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S.R. COOVER , P.C. REIST & P.A. HUDGINS

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Current air purifying organic vapor design criteria require inhalation and exhalation valving to assure that exhalation does not occur through the sorbent bed. Testing of two brands of air purifying respirators in a bidirectional valveless configuration indicated that service lives for carbon tetrachloride and vinyl chloride could be extended by factors ranging from 1.5 to 3.6 as compared to conventional unidirectional valved configurations. Exhalation through the sorbent can partially desorb the contaminant without saturating the sorbent with water. These results suggest that it may be possible to extend the service lives of air purifying organic vapor respirators by deleting inhalation and exhalation valves. A disadvantage of a valveless configuration is extra breathing resistance encountered upon exhalation which may be intolerable to certain individuals.

Performance of air purifying organic vapor respirators in valveless, bidirectional flow configurations

S.R. COOVER, Ph.D., P.C. REIST, Sc.D. and P.A. HUDGINS,[A] MSPH
University of North Carolina at Chapel Hill, Dept. of Environmental Sciences and Engineering, School of Public Health, Chapel Hill, NC 27514

introduction

National Institute for Occupational Safety and Health (NIOSH) design criteria for air purifying organic vapor respirators require inhalation and exhalation valves to assure that exhalation does not occur through the air purifying cartridge.[1] Moisture in exhaled breath was assumed to saturate the air purifying cartridge rendering it ineffective. The recent introduction by the 3-M Company of a valveless long life air purifying respirator for vinyl chloride (part number 08716) casts doubt upon this assumption.

This study[2] was undertaken to characterize the performance of sorbents under bidirectional flow conditions using the new 3-M respirator and a standard air purifying organic vapor respirator cartridge (Pulmosan Safety Equipment Company).

experimental design

Respirator performances were characterized for exposure to carbon tetrachloride (500 and 1000 ppm) and vinyl chloride (10 and 50 ppm). All tests were performed in duplicate. All respirators were tested as received with no preconditioning. Five test configurations, Table I, were used.

The first phase of testing involved two tests using a continuous flow of air through the respirator. Test I consisted of flowing a continuous stream of contaminated air through the respirator at a flowrate of 64 Lpm following standard cartridge testing procedures.[1] Tests continued until breakthrough occurred, defined as 5 ppm for carbon tetrachloride and 1 ppm for vinyl chloride.

Test II involved the same flow of air through the respirator, but the contaminant was present in alternating cycles. Based on the service life determined in Table I, intervals were specified by dividing this service life by ten. For example, if Test I resulted in a breakthrough time of 100 minutes, Test II would include cycles of 10 minutes of contaminated air followed by 10 minutes of uncontaminated air. Flowrate through the respirator was held constant at 64 Lpm.

The next phase of experimentation utilized a breathing machine. Test III consisted of inspiring contaminated air through the respirator and then expiring the air back through the respirator. The breathing apparatus provided a minute volume of 32 liters through the respirator at a respi-

[A]Present Address: Mobile Chemical Co., High Point, NC 27261.

TABLE I
Test Configuration

Test No.	Flow Rate, Lpm		Contaminant Presence	Humidification
	Inhalation	Exhalation		
I	64	0	100% of time	No
II	64	0	50% of time*	No
III	32	32	100% of time	No
IV	30.5	30.5	100% of time	Yes
V	32	0	100% of time	No

*Alternating on and off periods with each on or off period equal to 10% of Test I breakthrough time.

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TABLE II
Carbon Tetrachloride Breakthrough Time, Minutes

	500 ppm		1000 ppm	
Test	Pulmosan	3-M	Pulmosan	3-M
I	109±1.5	115.1±2.5	67.2±0.6	65.4±.4
II	186.5±0.5	198.7±2.5	113.0±1.0	113.9±1.0
III	---	---	>480	>480
IV	---	---	>480	386.1±2.8
V	---	---	131.0±1.0	131.0±2.6

Errors represent ranges of values observed.

ration rate of 42 per minute, corresponding to a moderate work rate. The contaminated atmosphere was drawn across the face of the cartridge at 100 Lpm which is equal to the peak inspiratory flowrate through the cartridge during the sinusoidal breathing cycle.

Test IV consisted of the same configuration as Test III except the expired air was heated and humidified (37-38° C, 90% RH) to simulate exhaled air. Added resistance of the heating and humidification apparatus reduced the minute volume to 30.5 liters. Respiration rate remained at 42 per minute. The contaminated test atmosphere flowrate across the face of the respirator remained at 100 Lpm.

