0.10
MSA Betex®	1	0.453		>850			
Butyl on Polyester	2	0.455		>850			
on Neoprene	3	0.455	0.454 ± 0.001	>850	>850	---	---
MSA Vautex®	1	0.520		>350			
Viton on Nylon	2	0.528		>350			
on Neoprene	3	0.527	0.525 ± 0.004	>350	>350	---	---

TABLE II (Continued)

Permeation of 0.2% Ammonia Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate ($\mu g/cm^2/min$)	Mean Steady State Permeation Rate ± Standard Deviation
Fairprene®	1	0.435		350		0.14	
Neoprene	2	0.444		275		0.39	
	3	0.441	0.444 ± 0.004	285	303 ± 41	0.11	0.22 ± 0.15
Saranex-Tyvek®	1	0.171		>300			
	2	0.178		>300			
	3	0.165	0.171 ± 0.006	>300	>300	---	---
Chem Fab Nonwoven Nomex on Teflon	ND						
Pioneer	1	0.328		520			
Nitrile Glove	2	0.322		600			
A-15	3	0.344	0.331 ± 0.011	743	621 ± 113	0.39	0.39 ± 0.10
Chemron	1	0.255		162		0.01	
Chemrel®	2	0.272	0.264 ± 0.12	120	141 ± 30	0.02	0.02 ± 0.00
ILC Dover	1	0.455		50		0.25	
Urethane	2	0.433		55		0.72	
	3	0.447	0.445 ± 0.011	70	58 ± 48	0.09	0.35 ± 0.33

ND = Not Determined

TABLE III

Permeation of 100% Ethylene Oxide Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time (min) ± Standard Deviation	Steady State Permeation Rate (μg/cm²/min)	Mean Steady State Permeation Rate ± Standard Deviation
Wheeler	1	0.442		14		136.5	
Polyvinylchloride	2	0.439		14		34.7	
(PVC)	3	0.431	0.437 ± 0.006	12	13 ± 1	132.6	108.0 ± 46.3
Wheeler	1	0.281		85		0.09	
Butyl	2	0.280		71		0.11	
	3	0.286	0.282 ± 0.003	99	85 ± 14	0.79	0.09 ± 0.1
Fyrepel	1	0.223		130		2.39	
Viton®	2	0.223		115		1.66	
	3	0.222	0.223 ± 0.001	102	116 ± 14	2.15	2.07 ± 0.37
Dayton	1	0.170		3		136.1	
Surgical Latex	2	0.150		4		142.1	
	3	0.160	0.160 ± 0.010	3	3 ± 1	126.1	134.7 ± 8.1
ILC Dover	1	0.438		28		62.68	
Urethane	2	0.450		29		40.69	
	3	0.438	0.442 ± 0.007	29	29 ± 1	44.89	49.42 ± 11.68
ILC Dover	1	0.528		140		22.76	
Chloropel	2	0.537		171		18.01	20.12 ± 2.41
	3	0.536	0.534 ± 0.005	113	118 ± 6	19.60	
MSA Betex®	1	0.450		155		0.12	
Butyl on Polyester	2	0.460		164		0.18	
on Neoprene	3	0.460	0.457 ± 0.006	175	165 ± 10	0.11	0.14 ± 0.04

TABLE III (Continued)

Permeation of 100% Ethylene Oxide Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate (µg/cm²/min)	Mean Steady State Permeation Rate ± Standard Deviation
MSA Vautex®	1	0.500		60		1.53	
Viton on Nylon	2	0.493		84		2.58	
on Neoprene	3	0.511	0.501 ± 0.009	96	80 ± 18	1.90	2.00 ± 0.53
Fairprene®	1	0.425		54		9.72	
Neoprene	2	0.427		51		12.22	
	3	0.422	0.425 ± 0.002	49	51 ± 2	16.50	12.81 ± 3.43
Saranex-Tyvek®	1	0.178		117		6.20	
	2	0.151		120		5.89	
	3	0.160	0.163 ± 0.014	126	121 ± 5	8.20	6.76 ± 1.25
Chem Fab	1	0.270		>950			
Nonwoven Nomex	2	0.270		>950			
on Teflon	3	0.270	0.270 ± 0.0	>950	>950	---	---
Pioneer	1	0.333		200		15.91	
Nitrile Glove	2	0.349		196		10.38	
A-15	3	0.352	0.345 ± 0.010	189	195 ± 6	8.14	11.45 ± 4.00
Chemron	1	0.276		>1050			
Chemrel®	2	0.305		>1050			
	3	0.292	0.291 ± 0.014	>1050	>1050	---	---
ILC Dover	1	0.438		28		62.68	
Urethane	2	0.450		29		40.69	
	3	0.438	0.442 ± 0.007	29	29 ± 1	44.89	49.42 ± 11.68

