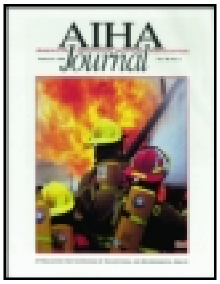

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Effects of Humidity and Contaminant Concentration on Respirator Cartridge Breakthrough*

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A model described previously was developed further to examine the effect of both test humidity and contaminant assault concentration on respirator cartridge service life. The model emphasized the characterization of cartridge performance in the range of 0% to 50% breakthrough. This study specifically addressed a contaminant concentration range of 250–2000 ppm and test humidities ranging from 0% to 80%. The preconditioning humidity was fixed at 50%. The compounds studied were benzene and methyl chloroform. Two parameters, k′ and τ, were described and values of these parameters were determined for each of several different sets of experimental conditions. The determined values of k′ and τ were applied using derived expressions to generate each of several complete breakthrough curves for benzene and for methyl chloroform at specified contaminant assault concentrations and test humidities. The effect of humidity on the value of an additional theoretical parameter, a, was investigated. Values of this parameter and the parameters, k and K″, were determined for specific test conditions. These values were substituted into pertinent expressions to produce a complete set of breakthrough curves (each curve corresponding to a particular contaminant assault concentration) for a given compound at a fixed test humidity. Several examples of breakthrough curves were generated for methyl chloroform. The results derived from the study agreed with corresponding experimental data.

The effects of relative humidity and contaminant assault concentration on respirator cartridge service life are of considerable interest to both users and manufacturers of the cartridges. Accordingly, these phenomena have been investigated by both experimentalists and theoreticians.(1-14) To augment the research that has been pursued to date, there is need for the development of systematic procedures capable of assessing the effect of both humidity and contaminant concentration on respirator performance. A theoretical model has been developed which addresses this problem.

Previously published papers(14-16) have presented and discussed theoretical approaches addressing breakthrough problems associated with the use of respirator cartridges. These approaches consist of the following. (1) The introduction of two parameters, k′ and τ, to characterize chemical contaminant breakthrough at a fixed level of contaminant assault concentration. The parameter τ is the time required for 50% breakthrough; k′ is a rate constant. Applying appropriate values of k′ and τ and the associated expressions, one may generate an entire breakthrough curve, i.e., a plot of percent breakthrough versus time, for a specific contaminant concentration. (2) With the introduction of an additional parameter, a, and further development of the model, it is possible to generate a complete set of breakthrough curves over a wide range of contaminant concentrations and at various flow rates. (3) The model has been modified further to consider the effect of humidity on respirator cartridge service life at a fixed contaminant concentration. Both the preconditioning humidity and the test (use) humidity are considered. The preconditioning humidity is the humidity of the environment in which the respirator cartridge is equilibrated prior to use.(1)

The original model was designed to provide symmetric sigmoidal breakthrough curves. This model was modified to permit the generation of nonsymmetric curves; such curves are frequently observed at high humidity. Curves derived from application of the model modified to generate nonsymmetric breakthrough curves agree with corresponding nonsymmetric experimental data over the entire breakthrough region of 0–100%.(14) The modified model is, however, somewhat complicated, requiring values of three parameters for each specific set of conditions. Therefore, in this study, the original (simpler) theory (symmetric curves) was applied to assess the effect of both humidity and contaminant concentration on respirator cartridge performance. This study emphasizes the potential application of the original model to the assessment of the effects of humidity and contaminant assault concentration on contaminant breakthrough in the breakthrough region of approximately 0–50%. The study specifically addresses a contaminant concentration range of 250–2000 ppm and a relative humidity range of dry to 80% for the environment in which the respirator is used. The cartridge precondi-

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tioning humidity is considered fixed at a value of 50% relative humidity. The contaminants investigated are benzene and methyl chloroform.(1,2)

APPLICATION OF THE MODEL

Each contaminant breakthrough profile (the plot of percentage breakthrough versus time) is considered to be a symmetric sigmoidal curve; further, the following expressions introduced in previous papers(15,16) are employed:

$$P = \frac{1}{1 + e^{k'(\tau - t)}} \quad (1)$$

$$\ln \frac{P}{1 - P} = -k'(\tau - t) \quad (2)$$

$$t = \tau + \frac{1}{k'} \ln \frac{P}{1 - P} \quad (3)$$

where

$$k' = \frac{k\,C\,F}{W_e} = \frac{k}{\tau} \quad (4)$$

and

$$W_e = F\,C\,\tau \quad (5)$$

The following definitions apply:

