METHODOLOGY TO DETERMINE THE NET VOLUME OF AN ENCLOSURE USING A FAN PRESSURISATION METHOD

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Summary

The emissions of Halon 1301 and 1211, i.e. halogenated bromides and chlorides, mainly used for fire protection, into the atmosphere can be markedly reduced by employing an Enclosure Integrity Testing Procedure to avoid discharge testing[1]. Halon concentrations to actually combat fires are based on an enclosures total volume yet if Halon usage is to be minimised the correct concentration should be based upon the enclosures total volume minus any equipment volume. The correct enclosure net volume not only reduces the Halon required, but also gives significant cash saving on fire agents, especially the new substitutes which cost from three to five times the price of existing Halons.

Due to the size and the shape of possible equipment, determining the net volume of any enclosure can be a formidable task, but a methodology has now been developed by the authors, using a variation on the fan pressurisation method, to determine the net volume of any enclosure. Here the relationship between the enclosures pressure build-up rate and the net volume are established using ideal gas equations. From the experiments carried out to validate the theoretical model, actual net volumes have been compared with predicted volumes, and the deviations indicate the accuracy needed from the pressure readings. In particular, house pressure build-up can typically effect the net volume prediction by between 5.0 and 15.0 cu.meters per pascal difference.

Introduction

Emissions of Halon gases into the atmosphere have been greatly increased by past discharge tests carried out to validate the Halon systems installed [1]. The initial Halon discharge concentration for an enclosure is generally based upon a percentage of the total enclosure volume, yet the correct Halon concentration should be based upon the space occupied by air, which is the total volume minus any equipment volume. It is an enormous task to determine the total equipment volume of a complex enclosure since the equipment involved can differ from a multi-storey marine diesel engine, to complex control rooms for nuclear plant. The authors have now shown however that the net volume of an enclosure can be determined by using a variation on the existing fan pressurisation method, used in energy conservation programmes[2] and subsequently for enclosure integrity test procedures[3]. The mathematical model developed is based on classical mechanics and takes account of the macroscopic properties of ideal gases.

The Ideal Gas Law

The ideal gas model[4] assumes that molecules are point particles that never collide or interact with each other, and each molecule travels in a straight line until it recoils from a container's walls. Within these assumptions, and

Newton's laws of motion, it can be predicted how the pressure **P**, volume **V**, and temperature T of such molecules are related. From experiment, the relationship between these properties can be written as :

$$PV = nRT \qquad (1)$$

This is the ideal gas equation, where n is the amount of the gas present in moles and R is the ,universal gas constant', equal to 8.314 Joules/mole K, and T is degrees absolute.

A mole, or a gram-mole, of a gas is an amount whose mass in grams is numerically equal to the molecular mass in atomic mass units. For example, 1 mole of CO_2 has a mass of 44.009 g, and 20.16 g of H_2 is 10 moles. The numbers of molecules in 1 mole is called Avogadro's number, and N_A is the same for all gases, where

$$N_A = 6.02 \times 10^{23} \text{ molecules/mole,}$$

Although the ideal gas law holds true for real gases at low densities and pressures, it also provides a good approximation to the behaviour of real gases at moderate pressures and temperatures (4).

<u>Relationship between an enclosures pressure build-up and its</u>
net volume at <u>Constant temperature</u>

If the volume V and temperature T are constant in equation (I), then the pressure P of a gas is a function of the number of moles, n.

$$P = f(n),$$

hence,

$$P = C(n)$$

where

$C = RT / V$

4 = universal gas constant (8.311 J/moles K)

Therefore differentiating the number of moles with respect to pressure gives :

$$dP = C(dn) \qquad (2)$$

where dP = differential pressure;
dn = differential number of moles.

The volume **V**, of a gas having the number of moles n, can be determined by:

$$V = n\, v_o$$

where v_o = the molar volume of the gas (liters/mole or cu.m/kmole)

Therefore, $dn = dV/v_o$ ....(3)

where dV = differential volume.

The differential volume of an enclosure is the difference per unit time between the incoming volume and the out going volume if leakage exists.

