EVALUATION OF THE DOOR FAN PRESSURIZATION LEAKAGE TEST METHOD APPLIED TO HALON 1301 TOTAL FLOODING SYSTEMS

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SUMMARY

In view of current and future regulations on the emissions of Halon 1301 due to its contribution to stratospheric ozone depletion, alternatives to total flooding discharge tests with Halon 1301 are desirable. An important aspect of these tests is the determination of the leakage rate of the Halon 1301-air mixture from the enclosure.

One method for estimating leakage is the door fan pressurization test. This test was evaluated on its ability to estimate both the total leakage area and the interface decay rate.

This test procedure was found to be an adequate method to estimate the leakage rate from an enclosure, if a distribution of the leakage area over the compartment boundary can be assumed.

Equations relating the leakage area to the interface descent or Halon 1301 concentration decay are derived for the stratified or well mixed case respectively. Typical simplifications of these equations (flow exponent, leakage area distribution, etc.) are also given.

INTRODUCTION

In view of current and future regulation on the emissions of Halon 1301 due to its contribution to stratospheric ozone depletion, alternatives to total flooding discharge tests are desirable. This work is part of a project sponsored by the Naval Sea System Command and conducted by the Navy Technology Center for Safety and Survivability of the Naval Research Laboratory to investigate these alternatives.

An important aspect of these tests is the determination of the leakage rate of the Halon 1301-air mixture from the enclosure. The National Fire Protection Association (NFPA) in their Standard 12A requires that the leakage rate be low enough that the design concentration is held in the hazard area long enough to ensure complete extinguishment and to allow time to mitigate persistent ignition sources (typically 10 minutes at the elevation of the highest combustible material).

One method of estimating leakage area is the door fan pressurization test.

THEORY

In the door fan test, a calibrated fan is used to provide a known flow rate of air into the room. The corresponding increased pressure in the room is then measured. This is done for several flow rates. For readers not familiar with the procedure, Reference 5 and NFPA 12A, 1989 edition, are good sources.

The pressures and flow rates are correlated through the following equation:

\[ Q = C \left( \frac{\Delta P}{\rho_{\text{air}}} \right)^N \]  

where \( Q \) is the flow rate, \( \Delta P \) is the amount the pressure was increased, \( \rho_{\text{air}} \) is the density of air, \( N \) is the flow exponent (typically between 0.5 and 1), and \( C \) is a correlation constant.

The constant, \( C \), can be broken into three fac-
tors as follows:
\[ C = K_d A_T K_u \]  \hspace{1cm} (2)

where \( K_d \) is the flow or discharge coefficient, \( A_T \) is the total leakage area and \( K_u \) is a constant based on the value of \( N \) and the units used. Therefore, the total leakage area can be estimated based on an assumed value of \( K_d \).

### Prediction of Leakage Rate

In order to use this to predict the leakage rate of a Halon 1301-air mixture, a distribution of the leakage area over the compartment boundary (size and location of leaks) must be assumed. If the effective leakage area is assumed to be divided between the ceiling and floor, as shown in Figure 1, with the fraction of this area on the floor being known or assumed, then this situation can be modeled by extending the concepts of Yao and Smith as follows:

\[ A_L = F_A K_d A_T/K_{dL} \]  \hspace{1cm} (3)

\[ A_U = (1 - F_A) K_d A_T/K_{dU} \]  \hspace{1cm} (4)

\[ \Delta P_L - \Delta P_U = (\rho_m - \rho_{air}) gh \]  \hspace{1cm} (5)

\[ Q_U = -Q_L \]  \hspace{1cm} (6)

where \( A_L \) is the area of the lower leak, \( F_A \) is the fraction of the total effective leakage area that is the effective lower leakage area, \( A_U \) is the area of the upper leak, \( K_{dL} \) is the flow coefficient of the lower leak, \( K_{dU} \) is the flow coefficient of the upper leak, \( \Delta P_L \) is the pressure difference across the lower leak, \( \Delta P_U \) is the pressure difference across the upper leak, \( \rho_m \) is the density of the Halon 1301-air mixture, \( \rho_{air} \) is the density of the ambient air, \( g \) is acceleration due to gravity, \( h \) is the height of the interface, \( Q_U \) is the volume flow rate through the upper leak, and \( Q_L \) is the volume flow rate through the lower leak.