P = probability of contaminant breakthrough or breakthrough percentage
k' = rate constant (min^{-1})
τ = time required for 50% contaminant breakthrough (min/cartridge)
t = breakthrough time (min/cartridge)
k = proportionality constant
C = contaminant concentration (g/L)
F = flow rate (L/min)
W_e = capacity of adsorbed contaminant (g/cartridge)

Equation 1 defines the breakthrough curve. To generate a specific breakthrough profile for a particular contaminant assault concentration, the applicable values of k' and τ must be determined. These values are derived from a consideration of appropriate experimental data. In accordance with Equation 2, the slope of a plot of $\ln[P/(1 - P)]$ versus the breakthrough time (t) is k'; the value of t at $P = 0.5$ is τ. For the purposes of this study, only experimental data in the region of 0–50% breakthrough were used to determine the values of k' and τ. Only data from this breakthrough region were used because (1) the original breakthrough model is based on symmetric, sigmoidal breakthrough curves and (2) experimentally observed deviations from calculated (symmetric) curves (partially attributable to the effect of water vapor) is greater at breakthrough percentages exceeding 50%.(1) The values of k' and τ determined from a consideration of experimental data in the 0–50% breakthrough region were used to calculate the entire breakthrough curve (0–100%); the resulting curve was compared to available experimental data. This approach is expected to result in the generation of calculated breakthrough curves which agree most consistently with experimental data in the region of approximately 0–50% contaminant breakthrough, the region of most practical importance.

Presented in Table I are calculated values of k' and τ for benzene under various conditions of relative humidity and contaminant assault concentration. Experimentally observed values of τ are also listed. In addition, pertinent values of k determined from Equation 4 are summarized in this table. Note that k is independent of the contaminant concentration. Similarly, values of k', τ, and k for methyl chloroform are summarized in Table II. The experimental data utilized to derive the information summarized in Tables I and II are those of G.O. Nelson and coworkers.(1,2)

Each set of k' and τ values has been utilized by applying Equation 3 to calculate the entire breakthrough curve (breakthrough percentage versus time) for each of several contaminant assault concentrations under specified humidity conditions. A family of calculated breakthrough curves, each curve corresponding to a specific assault concentration of benzene under test conditions of 24% humidity, is presented in Figure 1. Benzene concentrations range from 250–2000 ppm. Pertinent experimental data are also provided in the plots. A similar plot for benzene at a test humidity of 80% is provided in Figure 2. The data presented in Figures 3 and 4 illustrate the effect of changes in test humidity on the breakthrough characteristics of methyl chloroform at a specific concentration. Test humidities range from 0% to 80%.

THE THEORETICAL PARAMETER, a

Previously,(16) the theoretical parameter, a, was introduced and the value of this parameter was determined for several contaminants. Both the preconditioning humidity and the test humidity were considered to be 50%. In the present study, the effect of different test humidities on the value of a was examined at a preconditioning humidity of 50%.

The following expressions were introduced in the previous paper:(16)

$$\log t = \log \frac{K_{wQ}}{F} - a \log C \quad (6)$$

$$K_{wQ} = K_w\left(1 - \frac{K_Q}{k}\right) \quad (7)$$

$$C = \frac{C_I\,M}{V_a \times 10^6} \quad (8)$$

Therefore,

$$\log t = \log \frac{K'_{wQ}}{F} - a \log C_I \quad (9)$$

where

$$K'_{wQ} = K_{wQ}\left(\frac{V_a \times 10^6}{M}\right)^a \quad (10)$$

Note that the following definitions apply. K_w is a proportionality constant, and $K_Q = \ln[Q/(1 - Q)] = -\ln[P/(1 - P)]$. Q is the probability of adsorption of the contaminant on the charcoal.

TABLE I

Values of k′, τ, and k for Benzene at Various Test Humidities[A] and Various Concentrations

Test Humidity (%)	Assault Concentration (ppm)	k′ (min^{-1})	τ (min)		r^{2}[B]	k
			Calculated	Experimental		
0	250	0.043	320	321	0.999	13.9
	500	0.072	195	195	0.999	14.1
	1000	0.118	120	121	0.984	14.1
	2000	0.206	66.9	67.8	0.990	13.8
24	250	0.047	322	324	0.996	15.0
	500	0.088	197	199	0.989	17.3
	1000	0.125	115	116	0.996	14.4
	2000	0.226	67.4	67.9	0.996	15.2
50	250	0.047	292	293	1.000	13.8
	500	0.080	198	199	0.996	15.9
	1000	0.137	104	106	0.993	14.3
	2000	0.224	64.9	65.6	0.992	14.6
80	250	0.063	207	212	0.976	13.0
	500	0.096	147	150	0.985	14.1
	1000	0.139	98.7	100	0.986	13.7
	2000	0.213	62.6	63.2	0.995	13.3

[A] Preconditioning humidity: 50%.

