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POWERED AIR-PURIFYING RESPIRATOR (PAPR) CANISTER PARTICULATE EFFICIENCY BENCHMARK TESTING

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14. ABSTRACT

This investigation performed particulate efficiency testing of commercial chemical, biological, radiological, and nuclear powered air-purifying respirator (PAPR) canister filters to provide benchmark data to the National Institute for Occupational Safety and Health (NIOSH). The data was provided to assist NIOSH in establishing appropriate test parameters and performance criteria for certifying the particulate efficiency of these filters. Two separate evaluations were performed under constant and cyclic flow conditions: an initial penetration test and an aerosol loading test. The initial penetration test assessed the particulate filtration efficiency of a poly-alpha olefin aerosol at two cyclic flow conditions (85 and 135 L/min) and one of three constant flow conditions (85, 270, or 360 L/min). The aerosol loading test assessed the effect of dioctyl phthalate (DOP) oil aerosol loading on particulate filtration efficiency at high cyclic (135 L/min) and constant (270 L/min) flow conditions. In both evaluations, the test airflow rates were reduced in direct proportion to the number of filters used in the PAPR model. The effect of increased airflow and DOP aerosol loading on particulate filtration efficiency was negligible, as all PAPR filters tested exceeded the 99.97% high efficiency particulate air efficiency criterion level.

15. SUBJECT TERMS

Powered Air-Purifying Respirator (PAPR)	High Efficiency Particulate Air (HEPA) Filter	Aerosol penetration
Respirators	Particulate efficiency	Cyclic flow
Constant flow	CBRN Filters	

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PREFACE

The work described in this report was authorized under Project No. 62262255200, Research, Development, Testing and Evaluation. This work was started in May 2005 and completed in July 2005.

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POWERED AIR-PURIFYING RESPIRATOR (PAPR) CANISTER PARTICULATE EFFICIENCY BENCHMARK TESTING

1. INTRODUCTION

In May 2005, the Respiratory Protection Team was tasked by the National Personal Protective Technology Laboratory (NPPTL), National Institute for Occupational Safety and Health (NIOSH), to conduct particulate efficiency testing of commercial powered air purifying respirator (PAPR) canisters under high airflow conditions. The testing was performed in support of NPPTL's chemical, biological, radiological, and nuclear (CBRN) PAPR respirator standards development effort. The overall objective was to provide benchmark data to facilitate the establishment of appropriate test parameters and performance criteria for certifying the particulate efficiency of CBRN PAPR filters. Two separate evaluations were performed under constant and cyclic flow conditions: an initial penetration test and an aerosol loading test. The initial penetration test assessed the particulate filtration efficiency of a poly-alpha olefin (PAO) oil aerosol, and the loading test assessed the effect of dioctyl phthalate (DOP) oil aerosol loading on particulate filtration efficiency. The tests were conducted at the Respiratory Protection Team's laboratory in Building E5604, Aberdeen Proving Ground, MD 21010. Testing was initiated in May of 2005 and completed in July of 2005.

Four PAPR canisters from different manufacturers were evaluated: MSA OptimAir 6HC, SEA 400 AT ABEK3HE, Scott C420 MPC Plus, and 3M Breathe Easy 10 FR-40. All canisters were from NIOSH-approved PAPRs that are currently marketed, but not yet certified, for CBRN homeland defense applications. The canisters were organic vapor/acid gas combination-type filters equipped with a pleated high efficiency particulate air (HEPA) filter. The MSA, SEA, and Scott PAPRs are two-canister systems while the 3M PAPR is a three-canister system. The MSA OptimAir PAPR is a loose-fitting hood device with a minimum flow rate of 170 L/min. The Scott and 3M PAPRs are tight-fitting facepiece, constant flow devices having a minimum flow rate of 115 L/min. The SEA PAPR is equipped with a breath responsive ("on-demand" type) blower capable of providing peak airflow in excess of 350 L/min.

