The Effects of Flow Rate, Back Pressure, and Cell Design on Permeation Results

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Objectives

- **Better understand how flow rate, back pressure, and cell design contribute to variability in cumulative permeation (CP)**
- **Translate project findings into improving ASTM and National Fire Protection Association (NFPA) standard test methods**

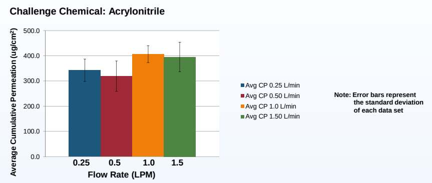
Background

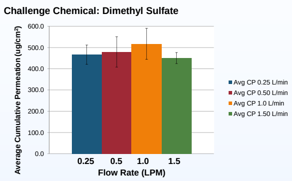
- **Chemical permeation testing measures how much and/or how fast a chemical test agent passes through a material and is used to evaluate the performance of protective clothing[1]**
- **NFPA 1994[2] uses a CP test as a requirement for first responder protective clothing. The CP test in this standard requires strict humidity and temperature conditions and the use of the Aerosol, Vapor, Liquid, Assessment Group (AVLAG) permeation cell**
- **Several factors can affect permeation test results, but few studies focused solely on these factors and quantified their effects on CP**
- **Chemical permeation is driven by concentration gradient**
  - Flow rate must be enough to sufficiently clear permeant away from material to maintain concentration gradient across test material
- **Collection Efficiency**
  - If sorbent tubes are used to collect permeant, a high flow rate may not allow the analyte to sorb causing pass-through
- **Back Pressure**
  - Collection media that is forced through the test cell will result in back pressure which may distend the test material and increase its surface area

Materials and Methods

- **Emergency Medical Services (EMS) moisture barrier**
  - Selected because it exhibited significant CP after 1 hour
- **Environmental Conditions**
  - All samples tested at 80% ± 5%RH and 32°C ± 3°C
- **Collection Media Flow Rates**
  - Cumulative permeation measured for each challenge chemical at 0.25, 0.50, 1.00, and 1.50L/min
- **Challenge Liquid Concentration Density (35mm AVLAG Cell)**
  - 7.0uL for Acrylonitrile = 5.86g/m^2
  - 7.0uL for Dimethyl Sulfate (DMS) = 10.0g/m^2
  - Applied as ~1uL drops uniformly distributed over challenge area
- **Eight tests completed at each flow rate**
- **Average cumulative permeation (CP), standard deviation and coefficient of variation (CV) were calculated**

Flow Rate: Results and Discussion





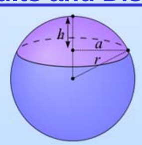
Flow Rate (L/min)	Average CP (µg/cm²)	Stdev	$2.8*CV_{cp}$
0.25	342.37	44.55	0.32
0.50	318.80	60.31	0.53
1.00	***406.27***	***33.39***	***0.23***
1.50	394.88	58.45	0.41

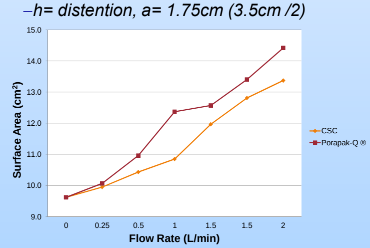
Flow Rate (L/min)	Average CP (µg/cm²)	Stdev	$2.8*CV_{cp}$
0.25	466.31	45.61	0.27
0.50	479.09	71.06	0.42
1.00	517.32	72.94	0.39
1.50	***450.18***	***25.94***	***0.16***

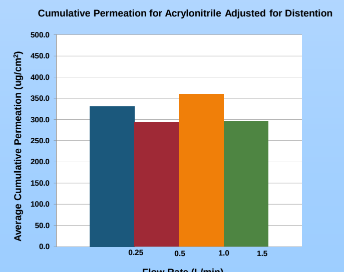
- **Low flow rates did not sufficiently remove permeant**
  - Decreased concentration gradient
- **Complex collection flow path required high flow rate**
- **Low vapor pressure associated with DMS required higher flow rate for consistent results**

Back Pressure (Material Distention): Results and Discussion

- **Calculating surface area increase:**
  - $S_{cap}=\pi(a^2+h^2)$
  - *h= distention, a= 1.75cm (3.5cm /2)*





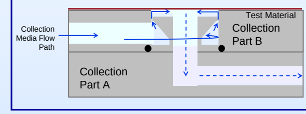


- **Results**
  - First time surface area increase caused by material distention has been calculated
  - Significant increase in surface area
  - Distention may impact results
  - May need to increase challenge volume to maintain challenge density

	Flow Rate (L/min)	Number of Sorption Tubes	Back Pressure (kPa)	Distention (mm)	Surface Area (cm²)	% Increase
CSC for Acrylonitrile	0.00	0	0.00	0	9.62	0.00
	0.25	1	0.49	3.22	9.95	3.40
	0.5	1	1.18	5.08	10.43	8.44
	1.00	1	2.75	6.25	10.85	12.77
	1.50	1	5.00	8.64	11.97	24.39
	1.50	2	9.91	10.08	12.81	33.19
	2.00	2	12.75	10.93	13.37	39.03
Porapak-Q® for DMS	0.00	0	0.00	0	9.62	0.00
	0.25	1	0.00	3.77	10.07	4.65
	0.5	1	0.00	6.53	10.96	13.94
	1.00	2	7.26	9.35	12.37	28.56
	1.50	1	6.87	9.69	12.57	30.68
	1.50	2	10.79	10.97	13.40	39.31
	2.00	2	11.79	12.36	14.42	49.90

NPPTL Cell Design: Results and Discussion

- **Partially based off of the Bromwich[3] Mk2 cell**
  - Collection media flows through 0.1mm annular slit, providing a radial collection flow culminating in the center of the cell
- **Hybrid design to fit certain AVLAG cell specifications to allow for ease in transition**
  - Challenge surface area and challenge free volume
- **Rugged aluminum construction similar to AVLAG design**
- **Can be used with both gas and liquid *collection* media and gas and liquid *challenge* chemicals**
- **Higher collection efficiency = lower collection media flow rate**



"NPPTL" Cell Initial Results

Challenge Chemical: DMS

Flow Rate (L/min)	Average CP (µg/cm²)	Stdev	$2.8*CV_{cp}$
0.25	556.82	28.61	0.14

Summary

- **Collection media flow rate is challenge chemical specific**
  - Challenge chemicals with lower vapor pressures may need a higher flow rate to effectively clear permeant from material surface
- **Material distention caused by back pressure may affect challenge density**
- **New cell design**
  - Increased collection efficiency allows the use of a lower flow rate
  - Designed specifically with the collection media flow rate in mind
  - Use of a lower flow rate decreases the resulting back pressure
  - New design needs to be validated against the AVLAG and F739 cell designs

Future Work

- **Measure flow rate effects on CP associated with ammonia**
  - Peer reviewed journal article
- **Validate "NPPTL" cell against F739 and AVLAG cell designs**
  - Choose flow rate appropriate for challenge chemical
- **New ASTM test method and NFPA proposal**
  - Describing and including "NPPTL" cell design

References
1 ASTM F739 – 07: ***Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact.*** **[Standard] ASTM, 2007**
2 National Fire Protection Association (NFPA): ***Standard on Protective Ensembles for First Responders to CBRN Terrorism Incidents*** **(NFPA Standard 1994). [Standard] NFPA, 2007**
3 Bromwich. D. W, The Design of Permeation Cells for Testing Chemical Protective Clothing. PhD thesis, School of Environmental Engineering. Nathan, Australia, Griffith University, p.107