[B] Square of the correlation coefficient.

TABLE II

Values of k′, τ, and k for Methyl Chloroform at Various Test Humidities[A] and Various Concentrations

Test Humidity (%)	Assault Concentration (ppm)	k′ (min^{-1})	τ (min)		r^{2}	k
			Calculated	Experimental		
0	250	0.041	270	276	0.985	11.0
	500	0.074	175	177	0.987	12.9
	1000	0.123	95.3	96.6	0.994	11.7
	1500	0.166	71.7	72.9	0.985	11.9
	2000	0.198	56.9	57.5	0.995	11.3
20	250	0.041	274	278	0.992	11.3
	500	0.067	182	182	0.999	12.1
	1000	0.131	97.5	98.9	0.988	12.8
	1500	0.171	71.0	72.5	0.981	12.1
	2000	0.212	59.1	60.2	0.987	12.5
50	250	0.040	266	269	0.991	10.7
	500	0.069	170	172	0.995	11.6
	1000	0.126	92.9	95.0	0.982	11.7
	1500	0.141	71.8	72.6	0.998	10.2
	2000	0.207	56.9	58.1	0.987	11.8
80	250	0.053	178	180	0.998	9.5
	500	0.072	129	129	0.996	9.3
	1000	0.133	84.0	85.9	0.980	11.1
	1500	0.171	65.4	66.4	0.987	11.2
	2000	0.225	52.9	53.9	0.986	11.9

[A] Preconditioning humidity: 50%.

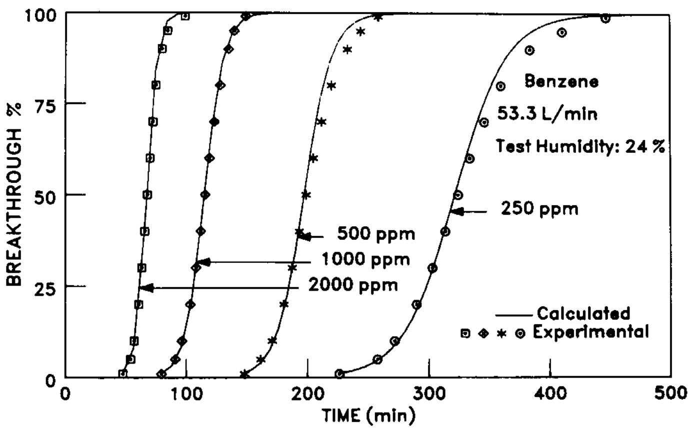

Figure 1—Comparison of calculated breakthrough curves (solid lines) with experimental data for benzene at various assault concentrations and a test humidity of 24%. The preconditioning humidity is 50%.

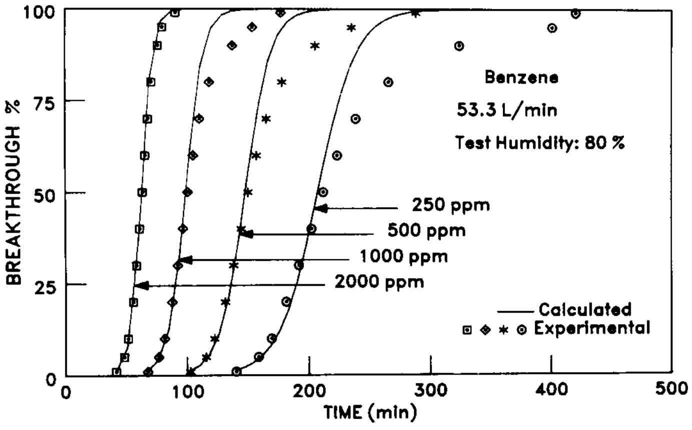

Figure 2—Comparison of calculated breakthrough curves (solid lines) with experimental data for benzene at various assault concentrations and a test humidity of 80%. The preconditioning humidity is 50%.