2. METHODS

2.1 Initial Penetration Test

The PAPR canister initial penetration tests were performed using an in-house fabricated test system. The test system consisted of an aerosol generation system, an exposure chamber, filter holder, breathing machine (or vacuum blower), and aerosol sampling system. The aerosol was generated using a nebulizer taken from an automated filter test apparatus (CERTITEST® Model 8130, TSI). The instrument is the same used by NIOSH to certify the efficiency of particulate filters in accordance with standard procedures in 42 CFR 84.[1] The aerosol measuring system used was a TSI DustTrak™ Model 8520. The DustTrak™ had a sensitivity of ± 0.001 mg/m^3, which corresponded to an approximate penetration sensitivity of ± 0.001%. The challenge aerosol consisted of a PAO synthetic oil (Durasyn 164™) that was generated at room temperature (25 ± 5 °C) and neutralized to the Boltzmann equilibrium state using a neutralizer (Model 3012, TSI). The particle size distribution was measured using a scanning mobility particle sizer (Model 3071, TSI). The challenge aerosol had a count median diameter (CMD) of ~ 0.14 microns with a geometric standard deviation (GSD) of ~ 1.60. The particle size distribution was slightly below the requirement for certifying particulate filters as specified in 42 CFR 84, and thus represented a conservative challenge aerosol with respect to particulate penetration. The average challenge concentration measured by the DustTrak™ was approximately 70 mg/m^3.

2.1.1 Test Matrix

The initial penetration test matrix is provided in Table 1. Three canisters were tested at each of two cyclic flow conditions (85 and 135 L/min) and only one of three constant flow conditions (85, 270 or 360 L/min). In each case, the test airflow rate was reduced in direct proportion to the number of filters used in the corresponding PAPR model. For the constant flow trials, the MSA, SEA, and Scott combination canisters were tested at 180, 135, and 42.5 L/min, respectively. Each test was repeated three times for a total of 27 initial penetration test trials.

Table 1. Initial Penetration Test Matrix

Canister	**System Cyclic Flow Rates[1]**		**System Constant Flow Rates[1]**
Scott MPC Plus	85 L/min [2.3 L, 37 BPM][2]	135 L/min [3.1 L, 44 BPM][2]	85 L/min
SEA ABEK			270 L/min
MSA 6HC			360 L/min

[1]Actual test airflow rate proportional to number of filters used in PAPR
[2][Tidal volume, breaths per minute]

2.1.2 Procedure

The canister was mounted on a 40 mm-threaded test fixture inside the test chamber. The test chamber was sealed and the breathing pump (Computerized

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[1] Code of Federal Regulations. (1995) Respiratory Protective Devices; Final Rules and Notice. U.S. Government Printing Office, Office of the Federal Register, Washington, D.C. Title 42 CFR, Part 84.

Breathing Simulator, FENZY, France) or vacuum blower (manufactured in-house) was started, as appropriate, depending on the test flow condition (i.e., cyclic or constant flow). The aerosol generation system was then started and allowed to operate for 15 min to ensure sufficient time for the chamber aerosol concentration to stabilize. During this time, the chamber aerosol challenge was pulled through a filter bypass fitting to minimize filter loading. The DustTrak™ was attached to a probe extending 8 cm inside the chamber and permitted to sample the challenge concentration for two min. Next, the DustTrak™ was attached to the downstream sample probe located directly beneath the canister, parallel to the airflow stream. The filter bypass valve was then switched to allow airflow from the chamber through the PAPR canister. After the DustTrak™ was given adequate time to stabilize, approximately 30 s, the DustTrak™ sampled downstream for 10 min.

After completion of the downstream sample, the DustTrak™ was attached to the chamber probe and a second two-minute challenge sample was taken. The difference between the initial and final chamber measurements never exceeded 5%. After the challenge sample was complete, the aerosol generation system was turned off and the chamber was flushed with clean air. The filter was removed from the test system, and the system was prepared for the next filter.