When Equations 1 through 4 are substituted in Equation 6 the following equation is arrived at:

\[ (1 - F_A)C \left( \frac{2\Delta P_U}{\rho_{air}} \right)^N = -FA C \left( \frac{2\Delta P_L}{\rho_m} \right)^N \]  \hspace{1cm} (7)

This equation is then rearranged and \( \Delta P_U \) is solved for to get the following:

\[ \Delta P_U = -\left[ \frac{F_A}{(1 - F_A)} \left( \frac{\rho_{air}}{\rho_m} \right) \Delta P_L \right]^{1/N} \]  \hspace{1cm} (8)

When this is substituted into Equation 5, \( \Delta P_L \) can be solved for:

\[ \Delta P_L = \frac{(\rho_m - \rho_{air}) gh}{1 + \left[ \frac{F_A}{(1 - F_A)} \left( \frac{\rho_{air}}{\rho_m} \right) \right]^{1/N}} \]  \hspace{1cm} (9)

The volume flow rate of the Halon 1301-air mixture is then determined by the following equation.

\[ Q_L = F_{AC} \left( \frac{2(\rho_m - \rho_{air}) gh}{\rho_m + \left( \frac{F_A}{(1 - F_A)} \right)^{1/N}} \right)^N \]  \hspace{1cm} (10)

As the rate of descent of the interface is related to the volume flow rate, a differential equation is arrived at.

\[ \frac{dh}{dt} = -\frac{Q_U}{A_R} = -\frac{F_{AC}}{A_R} \left( \frac{2(\rho_m - \rho_{air}) gh}{\rho_m + \left( \frac{F_A}{(1 - F_A)} \right)^{1/N}} \right)^N \]  \hspace{1cm} (11)

![Figure 1. System schematic and pressure diagram](image-url)
Where $A_R$ is the horizontal cross-sectional area of the enclosure. This can be rewritten as:

$$h^{-N} dh = -K_1 dt$$  \(\text{(12)}\)

where

$$K_1 = \frac{F_A C}{A_R} \left[ \frac{2 (\rho_m - \rho_{air}) g}{\rho_m + \left( \frac{F_A}{1 - F_A} \right)^{-N} \rho_{air}} \right]$$  \(\text{(13)}\)

This is then integrated as follows:

$$\int_{h_i}^{h} h^{-N} dh = -K_1 \int_{t=0}^{t} dt$$  \(\text{(14)}\)

$$\frac{(h_i^{[1-N]} - h^{[1-N]})}{1 - N} = -K_1 t$$  \(\text{(15)}\)

where $h_i$ is the initial height of the interface.

Note that the initial height of the interface would be equal to the enclosure height if the room is initially well mixed.

Solving for $t$,

$$t = \frac{h_i^{[1-N]} - h^{[1-N]}}{(1 - N) K_1}$$  \(\text{(16)}\)

or solving for $h$,

$$h = \left[ h_i^{[1-N]} - (1 - N) K_1 t \right]^{[1-N]}$$  \(\text{(17)}\)

where $K_1$ is given by Equation 13.

These equations are obviously very sensitive to the measured value of $N$. In general for laminar flow through single orifices, $N$ can be taken as $1/2$, from arguments used in the derivation of Bernoulli's equation. Variations from an $N$ of $1/2$, measured by the door fan test are expected. Note that for $N$ values of 1, Equation 16 becomes equal to zero, and Equation 17 is indeterminate. These equations should not be used where the measured $N$ value is greater than 0.9 or less than 0.1. These extremes are indicative of very complex leakage paths and/or unknown or varying bias pressures across leaks.

Note that a value of $F_A$ of approximately 0.5 results in the fastest descent of the interface and therefore represents a "worst case." Note that in the door fan test only total effective leakage area is determined, the location of the assorted leakage paths is not known. Hence an assumption of the distribution of the leak area and location is required. An assumption of 50% of the leakage area at the top of the compartment and 50% of the leakage area at the floor is the most conservative case.