But $dV = dV_{in} - dV_{out}$ .... (4)

where dV_{in} = differential volume (air in) cu.m;

dV_{out} = differential volume (air out) cu.m;

But $dV_{in} = Q_{in}\,dt$

and $dV_{out} = Q_{out}\,dt$

where Q_{in} = air flow rate (in) cu.m/sec;
Q_{out} = air flow rate (out) cu.m/sec;
dt = differential time (sec);

then equation (4) becomes

$$dV = Q_{in}\,dt - Q_{out}\,dt \text{ .... } (5);$$

From equations (2), (3) and (5)

$$dP = c/v_o\,(Q_{in}\,dt - Q_{out}\,dt)\text{... ....}(6)$$

But $Q_{out} = k\,(dP)^n$ (general flow equation)

where k = flow coefficient (cu.m/sec pascal):
n = flow exponent;
dP = pressure differential (pascal)

substituting into equation (6), this becomes

$$dP = c/v_o\,(Q_{in} - k(dP)^n)\,dt$$

$$dt\,v_o/c = (Q_{in}/dP - k(dp)^{n-1})\text{ ....}(7)$$

Integrating equation (7) and taking the limits that

when $t = 0$, $P = P_i$
and $t = t$, $P = P_f$, giving

$$v_o/c \int_{t=0}^{t=t} dt = Q_{in} / \int_{P=P_i}^{P=P_f} dP - k\left(\int_{P=P_i}^{P=P_f} dP\right)^{n-1};$$

$$v_o/c\;t = Q_{in}/(P_f - P_i) - k(P_f - P_i)^{n-1} \text{ .... } (8)$$

substituting $C = R\,T/V$ into equation (8), giving the net volume V :

$$V = [R\,T\,t/v_o][Q_{in}/(P_f - P_i) - k(P_f - P_i)^{n-1}]\text{ ....}(9)$$

where V = enclosure net volume (cu.m);
T = enclosure temperacure (deg. K);
R = universal gas constant (8.314X1000 J/kmole K):
v_o = air molar volume (cu.m/kmole);
P_i = initial enclosure pressure (pascal);

P_f = final enclosure pressure (pascal);
t = enclosure pressure build-up time (sec);
k = flow coefficient (cu.m/sec);
n = flow exponent;
Q_{in} = air flow rate (in) (cu.m/sec).

Equation (9) determines an enclosure's net volume for a constant temperature process, where the initial enclosure temperature T_i and final temperature T_f are assumed to be the same.

For a variable temperature process where an enclosure's initial temperature T_i and final temperature T_f are taken into account, then equation (9) can be written as :

$$V = [RT_fT_i\,t\,][Q_{in} - k(P_f-P_i)^n]/V_0\cdot[P_i(T_i-T_f)+T_i(P_f-P_i)] \quad \ldots(10)$$

Equation (10) is the general equation for calculating net volume, and it assumes that such flow parameters as k, n, and Q_{in} have already been established by the associated fan pressurisation technique.

In general an enclosure's tenperature does not change noticeably during the short pressurisation period and so equation (9) can be used.

<u>Net volume Tests using Fan Pressurisation Method</u>

To validate equations (9) and (10), the net volume of various enclosures were tested using the fan pressurisation method. The equipment used in the tests comprised a Minneapolis blower fan, two Air Neotronics Digital Micromanometers, a Rustrak Quartel - 4 channel Data Logger and Playback system, two signal conditioners (0-2 Volts DC) POD 13/14 for pressure signals, two thermocouples (Type K -250 to +1370 deg C) POD-04/15 for two temperature signals, and a PC Amstraa model-PPC 512 with Pronto application software, as shown in Figure (1). The flow characteristics of an enclosure were determined by applying the fan pressurisation technique. Hence the flow coefficient k, the flow exponent n, the equivalent leakage area ELA, and the flow rate (in) Q_{in} were established by using Wormald/Ansul's Enclosure Integrity Test Procedure software (5). The Rustrak Quartel 4 channel data logger was setup together with the two signal conditioners and the two thermocouples. one signal conditioner was connected to the dc output of the digital micromanometer, used to record the enclosure pressure, and a similar setup was established for the fan pressure. one thermocouple recorded the enclosure's inside temperature and the other noted the outside temperature. After initialising the input transducers and the appropriate channels, the data logger recorded the enclosure's pressure build-up, fan pressure, and the enclosure's inside and outside temperatures.

The recorded data, i.e. two pressures and two temperatures, were transferred to computer memory from the data logger by using playback mode, on the Pronto program, at the end of the recording session. The Pronto software converts the raw data into graphs, and plots and prints the graphs from the data collected remotely, see Figure (2). The analysis function print out reports and listings of the data points for each graph, see Table (1).

