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Evaluation of Carbon Tetrachloride Replacement Agents for Use in Testing Nonpowered Organic Vapor Chin-Style Canisters

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For years, charcoal's ability to adsorb organic compounds has been evaluated employing carbon tetrachloride. The breakthrough characteristics for chin-style canisters against organic vapors mandate the use of carbon tetrachloride as per 30 CFR, Part 11. However, due to carbon tetrachloride's toxicity and the lack of commercial availability, a substitute organic vapor test agent is needed. This article deals with the evaluation of four potential substitute agents (ethyl acetate, pentane, n-hexane, and heptane) for testing chin-style canisters. Screening tests identified replacement agent challenge concentrations that gave breakthrough characteristics similar to 5000 parts per million (ppm) carbon tetrachloride. Side-by-side correlation testing was done between 4000 ppm pentane at 64 L/min, 80 percent relative humidity (RH), and 25°C with the most critical 30 CFR, Part 11 test condition (85% precondition followed by testing at 50% RH, 32 L/min, and 25°C). Finally, a reproducibility study was performed employing the 4000 ppm pentane system. The data show that pentane at 4000 ppm, 80 percent RH, 64 L/min, and 25°C correlated with carbon tetrachloride data, and that the pentane system gives reproducibility test breakthrough times. A pentane testing regimen using "as received" canisters tested at 25, 50, and 80 percent RH at a flow rate of 64 L/min and 25°C can be established to replace the present 30 CFR, Part 11 carbon tetrachloride test criteria for chin-style canisters. MOYER, E.S.; PETERSON, J.A.; CALVERT, C.: EVALUATION OF CARBON TETRACHLORIDE REPLACEMENT AGENTS FOR USE IN TESTING NONPOWERED ORGANIC VAPOR CHIN-STYLE CANISTERS. APPL. OCCUP. ENVIRON. HYG. 10(9):769–775; 1995.

The National Institute for Occupational Safety and Health has instituted a program to find a suitable replacement substance for carbon tetrachloride in evaluating organic vapor (OV) and gas cartridges and canisters. This program was expeditiously conducted, since carbon tetrachloride is a suspected carcinogen,[1,2] and is in limited supply. The Environmental Protection Agency recently proposed to conform its stratospheric ozone protection regulations (40 CFR 82) to the requirements of Title VI of the Clean Air Act Amendments of 1990 (PL 101-549). This action has affected the supplies of carbon tetrachloride, immediately limiting the supply and perhaps ultimately causing it to be phased out of production. The Code of Federal Regulations (30 CFR, Part 11) mandates carbon tetrachloride for testing organic vapor and gas cartridges and canisters. Therefore, it is necessary to find a suitable substitute test agent to replace carbon tetrachloride.

Moyer *et al.*[3] have reported on nonpowered negative pressure OV cartridge breakthrough characteristics against four potential replacement agents (ethyl acetate, pentane, n-hexane, and heptane). This evaluation identified replacement agent challenge concentrations that gave breakthrough characteristics equivalent to 1000 parts per million (ppm) carbon tetrachloride. Breakthrough time was the sole critical criterion. Two test conditions (550 ppm pentane and 1000 ppm n-hexane) were selected for side-by-side testing with 1000 ppm carbon tetrachloride. The results show that for the most critical test condition ["as received" cartridges tested at 64 L/min and 80% relative humidity (RH)] the breakthrough times for two different manufacturers' organic vapor cartridges were identical for these three test conditions (1000 ppm carbon tetrachloride, 550 ppm pentane, and 1000 ppm n-hexane). Due to pentane's lower toxicity, it was recommended as the replacement agent of choice.

This article presents breakthrough time data obtained for chin-style canisters against the four potential replacement agents studied previously for OV nonpowered negative pressure cartridges. The major difference in the testing conditions was that higher challenge concentrations were employed because chin-style canisters contain 2.5 to 3.0 times more sorbent than cartridges. The regulations (30 CFR, Part 11)[4] require a carbon tetrachloride challenge concentration of 5000 ppm to be used when testing chin-style canisters.