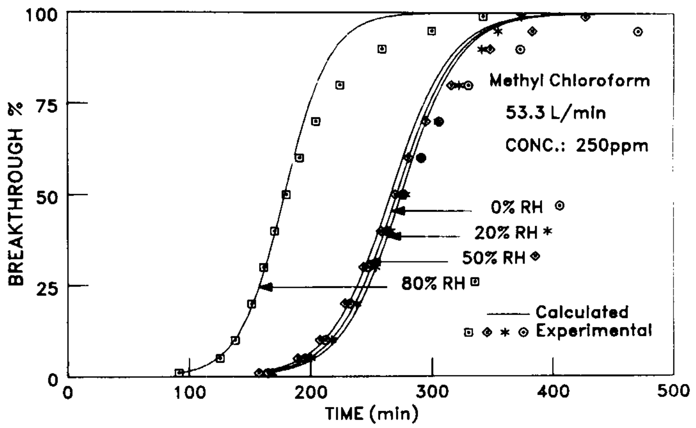

Figure 3—Comparison of calculated breakthrough curves (solid lines) with experimental data for methyl chloroform at various test humidities and at an assault concentration of 250 ppm. The preconditioning humidity is 50%.

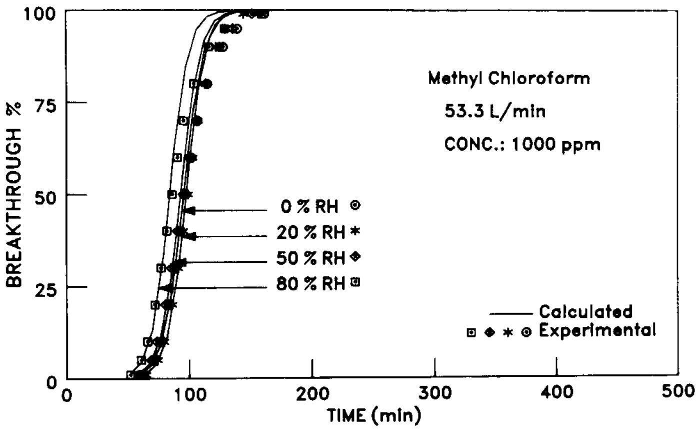

Figure 4—Comparison of calculated breakthrough curves (solid lines) with experimental data for methyl chloroform at various test humidities and at an assault concentration of 1000 ppm. The preconditioning humidity is 50%.

C_I is the contaminant assault concentration expressed in ppm. V_a is the molar volume of the contaminant at a specified temperature (L/mole). M is the molecular weight of the contaminant.

At 50% breakthrough, t = τ, and Equation 9 can be rewritten as follows:

$$\log \tau = \log \frac{K'_{wQ}}{F} - a \log C_I \qquad \textbf{(11)}$$

Equation 9 is employed to determine the value of the theoretical parameter a for specific humidity conditions. This expression is applied at a specified value of breakthrough percentage. Under these conditions, P is invariant; therefore, K_Q is fixed and log K'_{wQ}/F is a constant, provided that the flow rate F does not change. Accordingly, a plot of log t versus log C_I is linear; the slope of the plot is -a and the intercept is log K'_{wQ}/F. Representative plots of log t versus log C_I for methyl chloroform are presented in Figure 5. Note that plots for both benzene and methyl chloroform are, in fact, linear as expected. Linearity is observed for a range of test humidities from 0 to 80%. This is an extremely important observation because it indicates that the approach employed to predict the breakthrough characteristics of benzene and of methyl chloroform is reliable under conditions of variable test humidity and contaminant concentration.

For convenience, log K'_{wQ}/F is defined as K″. Therefore, Equation 11 may be rewritten as

$$\log \tau = K'' - a \log C_I \qquad \textbf{(12)}$$

Values of K″ and a for benzene and for methyl chloroform are tabulated in Tables III and IV, respectively. Data are provided for several different test humidities and for breakthrough percentages of 1, 5, 10, and 50. The correlation coëfficient (squared) corresponding to the linear regression fit of each data set is also provided.

DISCUSSION

The data presented in Table I and Figures 1 and 2 demonstrate that the curves calculated for benzene at concentrations of 250,

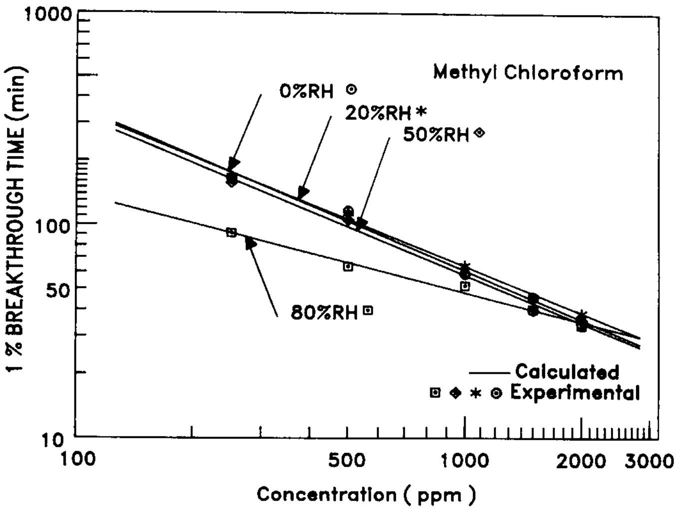

Figure 5—The effect of concentration on the 1% breakthrough time of methyl chloroform at various test humidities. The preconditioning humidity is 50%.