Test V consisted of the same configuration as Test III with the exception that expired air was vented through an exhalation valve directly to the laboratory fume hood instead of passing backward through the respirator. This resulted in a unidirectional pulsating flow with a minute volume of 32 liters passing through the respirator in only the inspiratory direction. All other test parameters remained as in Test III.

experimental system

respirator test chamber

The respiratory test chamber consisted of a 20 cm diameter by 32 cm vertical acrylic cylinder, with a center plate on which the respirator or cartridge was fastened. 3-M respirators required removal of the two elastic headbands and two lower strap fittings before they would fit in the test chamber. The 3-M respirators were held in place by two bolts through the upper strap fittings and a finger clamp at the respirator bottom. The respirator's rubber faceplate functioned as a gasket between the upper and lower portions of the test chamber. A portion of the rubber faceplate had to be cut away to prevent blockage of the air flow through the respirator. Pulmosan respirator cartridges were screwed into a receptable mounted on the chamber's center plate.

test atmosphere

Carbon tetrachloride vapor was generated by passing compressed air through a Greensburg-Smith impinger half filled with ACS reagent grade carbon tetrachloride. The vapor was mixed with a clean air stream in a one inch glass tee before introduction into the upper portion of the test chamber. Vapor flowrate was regulated with a needle valve and rotameter in the compressed air supply line.

A two percent mixture (Primary Standard) by volume of vinyl chloride in air was purchased from MG Scientific Gases. Gas flow rate was regulated with a pressure regulator, needle valve and rotameter. Gas was injected at the same point as was the carbon tetrachloride vapor.

A high volume air sampler attached to the lower portion of the test chamber pulled contaminated air through the respirator at 64 Lpm during Tests I and II. During Tests III-V the high volume air sampler was attached to a second baffled port on the upper portion of the test chamber so as to draw the contaminated air stream across the face of the respirator at 100 Lpm. Air flow was measured with a dry gas meter upstream of contaminant introduction (contaminant stream flow was insignificant as compared to main air flow). Air flow was adjusted by varying the input voltage to the high volume sampler with a variable autotransformer.

analysis of test atmosphere

Analysis of the test atmosphere was accomplished with two Wilkes Scientific Miran IA infrared spectrophotometers. Both the assult concentration and the downstream concentration were continually monitored. Carbon vane pumps were used to circulate the atmosphere through each Miran and return it to the test chamber.

During the study phase in which moisture saturated air at 37 °C was circulated, the Miran used to monitor the downstream concentration and its sample lines were heated to 40 °C with heat tape to prevent condensation. It was found that the addition of humidity directly influenced the absorbance readings of the downstream Miran. To correct for this, the Miran was first zeroed with dry air and then allowed to equilibrate with moisture laden air without rezeroing. The absorbance value which corresponded to the contaminant concentration in dry air at breakthrough was then added to this equilibrated absorbance value to yield an effective absorbance at breakthrough.

During humidified runs a Miran calibrated for water vapor was used to verify that the absolute humidity of the exhaled air corresponded to a relative humidity of at least 90% at 37-38 °C.

breathing apparatus

The breathing pump consisted of a 15 cm diameter by 20 cm long right cylindrical leather bellows which could be oscillated along its longitudinal axis by a crank having a 0-12 cm adjustable stroke. The crank was driven by a sprocket and chain drive from a 1/3 Hp electric motor with integral variable speed drive. Stroke rate was variable from nearly 0

TABLE III
Air Purifying Capacity: Carbon Tetrachloride
ppm-liters x 10^6

	500 ppm		1000 ppm	
Test	Pulmosan	3-M	Pulmosan	3-M
I	3.49	3.68	4.30	4.19
II	2.98	3.18	3.39	3.64
III	---	---	15.4	15.4
IV	---	---	14.6	11.8
V	---	---	4.19	4.19

to 42 per minute. Flapper check valves provided a unidirectional flow. Seven-eighths inch polyethylene respiratory therapy tubing was used to connect the bellows to the test system. Flowrate was measured with a dry gas meter connected in the bellows intake line. Maximum flowrate was 32 Lpm at 42 strokes per minute.

During Test III the intake to the dry gas meter and the bellows exhaust were connected to the lower portion of the cartridge test chamber. In this configuration a 32 liter minute volume was inspired and expired through the test respirator. During Test V the bellows exhaust was vented to a hood. In this configuration a 32 liter minute volume was inspired through the test respirator but no air was expired through the respirator.