Background

Chin-style canisters are presently tested and certified under 30 CFR, Part 11,[4] Subparts I and M. The specific performance requirements are given in 11.102-1 through 11.102-5 and 11.183-1 through 11.183-7. OV chin-style canisters are tested against a carbon tetrachloride challenge concentration of 5000 ppm. The specific test requirements are summarized in Table 1. Chin-style canisters are tested as received from the applicant and after preconditioning at either 25 or 85 percent RH. Varying flow rates are employed, but the minimum service life is 12 minutes at the various test conditions.

The rationale for equilibrating the canisters at 25 and 85 percent RH, followed by testing at 50 percent RH and at a

TABLE 1. 30 CFR, Part 11 Organic Vapor Tests for Chin-Style Canisters Against 5000 ppm Carbon Tetrachloride Challenge

Test Condition	Test Flow Rate (L/min)	No. of Tests	Maximum Allowable Penetration (ppm)	Minimum Service Life (min)
As received	64	3	5	12
Equilibrated 25% RH	32	2	5	12
Equilibrated 85% RH	32	2	5	12

All tests run at 50 percent RH.

reduced flow rate, has been questioned.[5] Further, it is thought that testing of as received canisters over a broad range of RHs at the higher flow rate, 64 L/min, appears more indicative of use-type conditions.[6] Such testing might, in fact, constitute an improved and more realistic performance standard for evaluating OV and gas respirator canisters.

Four possible replacement agents (ethyl acetate, pentane, n-hexane, and heptane) were selected and screened based on their physical characteristics and toxicity, as well as reported charcoal adsorption characteristics.[6–9] Chin-style canisters were tested as received from the manufacturer at 50 percent RH, 80 percent RH, and 25° ± 2°C with no preconditioning being performed. These tests were conducted at various challenge concentrations of carbon tetrachloride (control), ethyl acetate, pentane, n-hexane, and heptane at 50 percent RH, 80 percent RH, and 25°C. (Warning: ethyl acetate, pentane, n-hexane, and heptane are extremely flammable, and sparks and open flames must be avoided. Buildup of fumes in closed containers must be avoided. Further, the lower flammability limits for these agents are as follows: ethyl acetate, 22,000 ppm; pentane, 15,000 ppm; n-hexane, 11,000 ppm; and heptane, 10,500 ppm.) This portion of the study was to identify which potential replacement agent(s) at what challenge concentration would give chin-style canister breakthrough times equivalent to the 5000 ppm carbon tetrachloride test presently mandated in 30 CFR, Part 11.

The replacement agent(s)/challenge concentration conditions that showed equivalence with 5000 ppm carbon tetrachloride, based on breakthrough time as the critical evaluation criterion, were considered for further side-by-side correlation testing against 5000 ppm carbon tetrachloride. The correlation testing was to confirm that the test agent(s)/challenge concentration conditions gave cartridge breakthrough times equivalent to carbon tetrachloride at the most severe test condition. Further, the correlation testing determined which test condition was the most critical: equilibrated canisters, as per 30 CFR, Part 11; or as received canisters run at a higher test RH (80% RH).

Finally, a study was conducted to evaluate the reproducibility of the experimental testing procedure.

TABLE 2. Summary of Chin-Style Canister Breakthrough Time Data Against Various Carbon Tetrachloride Challenge Concentrations

Challenge Concentration (ppm)	Charcoal Weight (g)	% RH	Breakthrough Time Corrected to Challenge Concentration (min) 5 ppm	10 ppm	15 ppm
1000	201.8	50	140.2	146.5	150.5
1000	208.4	80	121.7	127.0	131.0
2000	194.2	50	69.7	73.5	75.3
2000	193.3	80	61.1	64.5	66.2
5000	200.4	50	36.8	38.4	39.2
5000	204.6	80	33.1	34.8	35.6
10,000	203.9	50	21.3	22.4	22.6
10,000	201.8	80	18.1	19.2	19.9

Lot A canister.