2.2 DOP Loading Test

Aerosol loading, aerosol penetration, and airflow resistance were measured using an automated filter test apparatus (CERTITEST® Model 8130, TSI). The PAPR canisters were loaded with a nebulized DOP oil aerosol that was generated at room temperature (25 ± 5 °C) and neutralized to the Boltzmann equilibrium state. The DOP size distribution was measured using a scanning mobility particle sizer (Model 3071, TSI). The challenge aerosol had a CMD of ~ 0.18 microns with a GSD of ~ 1.60 and met the size distribution requirements specified in 42 CFR 84. Two gravimetric samples were taken, one before and one after each day's test run, and averaged to determine the challenge concentration. The challenge concentration ranged from approximately 100 to 130 mg/m^3. The filters were incrementally loaded with approximately 200 mg DOP. Penetration and airflow resistance measurements were recorded at each 200 mg loading increment. The high cyclic and constant flow penetration tests were conducted on the same in-house system used to perform the initial penetration tests.

2.2.1 Test Matrix

The loading penetration test matrix is provided in Table 2. Three different canisters were loaded at three different flow rates based on the baseline flow rate for each PAPR model (i.e., minimum rated blower airflow rate). The MSA, Scott, and 3M combination canisters were loaded at 85, 57.5, and 38.3 L/min, respectively. Each filter was incrementally loaded with approximately 200 mg of

DOP and then tested at a high cyclic and constant flow of 135 and 270 L/min, respectively. This was repeated until at least 1000 mg of DOP had been loaded on the filter. The loading test was performed twice for each canister model for a total of six complete tests. In each case, the actual test flow rate was proportional to the number of filters used in the corresponding PAPR blower.

Table 2. Loading Penetration Test Matrix

Canister	**Loading Test Flow Rates (L/min)**	**Penetration Test Flow Rates**[1]	
		Constant	**Cyclic**
MSA 6HC	85	270 L/min	135 L/min [3.1 L, 44 BPM][2]
Scott MPC Plus	57.5		
3M FR-40	38.3		

[1] Actual test airflow rate proportional to number of filters used in PAPR
[2] [Tidal volume, breaths per minute]

2.2.2 Procedure

The canister was loaded with 200 mg of DOP using the CERTITEST® automated filter tester. Next, the canister was removed from the filter tester and mounted on the in-house test system's test fixture. The test chamber was sealed and the breathing pump (Computerized Breathing Simulator, FENZY, France) was started at the proper settings for the appropriate cyclic flow test condition. The aerosol generation system was then started and allowed to operate for 15 min to allow time for the chamber aerosol to stabilize. During this time, the aerosol challenge was pulled through a filter bypass to minimize filter loading. The DustTrak™ was attached to the chamber probe and a two-minute challenge sample was taken. Next, the DustTrak™ was attached to the downstream sample probe and allowed to sample for four min. After completion of the downstream sample, the aerosol challenge was switched back to the bypass and the DustTrak™ was attached to the chamber probe. A second two-minute challenge sample was taken.

After the challenge sample was complete, the breathing machine was switched to a vacuum blower (manufactured in house) for the constant flow test condition. The vacuum blower was adjusted to the appropriate flow rate. The challenge concentration was allowed to stabilize for five min. Next, the upstream/downstream sampling procedure was repeated. After the last challenge sample was complete, the aerosol generation system was turned off and the chamber was flushed with clean air. The difference between the initial and final chamber measurements was in all cases less than 5%. The canister was removed from the test system and placed back into the TSI filter tester to be loaded with another 200 mg of DOP. The test was repeated until a minimum total of 1000 mg DOP was loaded on the PAPR filter.

3. RESULTS

The percent penetration measurements were calculated by dividing the downstream aerosol concentration by the average of the initial and final upstream challenge concentration and multiplying by 100%. This was done manually for the data collected using the in-house test system and automatically by the TSI filter tester that was used to load the canisters with the DOP aerosol.

