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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[1,2,3]. 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[4] (typically 10 minutes at the elevation of the highest combustible material).

The leakage rate from an enclosure could be predicted from detailed knowledge of leak sizes, location and geometry. However, these details are rarely known as leaks are cracks around doors, windows, vents, pipes, electrical conduit, etc, distributed along the surfaces of the compartment.

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:

$$Q = C\left(2\,\Delta P/\rho_{air}\right)^{N} \quad (1)$$

where Q is the flow rate, ΔP is the amount the pressure was increased, ρ_{air} is the density of air, N is the flow exponent (typically between 0.5 and 1), and C is a correlation constant[5].

The constant, C, can be broken into three factors as follows:

$$C = K_d A_T K_u \qquad (2)$$

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[6] as follows:

$$A_L = F_A K_d A_T / K_{dL} \qquad (3)$$

$$A_U = (1 - F_A) K_d A_T / K_{dU} \qquad (4)$$

$$\Delta P_L - \Delta P_U = (\rho_m - \rho_{air}) gh \qquad (5)$$

$$Q_U = -Q_L \qquad (6)$$

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, ΔP_L is the pressure difference across the lower leak, ΔP_U is the pressure difference across the upper leak, ρ_m is the density of the Halon 1301-air mixture, ρ_{air} is 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:

$$((1 - F_A) C \left(\frac{2\Delta P_U}{\rho_{air}}\right)^N = -F_A C \left(\frac{2\Delta P_L}{\rho_m}\right)^N \qquad (7)$$

This equation is then rearranged and ΔP_U is solved for to get the following:

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

When this is substituted into Equation 5, ΔP_L can be solved for.

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

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

$$Q_L = F_A C \left[\frac{2(\rho_m - \rho_{air}) gh}{\left[\left[1 + \left[\frac{F_A}{1 - F_A}\right]^{1/N} \left[\frac{\rho_{air}}{\rho_m}\right] \rho_m\right]\right]}\right]^N \qquad (10)$$

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

$$\frac{dh}{dt} = \frac{-Q_L}{A_R} = \frac{-F_A C}{A_R} \left[\frac{2(\rho_m - \rho_{air}) gh}{\left[\left[\rho_m + \left(\frac{F_A}{1 - F_A}\right)^{1/N} \rho_{air}\right]\right]}\right]^N \qquad (11)$$

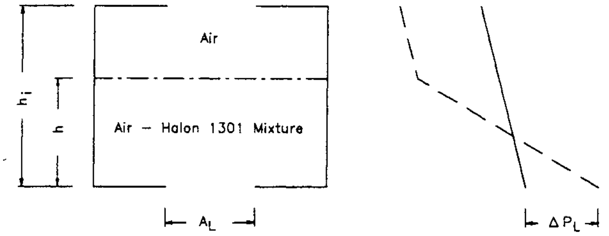

Figure 1. System schematic and pressure diagram

Where A_R is the horizontal cross-sectional area of the enclosure. This can be rewritten as:

$$h^{-N}\,dh = -K_1\,dt \tag{12}$$

where

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

This is then integrated as follows:

$$\int_{h=h_i}^{h} h^{-N}\,dh = -K_1\int_{t=0}^{t} dt \tag{14}$$

$$\frac{\left(h^{(1-N)} - h_i^{(1-N)}\right)}{1-N} = -K_1 t \tag{15}$$

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,

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

or solving for h,

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

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:

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

The differential equation to be solved is then:

$$\frac{dh}{dt} = \frac{-F_A C}{A_R}\left[\frac{2(\rho_m - \rho_{air})\,gh + P_b}{\left[\rho_m + \left[\frac{F_A}{1-F_A}\right]^{1/N}\rho_{air}\right]}\right]^N \tag{19}$$

This is then rewritten and integrated as follows:

$$\int_{h=hi}^{h}\left[K_2 h + K_3\right]^{-N} dh = \frac{-F_A C}{A_R}\int_{t=o}^{t} dt \tag{20}$$