Experimental Method

The test configuration for the initial tests on single canisters is as shown in Figure 1 and has been described previously.[9] Individual chin-style canisters were tested as received from the manufacturer at a flow rate of 64 L/min through the canister. The test humidities were 50 and 80 percent, and the temperature was 25° ± 1.5°C. Various challenge concentrations of carbon tetrachloride (control) and potential replacement agents (ethyl acetate, pentane, n-hexane, and heptane) were tested. Breakthrough times were determined as the single critical

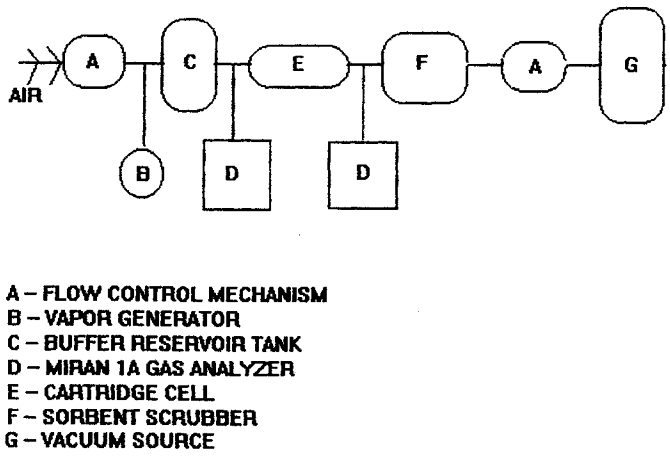

FIGURE 1. Canister test system.

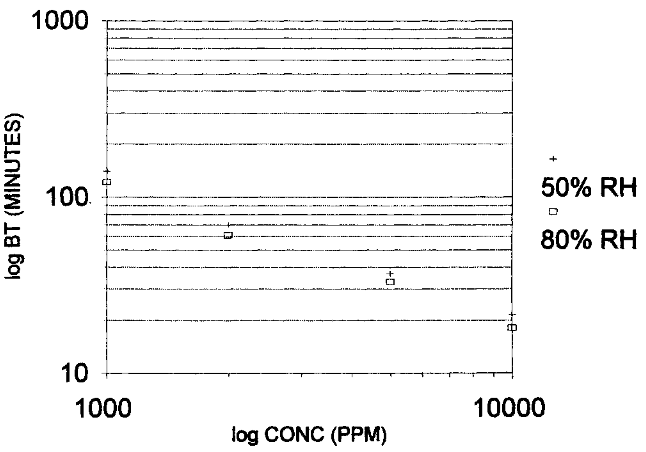

FIGURE 2. Carbon tetrachloride breakthrough data.

TABLE 3. Summary of Chin-Style Canister Breakthrough Time Data Against Various Ethyl Acetate Challenge Concentrations

Challenge Concentration (ppm)	Lot	Charcoal Weight (g)	% RH	Breakthrough Time Corrected to Challenge Concentration (min) 5 ppm	10 ppm	15 ppm
1000	C	201.5	50	127.4	132.0	134.7
1000	C	198.5	50	125.4	129.9	132.8
1000	A	192.0	80	78.0	81.5	83.8
1000	C	190.3	80	97.7	108.6	113.6
1000	C	199.4	80	98.8	107.4	110.8
2000	A	186.4	50	55.7	57.6	59.5
2000	A	184.2	80	44.0	46.2	48.0
5000	B	182.0	50	24.5	25.4	26.2
5000	B	182.5	80	16.6	17.3	17.9
7500	C	201.4	50	20.1	21.1	21.6
7500	B	202.7	80	10.8	17.4	18.1

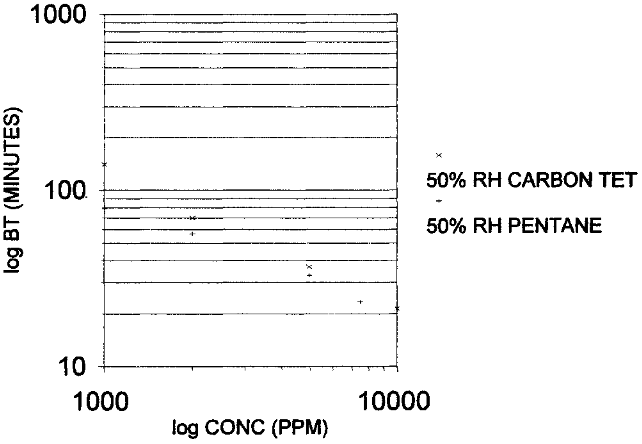

FIGURE 3. Carbon tetrachloride versus pentane. Breakthrough data at 50 percent RH.

criterion for determining equivalency with carbon tetrachloride.