**Effects of Bias Pressure**

In some instances, there are constant pressure differences across the leaks in addition to that attributed to the presence of Halon 1301-air mixture. These pressure differences are the result of HVAC systems, wind, etc. The result of subtracting the pressure difference at the upper leak from that at the lower leak is called a bias pressure. The effects of a constant bias pressure are illustrated in Figure 2. Equation 9 is modified to add the effects of the bias pressure as follows:

$$\Delta P_L = \left( \frac{\rho_m - \rho_{air}}{\rho_m} \right) gh + P_b \left[ 1 + \left( \frac{F_A}{1 - F_A} \right)^{-N} \frac{\rho_{air}}{\rho_m} \right]$$  \(\text{(18)}\)

The differential equation to be solved is then:

$$\frac{dh}{dt} = \frac{-F_A C}{A_R} \left[ \frac{2 (\rho_m - \rho_{air}) g}{\rho_m + \left( \frac{F_A}{1 - F_A} \right)^{-N} \rho_{air}} \right]$$  \(\text{(19)}\)

This is then rewritten and integrated as follows:

$$\int_{h_i}^{h} [K_2 h + K_3]^{-N} dh = -\frac{F_A C}{A_R} \int_{t=0}^{t} dt$$  \(\text{(20)}\)

$$\frac{[K_2 h + K_3]^{1-N} - [K_2 h_i + K_3]^{1-N}}{(1 - N) K_2} = -\frac{F_A C t}{A_R}$$  \(\text{(21)}\)

where

$$K_2 = \frac{2 (\rho_m - \rho_{air}) g}{\rho_m + \left( \frac{F_A}{1 - F_A} \right)^{-N} \rho_{air}}$$  \(\text{(22)}\)

$$K_3 = \frac{2 P_b}{\rho_m + \left( \frac{F_A}{1 - F_A} \right)^{-N} \rho_{air}}$$  \(\text{(23)}\)
Solving for $t$:

$$t = \frac{A_R}{FAC} \left[ \frac{K_2 h_i + K_3}{(1 - N) K_2} \right]^{1 - N} \left[ \frac{K_3}{K_2} \right]^{1 - N}$$  \hspace{1cm} (24)

or alternatively for $h$

$$h = \frac{\left[ \frac{K_2 h_i + K_3}{(1 - N) K_2} \right]^{1 - N} - \frac{FAC}{A_R} (1 - N) K_2}{K_2}$$  \hspace{1cm} (25)

Note that this development and therefore these equations do not cover the situation of the bias pressure being provided by an operating ventilation supply or exhaust within the enclosure or where a bias pressure is applied unevenly across compartment boundaries. They also do not cover the situations of the bias pressure resulting in a reversal of flow direction or where the variation of the bias pressure with time cannot be ignored. There are very substantial limitations in the application of these equations to real building compartments with ambient static pressure differentials. It is theoretically possible to predict the impact of the pressure differential if the details of leakage area location, source of bias pressure, etc. are known, but these cannot generally be ascertained in a practical way. In addition, of course, more detailed analytical treatment is necessary.

**Effects of Mixing**

If the Halon 1301 is continuously stirred so that no interface develops, then the height of the interface, $h$, is taken as a constant equal to the height of the enclosure and the density of the Halon 1301-air mixture, $\rho_m$, varies with time. This situation is shown schematically in Figure 3. The volume flow rate of the enclosure is given by the following:

$$Q_L = FAC \left[ \frac{2 (\rho_m - \rho_{air}) gh + 2 P_b}{1 + \frac{F_A}{1 - F_A} \frac{\rho_{air}}{\rho_m}} \right]$$  \hspace{1cm} (26)

As the volume flow rate out of the enclosure is proportional to the change in the mixture density, the following differential equation is arrived at:

$$\frac{d\rho_m}{dt} = \frac{-Q_L (\rho_m - \rho_{air})}{A_R h}$$  \hspace{1cm} (27)

$$= \frac{-FAC}{A_R h} \left[ 2 gh (\rho_m - \rho_{air})^{1/N} + 2 p_b (\rho_m - \rho_{air})^{1/N} \right]$$  \hspace{1cm} (28)

This can be solved for the time elapsed before the mixture density drops below a value of $\rho_m$ as follows:

$$t = \frac{A_R h}{FAC} \times$$

$$\int_{\rho_m}^{\rho_{mi}} \left[ \frac{2 gh (\rho_m - \rho_{air})^{1/N} + 2 p_b (\rho_m - \rho_{air})^{1/N}}{\rho_m + \frac{F_A}{1 - F_A} \rho_{air}} \right] \frac{d\rho_m}{\rho_{mi}}$$

where $\rho_{mi}$ is the density of the initial mixture.