500, 1000, and 2000 ppm agree reasonably well with experimental data at the following test humidities: 0, 24%, 50%, and 80%. At all concentrations and test humidities considered, experimental data closely follow symmetric, sigmoidal breakthrough curves in the breakthrough percentage range of 0–50%. There is excellent agreement between the calculated and experimental results in this breakthrough range. At higher breakthrough percentages, the deviation of experimental data from symmetric breakthrough increases, particularly at higher test humidities and lower concentrations. Accordingly, for the data presented, the greatest deviation between the theory and experimental results for benzene is observed at 250 ppm and a test humidity of 80% (Figure 2).

The effect of the test humidity on the breakthrough curves of methyl chloroform at specific assault concentrations is illustrated in Figures 3 and 4. At higher concentrations (e.g., 1000 ppm) the test humidity has little effect on methyl chloroform breakthrough (see Figure 4). As shown in Figure 3, there are no substantial differences in the breakthrough curves of methyl chloroform at 250 ppm over the test humidity range of 0–50%. If the humidity is increased to 80%, however, the breakthrough time decreases markedly. A similar phenomenon is observed for benzene. The decreased breakthrough time observed at 80% humidity may be attributed to the increased ability of water molecules to compete for adsorption sites. This effect may vary from compound to compound. Similar observations have been noted previously by Nelson and Harder.(2)

Regarding the data illustrated in Figures 3 and 4, for breakthrough percentages less than 50%, the breakthrough time for dry conditions (~ 0% test humidity) is less than that observed at approximately 20% relative humidity. Apparently, the presence of relatively small quantities of water vapor actually increases the adsorption of some organic vapors in comparison to the adsorption observed under dry conditions. The difference in adsorption at 20% relative humidity and ~ 0% is, however, very small, and the exact cause of this difference is not readily evident.

Tables III and IV provide values of the parameters a and K″ (under various experimental conditions) for benzene and for methyl chloroform, respectively. The corresponding values of a for benzene and methyl chloroform are similar. Note, however, that a previous study(16) has shown that the value of a may vary, depending on compound and cartridge type. For benzene and for methyl chloroform, the value of a is similar for all cases considered here except those derived for a test humidity of 80%. At this humidity, the value of a is reduced for both benzene and methyl chloroform. For each test humidity, the value of a is

TABLE III
The Effect of Test Humidity on the Values of a and K″ for Benzene

Test Humidity (%)	Breakthrough Percentage											
	1			5			10			50		
	a	K″	r^2	a	K″	r^2	a	K″	r^2	a	K″	r^2
Dry	0.733	4.10	0.996	0.757	4.23	0.998	0.757	4.26	0.998	0.742	4.29	0.998
24	0.762	4.20	0.995	0.757	4.23	0.999	0.757	4.26	0.998	0.755	4.33	1.000
50	0.729	4.07	0.982	0.747	4.18	0.989	0.743	4.19	0.989	0.739	4.26	0.992
80	0.584	3.56	0.991	0.571	3.59	0.993	0.572	3.61	0.991	0.581	3.73	0.996

TABLE IV
The Effect of Test Humidity on the Values of a and K″ for Methyl Chloroform

Test Humidity (%)	Breakthrough Percentage											
	1			5			10			50		
	a	K″	r^2	a	K″	r^2	a	K″	r^2	a	K″	r^2
Dry	0.765	4.08	0.988	0.759	4.14	0.993	0.758	4.16	0.995	0.764	4.29	0.997
20	0.729	3.99	0.995	0.748	4.12	0.992	0.760	4.18	0.991	0.758	4.28	0.996
50	0.747	4.01	0.991	0.740	4.07	0.996	0.744	4.11	0.996	0.748	4.23	0.998
80	0.460	3.06	0.985	0.560	3.45	0.996	0.570	3.52	0.996	0.577	3.65	0.995

generally independent of the breakthrough percentage. A notable exception is the smaller value of a derived for methyl chloroform at 1% breakthrough and a test humidity of 80%. This value is approximately 20% less than those obtained at 80% humidity and 5%, 10%, and 50% breakthrough. This may be attributed to a nonequilibrium situation. For a specific breakthrough percentage, the value of K″ at 80% humidity is considerably less than those derived at each of the other three test humidities. As noted previously, the same observation applies to the parameter a. Unlike a, however, K″ is a function of the breakthrough percentage. At a specific test humidity, the value of K″ increases with increasing breakthrough percentage. This is consistent with Equation 7 because both k and K_{wQ} are fixed for a specific test humidity.