The enclosure's previously recorded initial and final pressures, build-up time, inside and outside temperatures, and flow characteristics, established from the fan pressurisation method, were then fed into the Net Volume Calculation programme, based upon equations **(9)** and (lo), to determine the enclosure's net volume. A comparision of results for five net volume tests are shown in Table **(2)**. The first column represents the test number, whilst the second, third, and fourth represent the respective recorded build-up times, initial and final house pressure differentials $(P_f - P_i)$, and fan pressures. The last three columns represent net volumes. Here the first two were calculated using equation (9), and the third column is the estimated net volume, which is the total enclosure volume minus the estimated total equipment volume.

Two calculated net volumes are obtained by using two sets of input parameters. The first is frcm using a pressure build-up time (column **2**), a recorded house pressure (column **3**), and a recorded fan pressure (column **4**), and gives the calculated net volumes in column 6. The other set uses same the parameters except that a fitted fan pressure is used (column 5) instead of a recorded fan pressure (column **4**), giving the calculated net volumes in column 7.

Discussion and Analysis of the results

In Table **2**, the calculated net volumes, under column 6, show significant deviations when compared to the estimated net volumes under column **8**. This is probably due to two reasons, firstly, errors in the recorded house or enclosure pressure, and secondly, errors in the recorded fan pressure. The effects of these pressure differentials on the calculated net volume are shown in Table **3**. columns **2** and **3** show the estimated total and net volumes for particular tests. Under columns 4 and 5, the effect on the net volume due to fan and house pressures are listed in cu.m/pascal. These show that in test NET-05, for every pascal difference error in reading the fan and house pressure, the calculation of the net volume changes by **2.84** and *5.966* cu.meters respectively. Therefore, the sensitivity ratio for house pressure vs fan pressure is **3.126**, and this means that the effects on the calculated net volume of an error in reading the house pressure is more than **3** times that **of** a corresponding fan pressure error. similarly, the ratios for test MT-06, NET-07, and **NET-08** are **4.956**, **8.419** and **3.805**, respectively.

To predict the accurate net volume of an enclosure, the following three steps need to be taken. First, precise readings and recordings of fan and house pressures are required, i.e. pressure errors need to be minimised. second, the sample scan time: for pressure recording need to be more refined. The present data logger is limited to 1 second per sample reading, and so a higher resolution data recorder is required that can read at least to a tenth of a second per sample reading. Third, additional tests on various tests enclosures ***are*** required to generate a more significant relationship curve.

conclusions

Because of the damaging effect of Halon on the ozone layer, the usage of Ealon to extinguish fires should be based cn 'net volume'considerations. The net volume of an enclosure can now be determined by using a fan pressurisation merhod together with a mathematical model employing equations (9) and (10), and incorporating the three steps stated previously. An alternative method, using a depressurisation procedure incorporating high resolution data loggers, is now being investigated. The new results will be published when available.

REFERENCES

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4. Kane, S.W., and Sternheim, M.M., Physics, pp *209-210*, John Wileys & sons, *1983*, Second edition.

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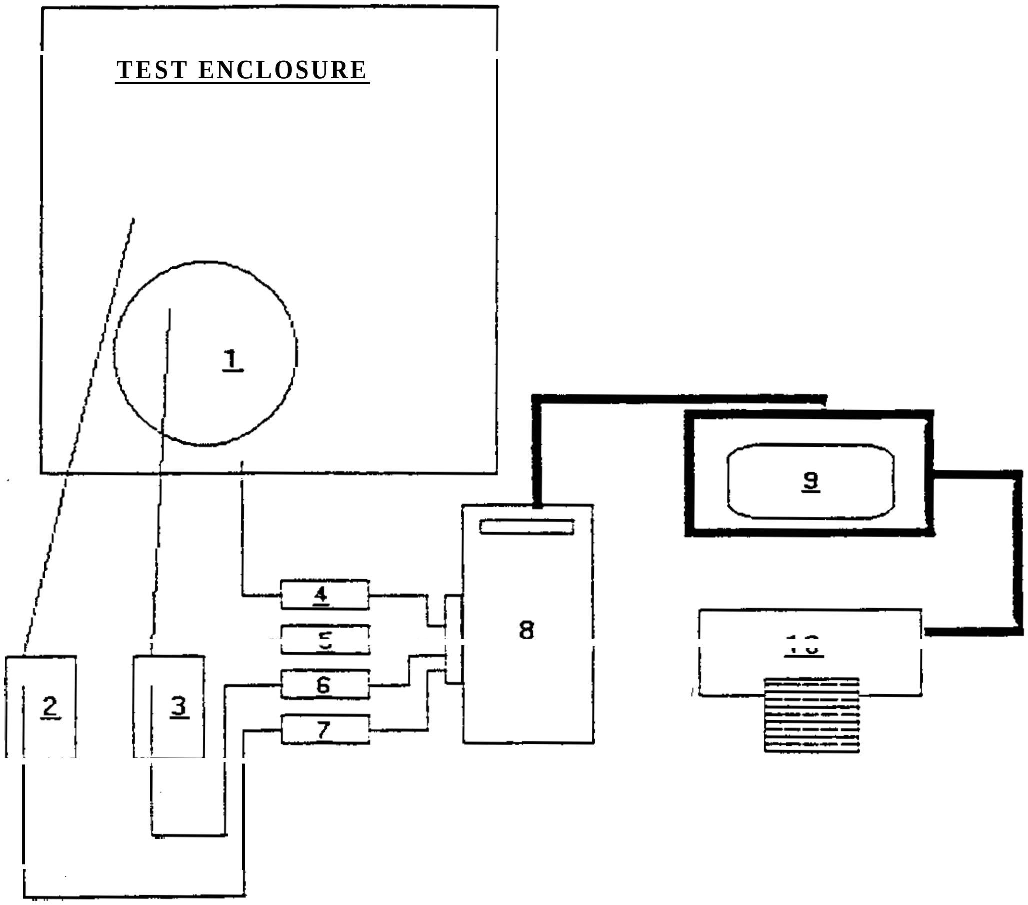
FIGURE NO. 1