Subsequent side-by-side testing was done as per the certification testing procedure with minor modification. These tests directly compared the replacement agent with the control carbon tetrachloride at 50 and 80 percent RH on as received canisters at 25°C. One manufacturer's chin-style canister was tested. The major experimental differences between the certification test system and the one shown in Figure 1 are (1) the air is pushed through the chin-style canisters rather than being pulled with a vacuum source, (2) a single canister is mounted on a holder as employed on the respirator, (3) the challenge concentration is determined gravimetrically rather than instantaneously over the entire test, (4) the breakthrough time is only determined at 5 ppm, and (5) the Teflon® needle rested on heated glass beads in the case of pentane. These equipment differences should not have any effect on the data obtained.

The detector system was a Miran 1A (Foxboro) general purpose infrared gas analyzer equipped with a variable path length gas cell. The analytical wavelength and minimum detectable limits, as specified by the manufacturer, with a 20-m cell for the test agents, are as follows: carbon tetrachloride, 12.6 μm and 1.1 ppm; ethyl acetate, 8.3 μm and 0.1 ppm; pentane, 3.4 μm and 0.2 ppm; n-hexane, 3.4 μm and 0.2 ppm; and heptane, 3.4 μm and 0.1 ppm.

The test agents evaluated were as follows: (1) carbon tetrachloride, Fisher Scientific, Pittsburgh, Pennsylvania, certified American Chemical Society (ACS) spectranalyzed, or Aldrich Chemical Company, Milwaukee, Wisconsin, ACS reagent 99 percent; (2) ethyl acetate, Fisher Scientific, certified ACS spectranalyzed; (3) n-pentane, Fisher Scientific, high pressure liquid chromatography (HPLC) grade; (4) n-heptane, Fisher Scientific, certified ACS 99 mol% pure, or J.T. Baker Chemical Company, Phillipsburg, New Jersey, HPLC 97 percent. House air which was passed through a dryer/sorbent system to remove contaminants was used.

Results and Discussion

The breakthrough data for the chin-style canisters against carbon tetrachloride are presented in Table 2. Challenge concentrations of 1000, 2000, 5000, and 10,000 ppm were used.

TABLE 4. Summary of Chin-Style Canister Breakthrough Time Data Against Various Pentane Challenge Concentrations

Challenge Concentration (ppm)	Charcoal Weight (g)	% RH	Breakthrough Time Corrected to Challenge Concentration (min) 5 ppm	10 ppm	15 ppm
1000	205.9	50	78.6	80.9	82.7
1000	207.9	80	73.8	76.9	79.0
2000	203.0	50	56.7	58.5	59.8
2000	214.7	80	49.8	51.7	53.0
5000	203.7	50	32.9	34.2	34.9
5000	216.7	80	30.4	32.3	33.0
7500	213.7	50	23.3	24.2	24.8
7500	218.5	80	21.1	22.1	23.1

Lot C canister.

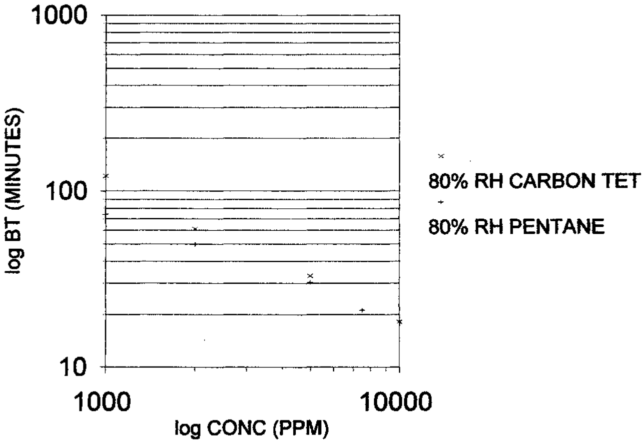

FIGURE 4. Carbon tetrachloride versus pentane. Breakthrough data at 80 percent RH.

TABLE 5. Summary of Chin-Style Canister Breakthrough Time Data Against Various *n*-Hexane Challenge Concentrations

Challenge Concentration (ppm)	Charcoal Weight (g)	% RH	Breakthrough Time Corrected to Challenge Concentration (min)		
			5 ppm	10 ppm	15 ppm
1000	208.5	50	106.0	109.7	111.9
1000	200.5	80	97.2	101.7	103.5
2000	209.8	50	55.4	57.2	58.5
2000	210.6	80	53.7	55.8	57.3
5000	202.3	50	28.7	30.0	30.6
5000	202.5	80	32.7	34.0	34.6
7000	199.8	50	21.2	22.2	22.7
7000	200.9	80	21.4	22.6	23.5

Lot C canister.