For the considerations of this study, the preconditioning humidity is fixed at 50%. Accordingly, if the test humidity is also 50%, the quantity of water adsorbed on the charcoal is not likely to change appreciably with exposure of the adsorbent to the test environment (if the effect of contaminant molecules on the adsorption of water is considered to be negligible). If the test humidity is different from that used to precondition the cartridge, the number of water molecules adsorbed on the carbon bed may either increase or decrease as testing proceeds. For example, use of a dry test atmosphere or a test humidity of 20% might be expected (on the basis of intuition) to result in a considerable decrease in the quantity of water vapor adsorbed on the sorbent bed. It appears, however, that this is not generally observed. For example, Hall et al.(12) have noted that there is a significant hysteresis effect for the water vapor-carbon desorption isotherm. In addition, Nelson and Harder(2) have indicated that organic vapors passing through a carbon bed containing adsorbed water do not necessarily displace the water vapor. Testing at a relative humidity of 80% is expected to increase the number of adsorbed water molecules as testing proceeds. One should note, however, that the presence of contaminant molecules could influence the degree of water vapor adsorption.(1)

Previous experiments(1,5) conducted in the absence of contaminant compounds have demonstrated that the amount of water adsorbed by activated carbon increases dramatically as the relative humidity increases above approximately 50%-60%. From these data, one could conclude that the effect of water vapor on contaminant adsorption is minimal for humidities in the approximate range of 0-50%. Likewise, the influence of water on the adsorption of contaminant compounds by carbon would be expected to increase as humidities exceed approximately 60%. The model is consistent with the preceding observations. For example, if the preconditioning humidity is maintained at 50%, the values of the theoretical parameters a and K″ change relatively little in the test humidity range: 0 to 50%. When the test humidity is increased to 80%, however, the values of both a and K″ decrease noticeably (Tables III and IV and Figure 5).

If water vapor is present, competition between water molecules and contaminant molecules for adsorption sites is a factor as testing proceeds. Under conditions of relative humidity of 20% or greater, the number of water molecules is much greater than that of the chemical contaminant at the contaminant concentrations pertinent to this study. For example, at 20% relative humidity and a contaminant concentration of 250 ppm, the ratio of water molecules to contaminant molecules is approximately 22; for 80% relative humidity and 250 ppm, this ratio is approximately 88. It is important to note, however, that the process of adsorption of water by activated carbon is extremely slow.(1) For example, Nelson et al.(1) have observed that 7-10 days are required for a desiccated cartridge to reach equilibrium (with respect to water adsorption) under a static storage humidity greater than 60%; 2 days are required to achieve 50% saturation of the cartridge by water vapor. At the higher levels of contaminant concentration (e.g., 1000–2000 ppm), the process of water adsorption is much slower than that of contaminant adsorption. Therefore, if the contaminant concentration is high, water has very little effect on the adsorption of contaminant molecules even though the water/contaminant molecular ratio is 10–20, a situation realized for 1000–2000 ppm and an 80% test humidity. For example, note that the breakthrough curve for methyl chloroform at 1000 ppm and 80% relative humidity is very similar to the corresponding curves observed at 0%, 20%, and 50% (Figure 4). As the contaminant concentration is decreased and the test humidity maintained at 80%, the water/contaminant ratio increases and water competes more effectively for active sites. This accounts for the relatively large deviation between experimental data and theory observed at 250 ppm and/or at 80% test humidity (see Figures 1–3). For breakthrough percentages exceeding 50%, deviation between experiment and theory increases with decreasing contaminant concentration and increasing test humidity. The humidity effect on the adsorption of compounds more soluble in water than those addressed in this study (benzene, methyl chloroform) may be somewhat different. Because only limited experimental data are available, it is difficult to derive general conclusions at this time.