3.1 Initial Penetration Test

The results of the initial penetration tests are shown in Table 3. The mean percent efficiency and the standard deviation of three trials are shown for each combination of canister, flow condition, and flow rate. The lowest efficiency was 99.992 % at the highest constant test flow assessed (180 L/min).

Table 3. Initial Penetration Test Results

Canister	Flow Condition	System Flow Rate Evaluated (L/min)	Actual Test Flow Rate (L/min)	Efficiency (%)
Scott MPC Plus	Cyclic	85	42.5	99.997 ± 0.001
		135	67.5	99.996 ± 0.001
	Constant	85	42.5	99.999 ± 0.000
SEA ABEK3HE	Cyclic	85	42.5	99.998 ± 0.001
		135	67.5	99.998 ± 0.001
	Constant	270	135	99.998 ± 0.001
MSA 6HC	Cyclic	85	42.5	99.996 ± 0.001
		135	67.5	99.995 ± 0.001
	Constant	360	180	99.992 ± 0.002

3.2 DOP Loading Test

The penetration and resistance results of the PAPR canisters loaded under baseline constant flow conditions are shown in Figures 1 and 2, respectively. The maximum baseline penetration measured was 0.002% after approximately 1100 mg of DOP was loaded. In addition, the maximum resistance of a single trial was 38.9 mmH_2O. It should be noted that both these maximums occurred with the MSA canister, which was loaded at the highest constant test flow rate (85 L/min). The results of the high cyclic and constant flow penetrations for canisters incrementally loaded with DOP are illustrated in Figure 3. Although the penetration was slightly higher than the penetration at the baseline loading constant flow conditions, the maximum penetration was only 0.009%, which is well below the 0.03% maximum requirement for HEPA filters.