TABLE IV

Permeation of 0.2% Ethylene Oxide Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate (μg/cm²/min)	Mean Steady State Permeation Rate ± Standard Deviation
Wheeler	1	0.436		30		18.96	
Polyvinylchloride	2	0.434		30		48.11	
(PVC)	3	0.442	0.437 ± 0.041	32	31 ± 1	38.26	34.78 ± 15.38
Wheeler	1	0.281		>400			
Butyl	2	0.280		>400			
	3	0.272	0.278 ± 0.005	>400	>400	---	---
Fyrepel	1	0.215		>800			
Viton®	2	0.215		>800			
	3	0.215	0.215 ± 0.0	>800	>800	---	---
Dayton	1	0.174		5		2.04	
Surgical Latex	2	0.166		4		3.61	
	3	0.186	0.17 ± 0.010	5	5 ± 1	3.39	3.01 ± 0.85
ILC Dover	1	0.544		>375			
Chloropel®	2	0.549		>375			
	3	0.546	0.546 ± 0.0002	>375	>375	---	---
MSA Betex®	1	0.460		>400			
Butyl on Polyester	2	0.455		>400			
on Neoprene	3	0.464	0.460 ± 0.004	>400	>400	---	---

TABLE IV (Continued)

Permeation of 0.2% Ethylene Oxide Through Selected Chemical Protective Clothing

Product	Runs	Thickness (mm)	Mean Thickness(mm) ± Standard Deviation	Breakthrough Time (min)	Mean Breakthrough Time(min) ± Standard Deviation	Steady State Permeation Rate ($\mu g/cm^2/min$)	Mean Steady State Permeation Rate ± Standard Deviation
MSA Vautex®	1	0.495		>450			
Viton on Nylon	2	0.498		>450			
on Neoprene	3	0.519	0.504 ± 0.013	>450	>450	---	---
Fairprene®	1	0.425		165		0.46	
Neoprene	2	0.430	0.426 ± 0.006	150	158 ± 11	0.65	0.56 ± 0.13
Saranex-Tyvek®	1	0.149		>400			
	2	0.152		>400			
	3	0.167		>400			
	4	0.159		>400			
	5	0.153		>400			
	6	0.148	0.155 ± 0.007	>400	>400	---	---
Chem Fab Nonwoven Nomex on Teflon	ND						
Pioneer	1	0.371		>315			
Nitrile Glove	2	0.358		>315			
A-15	3	0.357	0.368 ± 0.009	>315	>315	---	---
Chemron Chemrel®	ND						
ILC Dover	1	0.437		85		0.08	
Urethane	2	0.444		60		0.02	
	3	0.447	0.443 ± 0.005	50	65 ± 18	0.10	0.07 ± 0.04

Table V. Garment Material Breakthrough Time Groups for Ammonia

Breakthrough Time Groups	Ammonia Concentration 100%	0.2%
>240 minutes (4 hours)	Betex® (>850, --) Butyl (>560, --) Vautex® (>400, --) Nitrile (288, 0.6) Teflon (254, 0.03)	Betex® (>850, --) Butyl (--, --) Vautex® (>350, --) Saranex-Tyvek® (>300, --) Nitrile (631, 0.4) Neoprene (303, 0.2) Chloropel® (273, 0.2) Teflon (--, --)
60 - 240 minutes (1-4 hours)	Neoprene (163, 0.6) Chloropel® (154, 0.3) Saranex Tyvek (21, 0.3)	Chemrel® (141, 0.02) Viton® (80, 0.2)
<60 minutes (<1 hour)	Viton® (55, 0.4) Urethane (53, 1.0) Chemrel® (33, 0.2) PVC (19, 1.9) Surgical Latex (2, 26.5)	Urethane (58, 0.3) PVC (21, 1.0) Surgical Latex (5, 7.8)

-- = No Data

Data arranged within each group by decreasing breakthrough time. The first number in the parenthesis is the mean breakthrough time; the second number is the mean steady state permeation rate. (Example: For (55, 0.4), 55 is minutes of breakthrough time, and 0.4 is $\mu g/cm^2/mins$ steady state permeation rate.)