THE PRACTICAL APPLICATION OF THE MODEL

Presented in a previous section of this paper is the calculation (using Equation 3) of a single theoretical breakthrough curve for a given compound at a fixed assault concentration and at a specified test humidity using determined values of the parameters, k′ and τ. In the application illustrated here, previously determined values of k, a, and K″ were used to calculate the entire family of breakthrough curves (one curve for each concentration) for a given compound at a specified test humidity. This approach is illustrated with a specific example, methyl chloroform, at three different test humidities: dry, 50%, and 80%. The value of k (for each specific test humidity) used in this exercise was the mean of all k values listed in Table II. Pertinent values of k are 11.8 (dry); 11.2 (50%); and 10.6 (80%). Note that the value of k is independent of assault concentration. The values of a and K″ employed in this example are those listed in Table IV for 50% breakthrough and the test humidity of interest. Applying Equation 12 and the appropriate values of K″ and a (for a specific test humidity), one may calculate the value of τ for each concentration of interest. Determined values of τ for methyl chloroform are listed in Table V for test humidities of 0, 50%, and 80% at each of the following concentrations: 250, 500, 1000, 1500, and 2000 ppm. Pertinent values of k′ are required to generate the theoretical breakthrough curves of interest. Equation 4 may be applied to determine each required k′ value because corresponding values of τ (Table V)

TABLE V
Values of k′ and τ for Methyl Chloroform at Various Test Humidities^A and Concentrations

Test Humidity (%)	Assault Concentration (ppm)	k′ (min^{-1})	τ (min)
0	250	0.041	287
	500	0.070	169
	1000	0.118	99.5
	1500	0.161	73.0
	2000	0.201	58.6
50	250	0.041	273
	500	0.069	162
	1000	0.116	96.8
	1500	0.157	71.5
	2000	0.194	57.5
80	250	0.058	184
	500	0.086	123
	1000	0.129	82.4
	1500	0.163	65.2
	2000	0.192	55.2

^{A}Preconditioning humidity: 50%.

and k are known. Values of k′ pertinent to this example are listed in Table V. Each set of k′ and τ values is substituted into Equation 3 to generate the entire family of breakthrough curves for each test humidity. Representative curves for methyl chloroform at a test humidity of 80% are compared with corresponding experimental data in Figure 6.

In an addition application, the three parameters (k, a, and K″) were used to assess the breakthrough properties of benzene under conditions of high humidity. For example, at 80% relative humidity, k = 13.5 and a = 0.581. Note that the values of k and a are independent of the breakthrough percentage while the value of K″ varies with breakthrough percentage. At 50% breakthrough, K″ = 3.73.

A log-log plot of concentration versus breakthrough time was generated by using (in Equation 9) the specific (benzene) values of k, a, and K″ listed in the preceding paragraph. This plot, the extreme upper data plot in Figure 7, applies to 50% breakthrough because the value of K″ for 50% breakthrough was employed. Similar plots for any particular breakthrough percentage of interest may be generated as follows. At 50% breakthrough, $K_Q = 0$ (by definition of K_Q); therefore, by Equation 7: $K_{wQ} = K_w$. Note that K_w may be determined from the value of K″ at 50% breakthrough because

$$K'' = \log \frac{K'_{wQ}}{F} \qquad \textbf{(13)}$$

and

$$K'_{wQ} = K_{wQ}\left(\frac{V_a \times 10^6}{M}\right)^a \qquad \textbf{(10)}$$

Since K_w and k are known and are independent of the breakthrough percentage, Equation 7 may be used to calculate the value of K_{wQ} (and, therefore, the value of K″) for any breakthrough percentage of interest. For example, at 1% breakthrough:

$$K_Q = -\ln\left(\frac{0.01}{1 - 0.01}\right) \qquad \textbf{(14)}$$

and

$$K_{wQ} = K_w\left[1 + \frac{1}{k}\ln\left(\frac{0.01}{0.99}\right)\right] \qquad \textbf{(15)}$$

K″ is derived from K_{wQ}. Since a and K″ are known, Equation 9 may be used to generate a log-log plot of concentration versus breakthrough time for a specified breakthrough percentage. Representative plots for benzene at 50%, 10%, and 1% breakthrough are presented in Figure 7.

The preceding examples illustrate the practical utility of the model as they demonstrate that numerous breakthrough curves may be generated from the three theoretical parameters: k, a, and K″.

CONCLUSION

In this study, a useful model was employed to examine the effect of both test humidity and contaminant assault concentration on respirator cartridge breakthrough of benzene and of methyl chloroform. The approach assumes that the breakthrough curve for specified conditions of respirator cartridge use is symmetric and sigmoidal. This approach allows one to describe and examine the effect of humidity on respirator cartridge performance using simple theoretical expressions.