EQUIPMENTS LAYOUT FOR THE NET VOLUME TEST



EQUIPMENT LIST

1 - BLOWER FAN UNIT
2 - DIGITAL MANOMETER FOR HOUSE PRESSURE
3 - DIGITAL MANOMETER FOR FAN PRESSURE
4 - THERMOCOUPLE FOR ENCLOSURE INSIDE TEMPERATURE
5 - THERMOCOULPE FOR ENCLOSURE OUTSIDE TEMPERATURE
6 - SIGNAL CONDITIONER [0 - 2 V DC]
7 - SIGNAL CONDITIONER [0 - 2 V DC]
8 - DATA LOGGER [4 CHANNEL RECORDER]
9 - PERSONNEL COMPUTER USING PRONTO SOFTWARE
10 -PRINTER

FIGURE NO. 2

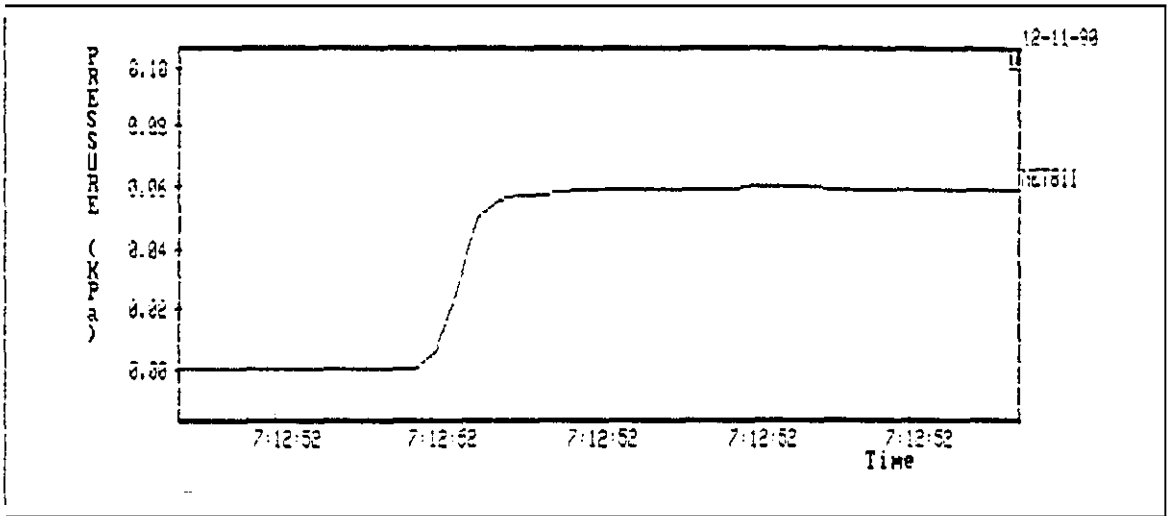


TABLE NO. 1

NET811

Sensor type 13 (Voltage).