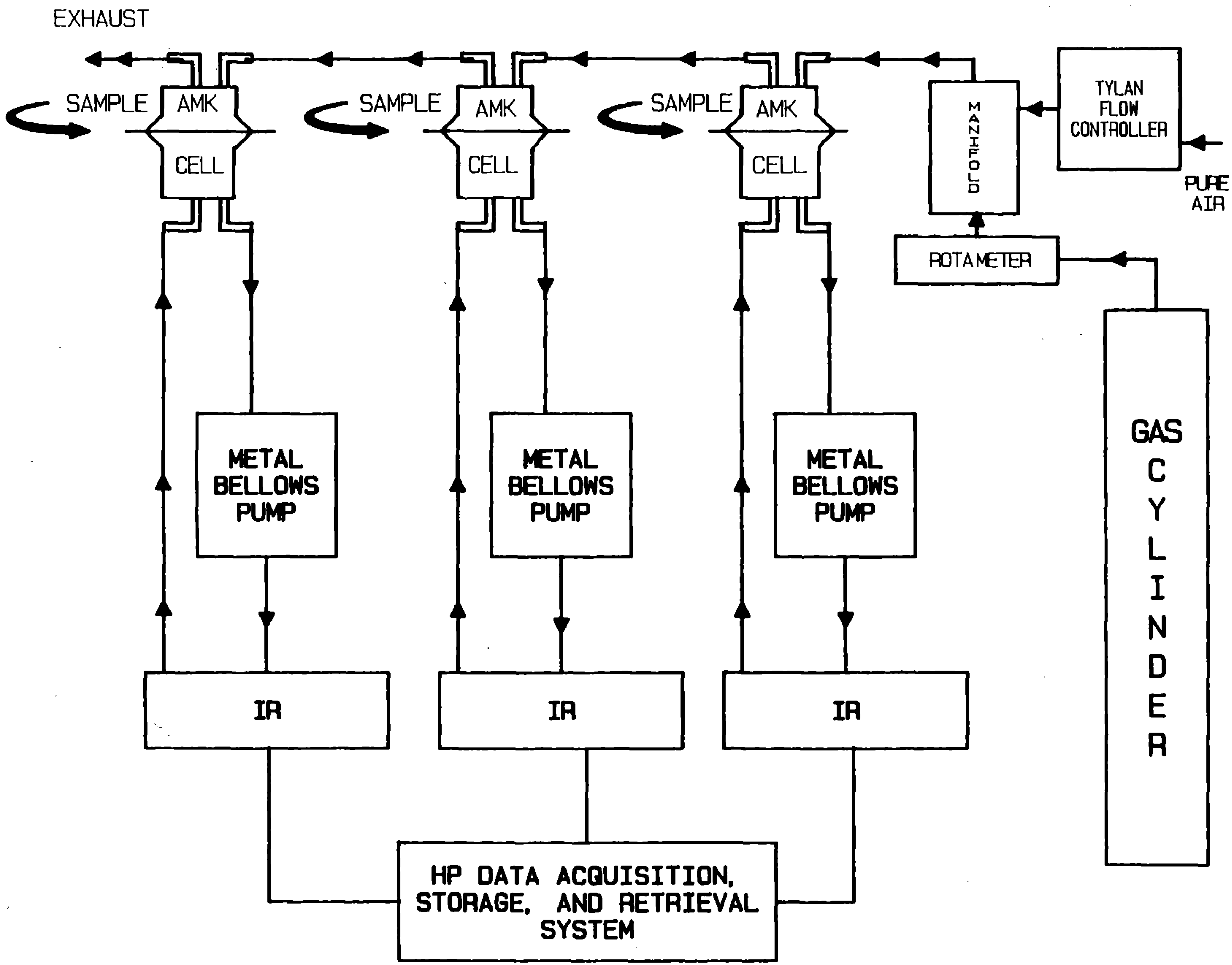
Table VI. Garment Material Breakthrough Time Groups for Ethylene Oxide

Breakthrough Time Groups	Ethylene Oxide Concentration 100%	Ethylene Oxide Concentration 0.2%
>240 minutes (4 hours)	Chemrel® (>1050, --) Teflon (>950, --)	Chemrel® (--, --) Teflon (--, --) Viton® (>800, --) Vautex® (>450, --) Betex® (>400, --) Nitrile (>400, --) Butyl (>400, --) Saranex-Tyvek® (>400, --) Chloropel® (>375, --)
60 - 240 minutes (1-4 hours)	Nitrile (195, 11.5) Betex® (165, 0.1) Saranex Tyvek (121, 6.8) Chloropel (118, 20.1) Viton® (116, 2.1) Butyl (85, 0.1) Vautex® (80, 2.0)	Neoprene (158, 0.6) Urethane (65, 0.1)
<60 minutes (<1 hour)	Neoprene (51, 12.8) Urethane (29, 49.4) PVC (13, 101.0) Surgical Latex (3, 134)	PVC (31, 34.8) Surgical Latex (5, 3.0)

-- = No Data

Data arranged within each group by decreasing breakthrough time. The first number in the parenthesis is the mean breakthrough time; the second number is the mean steady state permeation rate. (Example: For (195, 11.5), 195 is minutes of breakthrough time, and 11.5 is $\mu g/cm^2/mins$ steady state permeation rate.)

Figure Caption Listing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CELL
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CELL
MANIFOLD
TYLAN FLOW CONTROLLER
PURE AIR
ROTAMETER
GAS CYLINDER
METAL BELLOWS PUMP
METAL BELLOWS PUMP
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HP DATA ACQUISITION, STORAGE, AND RETRIEVAL SYSTEM