An analytical solution can only be found if the value of $N$ is 0.5 and $P_b$ can be ignored. Under these conditions, Equation 29 becomes:
Figure 3. Well Mixed System Schematic and Pressure Diagram with Bias Pressure

\[ t = \frac{1}{K_5} \log \left[ \frac{\left( \rho_{m} - \rho_{air} + \left( \left( \rho_{m} - \rho_{air} \right) \left( \rho_{m} + K_4 \rho_{air} \right)^{0.5} \right)^2 \left( \rho_{m} - \rho_{air} \right) \right)}{\left( \rho_{m} - \rho_{air} + \left( \left( \rho_{m} - \rho_{air} \right) \left( \rho_{m} + K_4 \rho_{air} \right)^{0.5} \right)^2 \left( \rho_{m} - \rho_{air} \right) \right)} - 2 \sqrt{\frac{\rho_{m} + K_4 \rho_{air}}{\rho_{m} - \rho_{air}}} + 2 \sqrt{\frac{\rho_{m} + K_4 \rho_{air}}{\rho_{m} - \rho_{air}}} \right] \]

where:

\[ K_4 = \left[ \frac{F_A}{1 - F_A} \right]^2 \]  

\[ K_5 = \frac{F_A C \sqrt{2g}}{A_R \hat{V}_h} \]  

**Simplifications for Typical Situations**

If ambient air properties (\( \rho_{air} = 1.2 \text{ kg/m}^3 \)) and a 5% by volume Halon 1301 mixture is assumed, then the equation for the nonmixing case, Equation 24, becomes:

\[ t = \frac{A_R}{F_A C} \left[ \frac{K_2 h_1 + K_3}{1 - N} \right]^{1/N} - \left[ \frac{K_2 h_1 + K_3}{(1 - N) K_2} \right]^{1/N} \]

with \( P_b \) in Pa

If the flow exponent, \( N \), is assumed to be 0.5 (as is done when leakage area estimates are accomplished by methods other than a door fan test) and the bias pressure \( P_b \) can be ignored, then Equation 33 is further simplified to obtain the following:

\[ t = \frac{0.083 A_R}{F_A C} \sqrt{1 + 0.826 \left[ \frac{F_A}{1 - F_A} \right]^2 \left[ \frac{h_1}{\rho_{air}} + \frac{h_2}{\rho_{air}} \right]} \]

With the further assumption that the effective leakage area of the upper leak is equal to that of the lower leak (worst case assumption), the equation for the nonmixing case becomes:

\[ t = \frac{2.927 A_R}{C} \left( \sqrt{h_1} - \sqrt{h_2} \right) \]

Under these same conditions, the equation for the mixing case, Equation 29, becomes:

\[ t = \frac{A_R \sqrt{h_1}}{2214 C} \left[ 2 \sqrt{\frac{\rho_{m} + 1.2}{\rho_{m} - 1.2}} \right. \]

\[ - \log \left[ \frac{\left( \frac{\rho_{m} - 1.2}{\rho_{m} - 1.2} \right) \left( \frac{\rho_{m} - 1.2}{\rho_{m} - 1.2} \right)^{1.44}}{4.963} \right] \]

**Experimental**

The purpose of these tests was to evaluate the door fan pressurization leakage tests as a method for estimating Halon 1301 leakage rates from an enclosure. This evaluation was based upon both the estimated leakage area and inter-
face decay rate. These tests were performed as part of a larger project examining alternative test gases for Halon 1301 discharge testing\(^7,8\).

These tests were conducted at the Chesapeake Bay Detachment (CBD) of the Naval Research Laboratory, Chesapeake Beach, Maryland. A test enclosure was constructed with nominal inside dimensions of 3.7 m x 3.7 m x 3.7 m (12 ft x 12 ft x 12 ft) providing a floodable volume of approximately 43 m\(^3\) (1519 ft\(^3\)). The test enclosure has been built using conventional 5.1 x 10.2 cm (2 x 4 in.) framing, with 5.1 x 16.2 cm (2 x 6 in.) floor and ceiling joists. The entire test enclosure is located inside building #244, at CBD. This not only facilitates easier testing but any ambient weather effects are also eliminated. To ensure an air tight environment, two layers of 1.3 cm (0.5 in.) painted gypsum wallboard were attached to all interior surfaces. All wallboard joists were than taped and spackled prior to the application of two coats of water based interior paint. The enclosure was also fitted with 203 x 91.4 cm (80 x 36 in.) steel door assembly that utilized magnetic seals and two 45.7 x 81.3 x 0.6 cm (18 x 32 x 0.25 in.) plexi-glass observation windows.