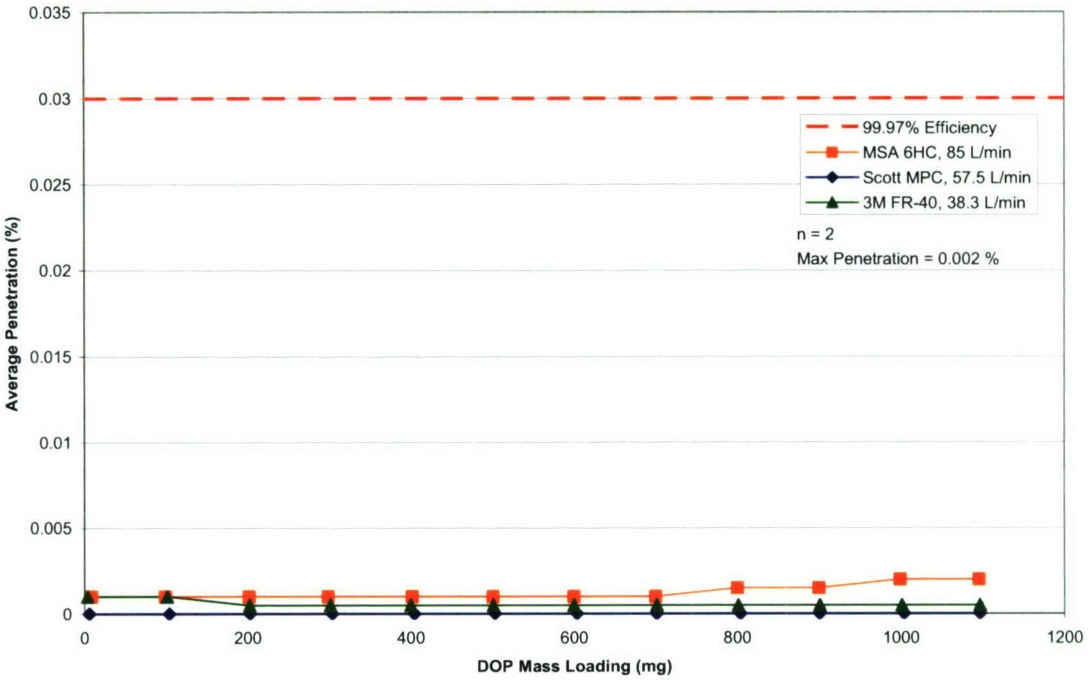

Figure 1. Penetration during DOP Canister Loading

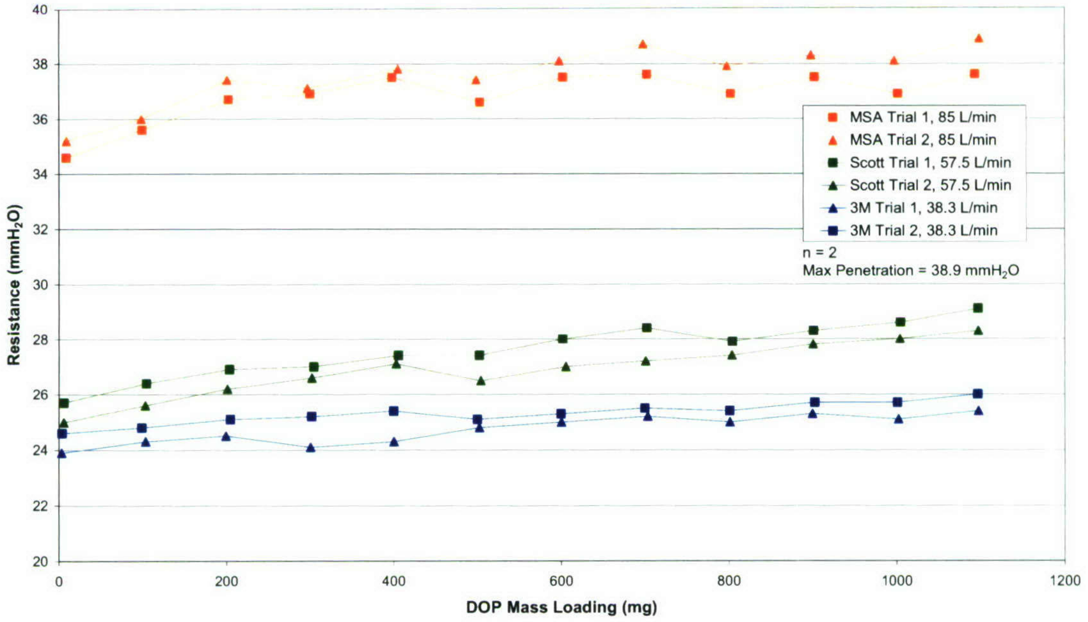

Figure 2. Resistance during DOP Canister Loading

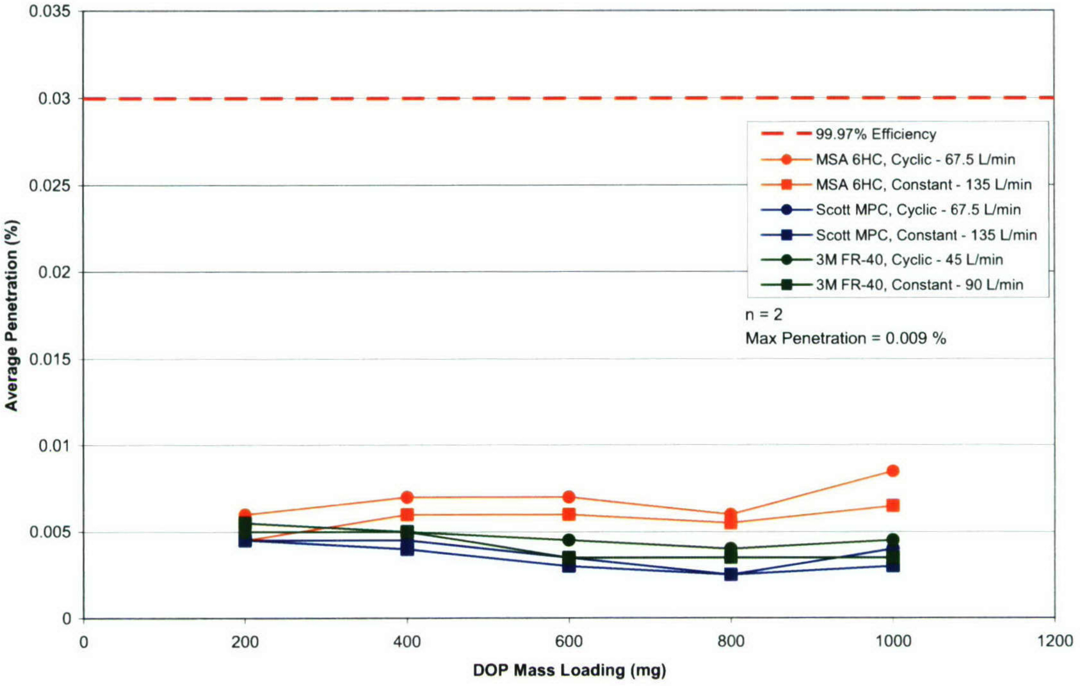

Figure 3. Constant and Cyclic Flow Penetration of Canisters Loaded with DOP

3.3 Statistical Analysis

Statistical analysis of the initial penetration results included a one-way analysis of variance (ANOVA) of the cyclic and constant flow conditions, and a two-way ANOVA of the filter and flow rate at cyclic conditions. A three-way ANOVA of filter, flow rate, and flow condition could not be completed since each filter was only tested at one constant flow. The one-way ANOVA of the cyclic and constant flow conditions confirmed flow condition was not significant ($p = 0.723$). The two-way ANOVA results for only the cyclic conditions are shown in Table 4. Although flow rate and filter were significant ($p < 0.05$), their means are only separated by a few thousandths of a percent. Hence, flow rate and filter are not practically significant. Also, the filter-flow rate interaction was not significant ($p = 0.245$). Only two trials were performed on each cartridge for the DOP loading penetration tests. Thus, no significant statistical analysis could be performed.

Table 4. Cyclic Flow ANOVA Table for Percent Efficiency

Treatment	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Flow Rate Tested (L/min)	1	3.556E-6	3.556E-6	5.333	.0395	5.33	.559
Filter	2	1.478E-5	7.389E-6	11.083	.0019	22.167	.972
Flow Rate Tested (L/min) * Filter	2	2.111E-6	1.056E-6	1.583	.2453	3.167	.264