TABLE 6. Summary of Chin-Style Canister Breakthrough Time Data Against Various Heptane Challenge Concentrations

Challenge Concentration (ppm)	Charcoal Weight (g)	% RH	Breakthrough Time Corrected to Challenge Concentration (min)		
			5 ppm	10 ppm	15 ppm
2500	200.8	50	59.2	61.7	63.3
2500	202.2	80	57.1	59.5	61.6
5000	198.8	50	25.9	27.3	27.9
5000	206.6	80	26.0	27.7	28.6
7500	202.1	50	19.0	20.4	21.0
7500	202.5	80	15.5	17.4	18.2

Lot C canister.

Tests were conducted at 50 and 80 percent RH. A plot of the data presented in Table 2 is shown in Figure 2. At higher challenge concentrations, the resulting increase in the challenge concentration to water ratio reduces the competitive effect of the water vapor. This was not the case with cartridges that were run at a lower concentration (1000 ppm) and where the sorbent weight for cartridges was significantly lower than for chin-style canisters (130 to 250 g).

The chin-style canister breakthrough data against ethyl acetate concentrations of 1000, 2000, 5000, and 7500 ppm at 50 and 80 percent RH are given in Table 3. Likewise, the breakthrough data against pentane concentrations of 1000, 2000, 5000, and 7500 ppm are presented in Table 4. Figures 3 and 4 illustrate the data comparison between carbon tetrachloride and pentane at 50 and 80 percent RH, respectively.

The n-hexane data at challenge concentrations of 1000, 2000, 5000, and 7000 ppm are presented in Table 5 for 50 and 80 percent RH. Table 6 presents the heptane breakthrough data (2500, 5000, and 7500 ppm challenge concentrations). Table 7 summarizes all the chin-style canister breakthrough data at a 5 ppm penetration value.

Ethyl acetate was eliminated from further consideration as the replacement agent due to its water solubility, which could introduce another potential variable. The above data on pentane, n-hexane, and heptane were evaluated to identify the best agent and challenge concentration for further testing. The evaluation was based solely on the equivalency of breakthrough time as compared with the breakthrough time of the 5000 ppm carbon tetrachloride control. The best candidate for direct comparison with 5000 ppm carbon tetrachloride was determined to be 4000 ppm pentane.

As received chin-style canisters underwent additional testing at 50 and 80 percent RH (64 L/min) employing the certification test methodology. The results for the 5000 ppm carbon tetrachloride (control) and 4000 ppm pentane are given in Table 8. These data confirm previous results that indicate there is little difference in breakthrough times between the 50 and 80 percent RH conditions at these higher challenge concentrations and added sorbent weights.

The breakthrough times for the chin-style canisters against 5000 ppm carbon tetrachloride were 39.6 and 35.7 minutes at 50 percent RH as compared with 38.1 and 37.5 minutes against 4000 ppm pentane. The 80 percent RH breakthrough times against 5000 ppm carbon tetrachloride were 38.5 and 35.1 minutes as compared with 36.3 and 40.7 minutes against 4000 ppm pentane. These data indicate that 4000 ppm pentane

TABLE 7. Summary of Chin-Style Canister Breakthrough Data at 5 ppm Penetration

Challenge Agent	Test RH (%)	Breakthrough Time at Challenge Concentration (min)						
		1000 ppm	2000 ppm	2500 ppm	5000 ppm	7000 ppm	7500 ppm	10,000 ppm
Carbon tetrachloride	50	140.2	69.7		36.8			21.3
	80	121.7	61.1		33.1			18.1
Ethyl acetate	50	127.4	55.7		24.5		20.1	
	50	125.4						
	80	78.0	44.0		16.6		10.8	
	80	97.7						
	80	98.8						
Pentane	50	78.6	56.7		32.9		23.3	
	80	73.8	49.8		30.4		21.1	
n-Hexane	50	106.0	55.4		28.7	21.2		
	80							
Heptane	50			59.2	25.9		19.0	
	80			57.1	26.0		15.5	

TABLE 8. Comparison of Breakthrough Times Against 4000 ppm Pentane and 5000 ppm Carbon Tetrachloride for As Received Manufacturer A Organic Vapor Chin-Style Canisters