The results of this study demonstrate that (for the compounds investigated) the logarithm of the breakthrough time (log t) is proportional to the logarithm of concentration (log C_I).(1) The constant of proportionality is the parameter a. The linear relationship between log t and log C_I, the development of associated expressions, and the determination of pertinent values of a and additional theoretical parameters (k and K″) permits one to generate an entire set of contaminant breakthrough curves (each curve corresponding to a specific contaminant concentration) for a specified test humidity and a given contaminant. This was

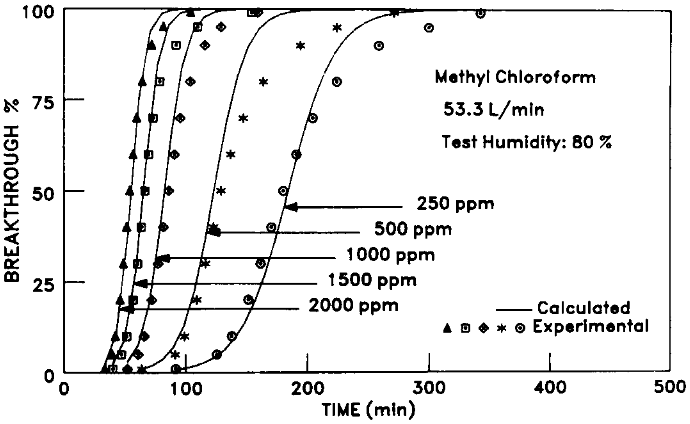

Figure 6—Comparison of theoretical breakthrough curves (solid lines) with experimental data for methyl chloroform at various assault concentrations and a test humidity of 80%. The preconditioning humidity is 50%.

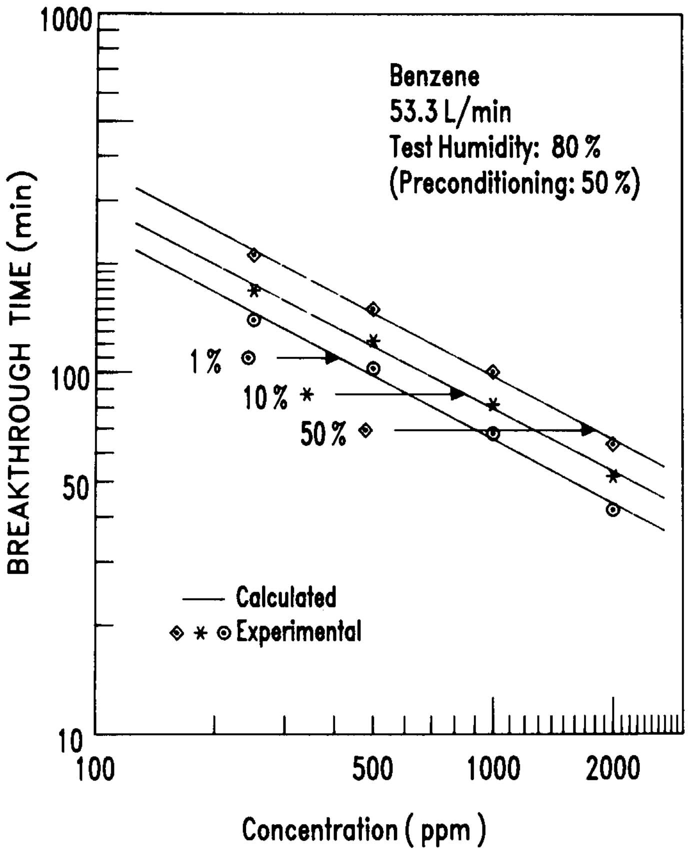

Figure 7—Concentration effect on breakthrough time for benzene at breakthrough percentages of 50%, 10%, and 1%. The test and preconditioning humidities are 80% and 50%, respectively.

not possible with the application of the model developed previously to generate nonsymmetric curves.(14) Accordingly, the approach presented in this study represents a more efficient means of assessing the effect of humidity on contaminant breakthrough.

It is important to emphasize that the value of K″ depends on the breakthrough percentage. This fact was recognized by Nelson et al.(1) in an earlier paper. The significance of the present paper is that a model has been developed which can be applied successfully to calculate the actual values of K″ pertinent to conditions of high humidity.

If manufacturers of respirators or other interested parties provided pertinent values of a, k, and K″ for each combination of cartridge type, humidity conditions, and contaminant, the user could evaluate the potential efficacy of respirator cartridge type regarding specific applications. In particular, the effect of humidity on cartridge performance could be assessed.

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