Two, nominally, 20.3 cm (8 in.) ID PVC pipes 35.6 cm (14 in.) in length were inserted through the walls of the enclosure to provide known leak areas. One pipe was inserted at the top of the back wall. The other was inserted at the bottom of the front wall. Two sets of inserts were made to vary the diameter of both the top and bottom leak. The inserts are nominally 15.24 cm (6 in.) and 6.3 cm (2.5 in.) in diameter and 35.6 cm (14 in.) in length. Actual leak diameters are given in Table 1. The enclosure is shown schematically in Figure 4.

**Table 1: Leak Diameters**

<table>
<thead>
<tr>
<th>Nominal Diameter</th>
<th>Actual Diameter</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.3 cm (8 in.)</td>
<td>20.8 cm (8.1875 in.)</td>
<td>340 cm(^2) (52.6 in(^2))</td>
</tr>
<tr>
<td>15.24 cm (6 in.)</td>
<td>15.24 cm (6 in.)</td>
<td>182 cm(^2) (28.3 in(^2))</td>
</tr>
<tr>
<td>6.35 cm (2.5 in.)</td>
<td>6.03 cm (2.375 in.)</td>
<td>28.6 cm(^2) (4.43 in(^2))</td>
</tr>
</tbody>
</table>

![Figure 4. Test enclosure](image-url)
Door Fan Tests

Door fan pressurization tests were performed on April 19, 1988, by David Saum and John Hupman of Infiltec. Between three and six flow and differential pressure measurements were taken for each leak configuration. The constants \( C \) and \( N \) were then determined numerically. A total leakage area was then estimated based on an assumed discharge coefficient of 0.61. The door fan equipment used was provided by Infiltec. It consisted of a calibrated variable speed fan, a mounting frame for the fan with inflatable seals that fit into a door frame and a differential pressure gauge. An orifice plate was used to extend the range of the fan.

Results

The leak configuration, door fan orientation, and the door fan correlation constants, \( C \) and \( N \), are given in Table 2. The correlation coefficient, \( R \), is given in the next column. \( R \) represents the degree to which the correlation fits the data, as an \( R \) of 1 means a perfect fit, and a 0 would mean no fit at all. In the next two columns are the total leak area estimated from \( C \) based on the assumed discharge coefficient of 0.61 and the actual leak area. A large portion of the difference between these two columns is due to the assumed discharge coefficient. In previous work with this enclosure, the discharge coefficient was determined to be 0.82 by comparison with leakage data\(^7,8\), 35% higher than the assumed coefficient. The last two columns are the total effective leak area, \( K_D A_T \), as estimated from \( C \) and as determined from the actual area and the discharge coefficient of 0.82. This effectively removes the assumed discharge coefficient and consequently these two columns are much closer together.

A comparison between the interface descent predicted from the door fan tests and that measured experimentally in previous work\(^7,8\) is shown in Figures 5 and 6 for Test 15 and 16, respectively (the only dual leak tests). The experimental interface height is difficult to measure as the interface spreads over time due to a combination of mixing caused by air currents and diffusion. Therefore two experimental curves are given. The first, labeled Experimental-Initial Drop, takes the interface to be where the concentration just starts to drop. The second, labeled Experimental-50% Conc., takes the interface to be where the concentration is half the initial concentration. Two predicted curves are shown in Figures 5 and 6. The first, labeled Predicted-Actual Area, is the interface recession predicted in previous work based on the actual leak area and discharge coefficient. This prediction is similar to Equation 17 with \( N \) equal to 0.5 and \( C \) determined from the actual area and discharge coefficient \( (F_A = 0.5) \). The other, labeled Predicted-Door Fan, is the interface recession determined by Equation 17 with \( C \) and \( N \) from Table 2 \( (F_A = 0.5) \). This comparison is based on an initial 5% by volume Halon 1301 concentration and an initial interface height of 3.2 m (measured from the center line of the lower leak), 0.3 m below the ceiling. As can be seen from this comparison, the prediction of the interface recession from the door fan test, is very good.