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

where

$$K_2 = \frac{2(\rho_m - \rho_{air})\,g}{\left[\rho_m + \left[\frac{F_A}{1-F_A}\right]^{1/N}\rho_{air}\right]} \tag{22}$$

$$K_3 = \frac{2\,P_b}{\left[\rho_m + \left[\frac{F_A}{1-F_A}\right]^{1/N}\rho_{air}\right]} \tag{23}$$

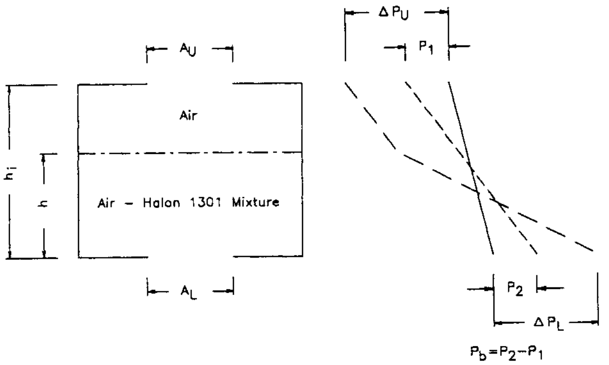

Figure 2. System schematic and pressure diagram with bias pressure

Solving for t:

$$t = \frac{A_R}{F_A C}\left[\frac{[K_2 h_i + K_3]^{1-N} - [K_2 h + K_3]^{1-N}}{(1-N)K_2}\right] \quad (24)$$

or alternatively for h

$$h = \frac{\left[[K_2 h_i + K_3]^{1-N} - \frac{F_A C}{A_R}(1-N)K_2 t\right]^{\frac{1}{1-N}} - K_3}{K_2} \quad (25)$$

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 can not 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, ρ_m, varies with time. This situation is shown schematically in Figure 3. The volume flow rate of the enclosure is given by the following:

$$Q_L = F_A C\left[\frac{2(\rho_m - \rho_{air})gh + 2P_b}{\left[1 + \left[\frac{F_A}{1-F_A}\right]^{1/N}\left[\frac{\rho_{air}}{\rho_m}\right]\right]\rho_m}\right]^N \quad (26)$$

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:

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

$$= \frac{-F_A C}{A_R h}\left[\frac{2gh(\rho_m - \rho_{air})^{\frac{N+1}{N}} + 2P_b(\rho_m - \rho_{air})^{1/N}}{\rho_m + \left[\frac{F_A}{1-F_A}\right]^{1/N}\rho_{air}}\right]^N \quad (28)$$

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

$$t = \frac{A_R h}{F_A C} \times \quad (29)$$

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

where ρ_{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:

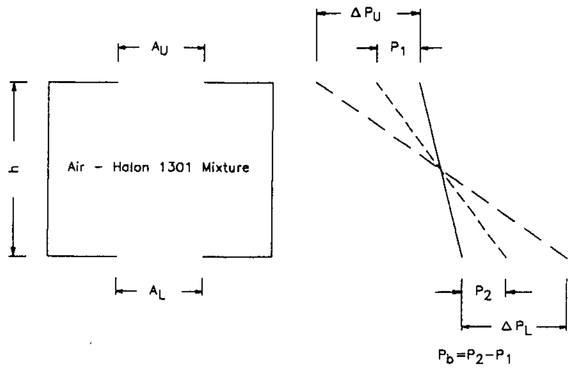

Figure 3. Well Mixed System Schematic and Pressure Diagram with Bias Pressure

$$t = \frac{1}{K_5}\left[\log\left(\frac{\left(\rho_{mi}-\rho_{air}+\left((\rho_{mi}-\rho_{air})(\rho_{mi}+K_4\rho_{air})\right)^{0.5}\right)^2(\rho_m-\rho_{air})}{\left(\rho_m-\rho_{air}+\left((\rho_m-\rho_{air})(\rho_m+K_4\rho_{air})\right)^{0.5}\right)^2(\rho_{mi}-\rho_{air})}\right) - 2\sqrt{\frac{\rho_{mi}+K_4\,\rho_{air}}{\rho_{mi}-\rho_{air}}} + 2\sqrt{\frac{\rho_m+K_4\,\rho_{air}}{\rho_m-\rho_{air}}}\right] \quad (30)$$

where:

$$K_4 = \left[\frac{F_A}{1-F_A}\right]^2 \quad (31)$$

$$K_5 = \left[\frac{F_A C\sqrt{2g}}{A_R\sqrt{h}}\right] \quad (32)$$

Simplifications for Typical Situations

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

$$t = \frac{A_R}{F_A C}\left[\frac{[K_2 h_i + K_3]^{1-N} - [K_2 h + K_3]^{1-N}}{(1-N)K_2}\right] \quad (33)$$

where

$$K_2 = \frac{3.41\ \mathrm{m/sec^2}}{1 + 0.826\left[\frac{F_A}{1-F_A}\right]^{1/N}} \quad (34)$$

$$\frac{2\,\frac{\mathrm{m^2}}{\mathrm{Pa\ sec^2}}\,P_b}{1 + 0.826\left[\frac{F_A}{1-F_A}\right]^{1/N}} \quad (35)$$

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:

$$t = \frac{1.083\,A_R}{F_A C}\sqrt{1 + 0.826\left[\frac{F_A}{1-F_A}\right]^2}\left[h_i^{0.5} - h^{0.5}\right] \quad (36)$$

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:

$$t = \frac{2.927\,A_R}{C}\left(\sqrt{h_i} - \sqrt{h}\right) \quad (37)$$

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

$$t = \frac{A_R\sqrt{h}}{2{,}214\,C}\left[2\sqrt{\frac{\rho_m + 1.2}{\rho_m - 1.2}} - \log\left[\frac{\left((\rho_m - 1.2) + \sqrt{(\rho_m^2 - 1.44)}\right)^2}{\rho_m - 1.2}\right] - 4.963\right] \quad (38)$$

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-

Table 1: Leak Diameters

Nominal Diameter	Actual Diameter	Area
20.3 cm (8 in.)	20.8 cm (8.1875 in.)	340 cm^2 (52.6 $in.^2$)
15.24 cm (6 in.)	15.24 cm (6 in.)	182 cm^2 (28.3 $in.^2$)
6.35 cm (2.5 in.)	6.03 cm (2.375 in.)	28.6 cm^2 (4.43 $in.^2$)

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 facilities 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 spackeled 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.) plexiglass 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.

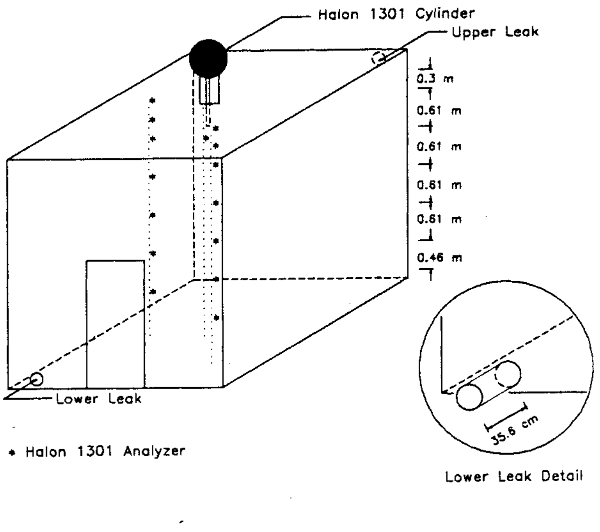

Figure 4. Test enclosure

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

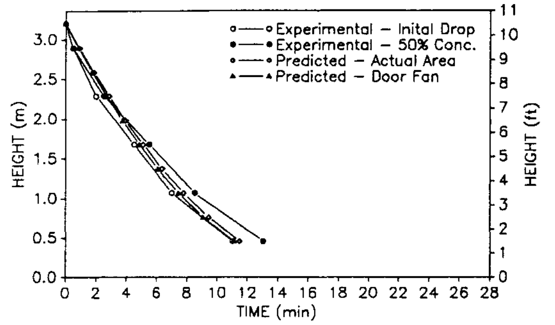

Figure 5. Interface height comparison with 20.8 cm (8 in.) leaks and 5% by volume Halon 1301

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 is 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