Residual	12	8.000E-6	6.667E-7				

4. DISCUSSION

In this benchmark study, the particulate filtration efficiency of commercial CBRN PAPR canisters was assessed at high airflow conditions and DOP loading levels. It was shown that all PAPR canisters tested exceeded the 99.97% HEPA efficiency criterion level. Initial penetrations measured under the highest flow conditions, equivalent to system cyclic and constant airflows of 135 L/min and 360 L/min, respectively, were less than 0.01%. In addition, the filtration efficiencies for the PAO and DOP test aerosols used in this study were not adversely affected by DOP loading. The pleated particulate filter media used in these canisters was not degraded by the DOP aerosol and demonstrated a high capacity for oil loading. Efficiencies measured at both the high constant and cyclic flow conditions remained above 99.99% at final DOP loading levels in the proximity of 1000 mg.

5. CONCLUSIONS

This study provided benchmark data to facilitate the establishment of appropriate test parameters and performance criteria for certifying the particulate efficiency of CBRN PAPR canister filters. All PAPR combination filters tested exceeded the 99.97% HEPA efficiency criterion level at the various airflow conditions and DOP loading levels evaluated. Furthermore, the effect of increased airflow and DOP loading on particulate filtration efficiencies was negligible. The PAPR canisters were highly efficient under all airflow and DOP aerosol loading levels assessed in this study.

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