NET VOLUPE CALCULATIONS FOR ANSUL TRAINING ROOM
CRAPH NO. NET811 HOUSE PRESSURE BUILD-UP (PASCAL)
CRAPH NO. NET812 FAN PRESSURE (PASCAL)
CRAPH NO. NETS13 ENCLOSURE TEMP. (INSIDE) DEG. C
CRAPH NO. NET814 ENCLOSURE TEMP. (OUTSIDE) DEG. C

Calendar	Value	Average	Max	Min	Events
7:12:52:25	0.0000	0.0000	0.0000	0.0000	0
7:12:52:26	0.0000	0.0000	0.0000	0.3000	0
7:12:52:27	0.0000	0.0000	0.0000	0.0000	0
7:12:52:28	0.0000	0.0000	0.3000	0.0000	0
7:12:52:29	0.0000	0.0000	0.0000	0.0000	0
7:12:52:30	0.0000	0.0000	0.0000	0.0000	0
7:12:52:31	0.0260	0.0103	0.0260	0.0000	0
7:12:52:32	0.0490	0.0396	0.0490	0.0260	0
7:12:52:33	0.0574	0.0563	0.0604	0.0490	0
7:12:52:34	0.0583	0.0579	0.0606	0.0574	0
7:12:52:35	0.0588	0.0586	0.0607	0.0576	0
7:12:52:36	0.0591	0.0590	0.0607	0.0577	0
7:12:52:37	0.0593	0.0592	0.0607	0.0577	0
7:12:52:38	0.0594	0.0594	0.0607	0.0577	3
7:12:52:39	0.0595	0.0595	0.0607	0.357:	0
7:12:52:40	0.0596	0.0595	0.0607	0.0577	0
7:12:52:41	0.0596	0.0596	0.0607	0.0577	0
7:12:52:42	0.0600	0.0596	0.0607	0.0577	0
7:12:52:43	0.0588	0.359'	0.0600	0.0580	0
7:12:52:44	0.0588	0.0588	0.0600	0.0580	0
7:12:52:45	0.0588	0.0588	0.0600	0.0580	0

TABLE NO. 2

NET VOLUMES COMPARISION USING RECORDED & FITTED FAN PR.

TEST NO	TIME (sec)	REC HP (pa)	REC FP (pa)	FFT (pa)	CNV 1 (cu.m)	CNV 2 (cu.m)	E.N.V. (cu.m)
NET-05	6.00	33.00	43.00	37.56	127.45	38.46	33.00
NET-05	7.00	36.60	43.50	42.52	15.13	38.31	38.00
NET-06	2.00	49.20	169.00	185.50	90.88	156.71	157.00
NET-06	3.00	51.90	145.00	135.50	-82.21	156.92	157.00
NET-06	4.30	53.00	159.70	133.60	-23.62	156.59	157.00
NET-07	2.00	35.50	167.00	127.55	1523.73	249.43	250.00
NET-07	3.00	35.90	187.00	184.55	2137.91	249.80	250.00
NET-08	2.00	49.00	163.00	151.00	254.50	162.06	162.00
NET-08	3.00	57.40	179.30	174.90	207.67	162.28	162.00
NET-08	4.00	58.30	174.00	173.80	164.48	162.02	162.00
NET-08	5	58.80	172.00	172.90	147.62	161.38	162.00

E.N.V. - ESTIMATED NET VOLUME
CNV 1 - CALCULATED NET VOLUME USING REC HP & REC FP
CNV 2 - CALCULATED NET VOLUME USING REC HP & FFT
REC HP - RECORDED HOUSE/ENCLOSURE PRESSURE
REC FP - RECORDED FAN PRESSURE
FFT - FITTED FAN PRESSURE TO ACHIEVE CNV 2.

TABLE N0.3

TEST NO	E.T.V. (cu.m)	E.N.V. (cu.m)	(cu.m / pa)	(cu.m / pa)	-	(sq.m)
NET-05	39.00	28.50	2.84	5.966	3.126	0.0120
NET-06	159.00	157.00	2.41	11.944	4.956	0.0505
NET-07	2713.90	250.00	25.59	215.450	8.419	0.2719
NET-08	167.00	162.00	3.67	13.965	3.805	0.0826

E.T.V. - ESTIMATED TOTAL VOLUME
E.N.V. - ESTIMATED NET VOLUME
dV/dFP - DIFFERENTIAL NET VOLUME/DIFFERENTIAL FAN PRESS.
dV/dHP - DIFFERENTIAL NET VOLUME/DIFFERENTIAL HOUSE PRESS.
dHP/dFP - DIFFERENTIAL HOUSE PRESS/DIFFERENTIAL FAN PRESS.