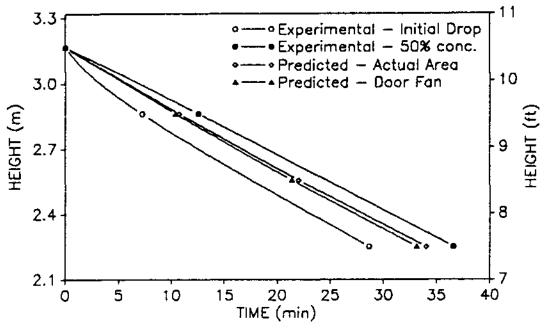

Figure 6. Interface height comparison with 6 cm (2.5 in.) leaks and 5% by volume Halon 1301

Table 2: Door Fan Tests

Test #	Leak Configuration	Fan Orientation	*N*	**C*	*R*	†Door Fan Estimated Total Leak Area (cm^2)	Actual Total Leak Area (cm^2)	ΔDoor Fan Estimated Total Leak Area (cm^2)	+Actual Total Effective Leak Area (cm^2)
1	no leaks	positive	.633	.9557	1.0	19.4	0	11.6	0
2	20.8 cm top	positive	.530	28.28	.999	497	340	303	279
[1]3	20.8 cm top	positive	.530	28.28	.999	497	340	303	279
4	20.8 cm bottom	positive	.547	25.95	.999	470	340	287	279
8	15.2 cm bottom	negative	.534	14.64	.998	259	182	158	150
9	15.2 cm bottom	positive	.534	14.78	.999	260	182	159	150
11	20.8 cm bottom	negative	.508	26.49	.999	443	340	270	279
12	no leaks	positive	.633	.9530	.999	19.4	0	11.6	0
[2]13	10 x 10 cm sq bottom	positive	.491	6.931	.999	112	93.7	68.4	–
14	6.0 cm bottom	positive	.597	.271	.999	45.2	28.6	27.7	23.5
15	6.0 cm top & bottom	positive	.561	4.338	.999	80.6	57.2	49.0	46.9
16	20.8 cm top & bottom	positive	.533	55.75	.999	981	679	599	557

1 relocated door fan pressure transducer in an attempt to correct readings and predict better data agreement
2 nominal 10 x 10 cm square hole formed by tape at the outside end of the bottom 20.8 leak
* *C* is based on ΔP in Pa, ρ_{air} in kg/m^3, and Q in l/s
† from Equation 2 with assumed discharge coefficient of 0.61
Δ from Equation 2
\+ 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[7, 8].

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).

Acknowledgements

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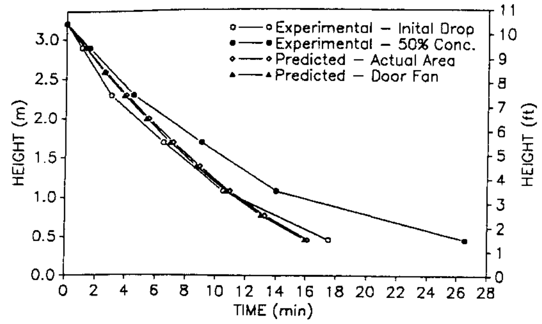

Figure 7. Interface height comparison with 20.8 cm (8 in) leaks and 5% by volume Halon 121 (R-22)

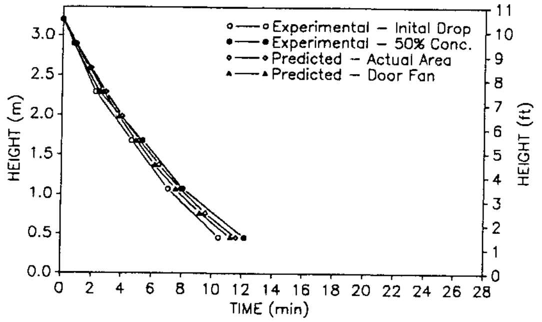

Figure 8. Interface height comparison with 20.8 cm (8 in.) leaks and 5% by volume Sulphur Hexafluoride (SF_6)

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
ΔP – Amount pressure increased by fan
ΔP_L – Pressure difference across the lower leak
ΔP_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
ρ_{air} – Density of air
ρ_m – Density of the Halon 1301-air mixture
ρ_{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

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