	Test RH (%)	Weight of Canisters (g)					Breakthrough Time at 5 ppm (min)
		Initial	Final	ΔW	Case	Sorbent	
Pentane	50	415.0	441.0	26.0	211.6	203.4	38.1
Pentane	50	409.0	435.1	26.1	211.0	198.0	37.5
Carbon tetrachloride	50	410.8	473.5	62.7	212.2	198.6	39.6
Carbon tetrachloride	50	409.0	468.0	59.0	211.6	197.4	35.7
Pentane	80	413.9	443.2	29.3	213.2	200.7	36.3
Pentane	80	410.1	439.1	29.0	210.8	199.3	40.7
Carbon tetrachloride	80	410.0	479.0	69.0	214.0	196.0	38.5
Carbon tetrachloride	80	417.8	468.9	51.1	211.7	206.1	35.1

All tests run at 64 L/min.

TABLE 9. Organic Vapor Cartridge Breakthrough Time Correlation Data for Chin-Style Canisters

			5000 ppm CCL_4, 64 L/min, 50% RH, 25°C		5000 ppm CCL_4, 85% Preconditioned, 32 L/min, 50% RH, 25°C		4000 ppm Pentane, 64 L/min, 80% RH, 25°C	
Manufacturer	Lot	Run	Sorbent Weight (g)	Breakthrough Time at 5 ppm (min)	Sorbent Weight (g)	Breakthrough Time at 5 ppm (min)	Sorbent Weight (g)	Breakthrough Time at 5 ppm (min)
A	A	1	249.5	52.1	232.6	48.8	243.3	51.3
		2	237.2	56.9	236.0	38.0	245.3	51.0
B	A	1	200.0	42.4	198.1	17.8	203.7	37.2
		2	200.3	34.5	204.7	28.9	204.9	37.3
C	A	1	134.3	46.4	134.5	42.5	154.0	44.8
		2	135.7	44.8	149.5	41.4	154.5	43.7

TABLE 10. Breakthrough Time Reproducibility Study Against 4000 ppm Pentane for Manufacturer B Organic Vapor Chin-Style Canisters at 50 Percent RH and 64 L/min

Sample Number	Weight of Cartridges (g)					Breakthrough Time at 5 ppm (min)
	Initial	Final	ΔW	Case	Sorbent	
1	407.5	433.2	25.7	211.8	195.7	36.1
2	409.2	436.1	26.9	212.6	196.6	38.1
3	415.5	442.0	26.5	212.6	202.9	37.2
4	414.9	441.0	26.1	213.2	201.7	36.0
5	415.0	442.0	27.0	213.1	201.9	38.6
6	413.2	439.1	25.9	211.8	201.4	37.3
7	415.5	441.9	26.4	213.2	202.3	38.3
8	415.0	441.0	26.0	212.7	202.3	40.3
9	416.5	442.0	25.5	210.6	205.9	37.3
10	415.0	440.8	25.8	214.1	200.9	39.3

TABLE 11. Breakthrough Time Reproducibility Study Against 4000 ppm Pentane for Manufacturer B Organic Vapor Chin-Style Canisters at 80 Percent RH and 64 L/min

Sample Number	Weight of Cartridges (g)					Breakthrough Time at 5 ppm (min)
	Initial	Final	ΔW	Case	Sorbent	
1	412.9	441.5	28.6	211.7	201.2	36.4
2	418.2	448.0	29.8	210.8	207.4	35.7
3	413.1	442.1	29.0	212.3	200.8	36.7
4	412.1	439.1	27.0	213.3	198.8	36.0
5	409.6	440.9	31.3	211.7	197.9	33.8
6	405.0	433.0	28.0	212.2	192.8	34.6
7	409.9	439.5	29.6	213.1	196.8	41.0
8	416.6	446.0	29.4	213.2	203.4	34.8
9	408.0	437.9	29.9	210.8	197.2	37.6
10	408.9	436.9	28.0	213.6	195.3	32.7

appears to be a suitable replacement agent for 5000 ppm carbon tetrachloride based on breakthrough times. Further, all chin-style canisters had breakthrough times substantially longer than the 12 minutes required in 30 CFR, Part 11.