The leakage of other heavier than air gas mixtures from an enclosure can also be predicted from a door fan test. The prediction of the

![Figure 5](image_url)  
**Figure 5.** Interface height comparison with 20.8 cm (8 in.) leaks and 5% by volume Halon 1301

to be where the concentration just starts to drop. The second, labeled Experimental-50% Conc., takes the interface to be where the concentration is half the initial concentration. Two predicted curves are shown in Figures 5 and 6. The first, labeled Predicted-Actual Area, is the interface recession predicted in previous work based on the actual leak area and discharge coefficient. This prediction is similar to Equation 17 with \( N \) equal to 0.5 and \( C \) determined from the actual area and discharge coefficient \( (F_A = 0.5) \). The other, labeled Predicted-Door Fan, is the interface recession determined by Equation 17 with \( C \) and \( N \) from Table 2 \( (F_A = 0.5) \). This comparison is based on an initial 5% by volume Halon 1301 concentration and an initial interface height of 3.2 m (measured from the center line of the lower leak), 0.3 m below the ceiling. As can be seen from this comparison, the prediction of the interface recession from the door fan test, is very good.

The leakage of other heavier than air gas mixtures from an enclosure can also be predicted from a door fan test. The prediction of the

![Figure 6](image_url)  
**Figure 6.** Interface height comparison with 6 cm (2.5 in.) leaks and 5% by volume Halon 1301
Table 2: Door Fan Tests

<table>
<thead>
<tr>
<th>Leak Test #</th>
<th>Configuration</th>
<th>Fan Orientation</th>
<th>N</th>
<th>$\Delta P$</th>
<th>$\rho_{air}$</th>
<th>$Q$</th>
<th>$\Delta L$</th>
<th>$\rho_{air}$</th>
<th>$Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>no leaks</td>
<td>positive</td>
<td>0.633</td>
<td>0.9557</td>
<td>1.0</td>
<td>19.4</td>
<td>0</td>
<td>11.6</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>20.8 cm top</td>
<td>positive</td>
<td>0.530</td>
<td>28.28</td>
<td>0.999</td>
<td>497</td>
<td>340</td>
<td>303</td>
<td>279</td>
</tr>
<tr>
<td>3</td>
<td>20.8 cm top</td>
<td>positive</td>
<td>0.530</td>
<td>28.28</td>
<td>0.999</td>
<td>497</td>
<td>340</td>
<td>303</td>
<td>279</td>
</tr>
<tr>
<td>4</td>
<td>20.8 cm bottom</td>
<td>positive</td>
<td>0.547</td>
<td>25.95</td>
<td>0.999</td>
<td>470</td>
<td>340</td>
<td>287</td>
<td>279</td>
</tr>
<tr>
<td>5</td>
<td>15.2 cm bottom</td>
<td>negative</td>
<td>0.534</td>
<td>14.64</td>
<td>0.998</td>
<td>259</td>
<td>182</td>
<td>158</td>
<td>150</td>
</tr>
<tr>
<td>6</td>
<td>15.2 cm bottom</td>
<td>positive</td>
<td>0.534</td>
<td>14.78</td>
<td>0.999</td>
<td>260</td>
<td>182</td>
<td>159</td>
<td>150</td>
</tr>
<tr>
<td>7</td>
<td>20.8 cm bottom</td>
<td>negative</td>
<td>0.508</td>
<td>26.49</td>
<td>0.999</td>
<td>443</td>
<td>340</td>
<td>270</td>
<td>279</td>
</tr>
<tr>
<td>8</td>
<td>20.8 cm bottom</td>
<td>positive</td>
<td>0.633</td>
<td>0.9530</td>
<td>0.999</td>
<td>19.4</td>
<td>0</td>
<td>11.6</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>10 x 10 cm sq bottom</td>
<td>positive</td>
<td>0.491</td>
<td>6.931</td>
<td>0.999</td>
<td>112</td>
<td>93.7</td>
<td>68.4</td>
<td>–</td>
</tr>
<tr>
<td>10</td>
<td>6.0 cm bottom</td>
<td>positive</td>
<td>0.597</td>
<td>0.271</td>
<td>0.999</td>
<td>45.2</td>
<td>28.6</td>
<td>27.7</td>
<td>23.5</td>
</tr>
<tr>
<td>11</td>
<td>6.0 cm top &amp; bottom</td>
<td>positive</td>
<td>0.561</td>
<td>4.338</td>
<td>0.999</td>
<td>80.6</td>
<td>57.2</td>
<td>49.0</td>
<td>46.9</td>
</tr>
<tr>
<td>12</td>
<td>20.8 cm top &amp; bottom</td>
<td>positive</td>
<td>0.533</td>
<td>55.75</td>
<td>0.999</td>
<td>981</td>
<td>679</td>
<td>599</td>
<td>557</td>
</tr>
</tbody>
</table>