Test IV required that the expired air be heated to 37-38 °C at 90 +% R.H. before passing through the test respirator. Heating and humidification were achieved by bubbling the air exhausted from the bellows through water heated to 43-44 °C in a 20 liter carboy before returning it to the lower portion of the test chamber. To prevent condensation of the moisture laden air within the dry gas meter and bellows upon inspiration, a condenser was placed between the test system and the dry gas meter intake. The condenser was a second 20 liter carboy packed in ice. Added resistance due to the heating, humidification and condenser systems reduced the maximum possible minute volume to 30.5 liters.

results and discussion

As design limitations dictated different flowrates and contaminant concentrations it is not meaningful to compare breakthrough times directly as an index of respirator cartridge performance. However, respirator performance can be compared in terms of "air purifying capacity". "Air purifying capacity" may be expressed in units of ppm liters and is computed by taking the product of breakthrough time in minutes, inspiratory flow minute volume in liters, contaminant concentration in ppm, and contaminant duty cycle. This definition excludes the small throughput of contaminant prior to breakthrough.

carbon tetrachloride results

Breakthrough times and "air purifying capacities" for carbon tetrachloride for both respirators are tabulated in Tables II and III respectively. Both Pulmosan and 3-M respirators exceed the NIOSH certification requirement for organic vapor respirators (a minimum 50 minute breakthrough time when tested at 1000 ppm and 64 Lpm).[1] Both respirators show marked reduction in "air purifying capacity" when operated under continuous flow but with lower challenge concentration (500 ppm) or alternating contaminant attack or a combination of lower concentration and alternating contaminant attack. Reduction of "air purifying capacity" under these conditions indicates that service life may not be limited by sorbent capacity alone but rather by solvent migration through the sorbent.

TABLE IV
Vinyl Chloride Breakthrough Time, minutes

	10 ppm		50 ppm	
Test	Pulmosan	3-M	Pulmosan	3-M
I	36.5±0.2	45.5±0.4	23.3±0.5	26.8±0.2
II	42.6±1.0	33.4±0.3	25.1±0.8	33.4±0.3
III	464.2±6.2	354.2±108.7	250.1±3.3	215.9±28.7
IV	277.5±2.6	195.0±5.2	136.3±3.5	87.8±4.8
V	92.1±1.0	101.5±1.2	53.8±0.3	51.8±1.8

Errors represent range of values observed.

TABLE V
Air Purifying Capacity: Vinyl Chloride, ppm-liters x 10^4

	10 ppm		50 ppm	
Test	Pulmosan	3-M	Pulmosan	3-M
I	2.34	2.91	7.46	8.58
II	1.36	1.07	4.02	5.34
III	14.9	11.3	40.0	34.5
IV	8.46	5.95	20.8	13.4
V	2.95	3.25	8.61	8.29

Dramatic increase in "air purifying capacity" is seen for both respirators when tested under bidirectional flow, i.e., expiration occurred through the respirator cartridges (Test III). Tests with the breathing machine at 500 ppm were deleted since neither respirator cartridge experienced breakthrough within 8 hours at 1000 ppm. Testing with humidified expired air (Test IV) indicated that the sorbents do not appear to saturate with water and retain most of their increased "air purifying capacity" as compared to continuous flow conditions. Test V indicated that "air purifying capacities" returned to continuous flow values when the beathing machine exhaust was vented directly to the hood rather than being directed back through the cartridge. Clearly exhalation through the cartridge partially desorbs the contaminant and extends "air purifying capacity."

vinyl chloride results

Breakthrough times and "air purifying capacities" for vinyl chloride for both respirators are tabulated in Tables IV and V respectively. The results found parallel those obtained for carbon tetrachloride.

conclusions

Utilization of air purifying respirators in a valveless configuration so as to produce bidirectional flow through the sorbent bed has been found to substantially extend service lives for carbon tetrachloride and vinyl chloride as compared to service lives using conventional unidirectional flow. Partial desorption of the contaminant from the sorbent during exhalation is responsible for service life extension. Saturation of sorbent with water from moisture in exhaled breath rendering the sorbent ineffective does not appear to occur.

It is likely that bidirectional flow will extend the service lives of respirators for other organic vapors. Caution must be exercised in the use of bidirectional air purifying respirators as such devices increase breathing effort which may be intolerable to certain individuals.

acknowledgements

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references

1. United States Code of Federal Regulations, Title 30, Part II, Subpart L, Paragraph 11.
2. **Hudgins, P.A.:** *A Service Life Comparison of the Valveless 3-M Vinyl Chloride Respirator and the Pulmosan Organic Vapor Respirator Cartridge,* Masters Technical Report, Dept. of Environmental Sciences and Engineering, Univ. of North Carolina (1980).

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