Next, a correlation study was done employing the two best candidates. Direct comparison with carbon tetrachloride controls was determined. The data for three manufacturers' chin-style cartridges are presented in Table 9. Data for the carbon tetrachloride controls at two certification conditions (as received and preconditioned at 85% RH) are compared with the as received test data at 80 percent RH for pentane (4000 ppm) and n-hexane (5000 ppm).

The correlation data in Table 9 indicate that in the case of chin-style canisters, the most critical 30 CFR, Part 11 test condition for the OV canister was the 85 percent preconditioned canisters tested at 5000 ppm, 32 L/min, 50 percent RH, and 25°C. This is not consistent with the cartridge data which identified the most critical test to be on as received cartridges tested at 1000 ppm, 50 percent RH, and 64 L/min. Also, the canister data showed little difference in breakthrough times between the 50 and 80 percent RH test conditions for as received canisters with either pentane or carbon tetrachloride. Significant differences were observed at these conditions for the cartridges. These differences are due to the higher challenge concentration for canisters (5000 ppm) as compared to cartridges (1000 ppm) and the increased canister sorbent weight (two to three times that of cartridges).

The chin-style canister correlation data in Table 9 compare the carbon tetrachloride 5000 ppm data with the pentane 4000 ppm data. A simple linear regression analysis comparison was done between these data. For the carbon tetrachloride (5000 ppm, 64 L/min, 50% RH, and 25°C) versus pentane (4000 ppm, 64 L/min, 80% RH, and 25°C) the equation of the line obtained was $y = 1.1492 \times -4.6323$ with an r^2 value of 0.8461. The equation of the correlation between the carbon tetrachloride (5000 ppm, 85% RH preconditioned, 32 L/min, 50% RH test, 25°C) versus pentane (4000 ppm, 64 L/min, 80% RH, and 25°C) was $y = 1.4548 \times -28.0947$ with an r^2 value of 0.6612. This shows that the preconditioned carbon tetrachloride data are more variable, resulting in a reduced r^2 value. The calculated point estimate for the pentane with the present most critical 30 CFR, Part 11 test (preconditioned at 85% RH) was found to be 27 minutes using the simple model. This model was used, since at present the number of manufacturers' products to evaluate is very limited. All manufactured products were evaluated as part of this study, and each product was tested in duplicate.

Finally, a set of experiments was conducted to determine the reproducibility of the pentane test procedure. The experiment was done employing the pentane 4000 ppm challenge concentration at both 50 and 80 percent RH on as received canisters. Tables 10 and 11 present the data for canisters of manufacturer B at 50 and 80 percent RH, respectively. The data at 50 percent RH gave a mean breakthrough time of 37.9 minutes with a standard deviation of 1.4, while the mean was 35.9 with a standard deviation of 2.3 for the 80 percent RH condition. These data agree with previous data and show that the breakthrough times at 50 and 80 percent RH are not significantly different. Further, the pentane procedure shows excellent reproducibility.

Conclusions

The data show that, based on breakthrough time as the critical criterion, 4000 ppm pentane is a suitable replacement for 5000 ppm carbon tetrachloride for testing organic vapor chin-style canisters. Side-by-side testing results showed the following: (1) that the breakthrough times for as received canisters tested at 50 and 80 percent RH and 64 L/min at 25°C gave quite similar breakthrough characteristics; (2) that the most severe 30 CFR, Part 11 test for chin-style canisters was 85 percent RH preconditioned canisters tested at 50 percent RH, 32 L/min, 25°C, and 5000 ppm carbon tetrachloride; (3) that correlation existed between the 4000 ppm pentane data and the 5000 ppm carbon tetrachloride data; and (4) that the point estimate between the 4000 ppm pentane (64 L/min, 80% RH, as received, and 25°C) and the most critical 30 CFR, Part 11 test (preconditioned at 85% RH and tested at 32 L/min, 50% RH, and 25°C) was 27 minutes using a regression model.

Pentane was the agent chosen to replace carbon tetrachloride for cartridge testing. Since pentane was found to be a suitable replacement agent for testing cartridges, it is logical to select pentane for chin-style canister testing. Also, pentane is the least toxic of the possible replacement agents studied. Finally, all breakthrough times greatly exceeded the 12-minute criterion in 30 CFR, Part 11, even when testing as received canisters at 64 L/min. Thus, a testing regimen using only as received canisters at 25, 50, and 80 percent RH (25°C) at a flow rate of 64 L/min could be established.

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