* $\Delta P$ in Pa, $\rho_{air}$ in kg/m$^3$, and $Q$ in l/s
* $C$ is based on $\Delta P$ in Pa, $\rho_{air}$ in kg/m$^3$, and $Q$ in l/s
* $\Delta L$ from Equation 2 with assumed discharge coefficient of 0.61
+ based on actual total leak area and discharge coefficient of 0.82 as determined from leakage data

interface recession for a 5% by volume chlorodifluoromethane (Halon 121, R-22)-air mixture and for a 5% by volume sulfur hexafluoride (SF$_6$)-air mixture, are shown in Figures 7 and 8 respectively. These predictions were done with the same conditions as for the Halon 1301-air mixture. Both Halon 121 and SF$_6$ are proposed Halon 1301 test gas simulants.

**CONCLUSION**

The door fan pressurization air leakage test appears to be a good method for estimating the leakage rate from an enclosure if a distribution of the leakage area over the compartment boundary can be assumed. It can also give a good estimate of the total leakage area if a discharge coefficient is known or can be assumed.

Simple equations relating leakage area to Halon 1301 leakage rate have been shown to give excellent agreement with the experimental data. These same equations can be used to model the leakage from an enclosure of other heavier than air gases, e.g., carbon dioxide or Halon 1301 test gas simulants, sulfur hexafluoride (SF$_6$) and chloro-difluoromethane (Halon 121, R-22).

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Figure 7. Interface height comparison with 20.8 cm (8 in) leaks and 5% by volume Halon 121 (R-22)

Figure 8. Interface height comparison with 20.8 cm (8 in.) leaks and 5% by volume Sulphur Hexafluoride (SF6)

NOMENCLATURE

\( A_L \) - Lower leakage area
\( A_R \) - Horizontal cross-sectional area of the enclosures
\( A_T \) - Total leakage area in the enclosure
\( A_U \) - Upper leakage area
\( C \) - Correlation constant
\( F_A \) - Fraction of the total effective leakage area in the lower leak
\( g \) - Acceleration due to gravity
\( h \) - Height of the interface (measured from the centerline of the lower leak)
\( h_i \) - Initial height of the interface (measured from the centerline of the lower leak)
\( K_d \) - Overall discharge coefficient
\( K_{dL} \) - Discharge coefficient of the lower leak
\( K_{dU} \) - Discharge coefficient of the upper leak
\( K_u \) - Units constant based on value of \( N \) and units used
\( K_1 \) - Constant defined in equation 13
\( K_2 \) - Constant defined in equation 22 or 34

\( K_3 \) - Constant defined in equation 23 or 35
\( K_4 \) - Constant defined in equation 31
\( K_5 \) - Constant defined in equation 32
\( N \) - Flow exponent
\( \Delta P \) - Amount pressure increased by fan
\( \Delta P_L \) - Pressure difference across the lower leak
\( \Delta P_U \) - Pressure difference across the upper leak
\( P_b \) - Bias pressure
\( P_1 \) - Pressure difference across upper leak due to bias pressure
\( P_2 \) - Pressure difference across lower leak due to bias pressure
\( \rho_{air} \) - Density of air
\( \rho_m \) - Density of the Halon 1301-air mixture
\( \rho_{mi} \) - Density of the initial Halon 1301-air mixture
\( Q \) - Volume flow rate of air driven by fan
\( Q_L \) - Volume flow rate through the lower leak
\( Q_U \) - Volume flow rate through the upper leak
\( R \) - Correlation coefficient
\( t \) - Time

REFERENCES

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