



DEPARTMENT OF
ENERGY, MINES AND RESOURCES
MINES BRANCH
OTTAWA

*DIFFUSION OF EXTERNAL METHANE
ATMOSPHERES THROUGH GAPS OF
VARIOUS SIZES AND WIDTHS INTO
ENCLOSURES OF DIFFERENT VOLUMES
AND THE EFFECT OF GREASED JOINTS*

E.D. DAINTY AND G.K. BROWN
FUELS RESEARCH CENTRE

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SUMMARY

Fifty per cent methane-air mixtures were prepared in a cubical case containing a cylinder which was divided in half by a joint at a right angle to the longitudinal axis. The gap, joint width and internal volume were varied to determine their effects on the diffusion rate of the external mixture into the cylinder.

The experimental results agreed well with those calculated using the following simplified logarithmic diffusion equation:

$$C_i = C_o \left(\frac{e^{xt} - 1}{e^{xt}} \right)$$

where C_i & C_o are the inside and outside methane concentrations, x is a function of the gap geometry, internal enclosure volume and the diffusion coefficient, and t is the elapsed time from the start of the diffusion process.

The application of grease on the gap surface in sufficient quantities stopped the diffusion process, and the effects on the grease seal of internal pressures simulating pressure changes due to thermal cycling of electrical equipment, were briefly studied. The results showed that the seal was effective for pressures greater than those considered possible during thermal cycling.

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INTRODUCTION

The safety of flameproof enclosures used in coal mines has been based on the premise that explosions may or are even likely to occur inside the enclosure because they are not hermetically sealed. This premise in turn causes concern about the damage that may be caused to the internal electrical components, the possibilities of short circuits due to the electrical conductivity of flames, and the possible effects of such occurrences on the safety provided by the enclosure itself. It is recognized that even if methane does not diffuse into closed flameproof enclosures, they must retain their present ability to prevent internal explosions from being transmitted to the mine atmosphere because a cover might be removed for a period of time before being replaced, during which time an explosive atmosphere might be unknowingly present. However, this is not expected to occur often and so the present diffusion study was made to assist in understanding the relative importance of problems concerning components inside flameproof enclosures. If the probabilities of an internal explosion occurring are low enough under coal mining conditions, then it is reasonable to accept internal electrical components designed for use in ordinary air.

For the reader interested mainly in the experimental results, they may be found in the tables of page 13 and Appendices 4 to 7. Their significance is discussed by the authors on pages 14 and 15.

DESCRIPTION OF THE APPARATUS

The primary pieces of equipment were the two diffusion cylinders, the principle difference between them being the wall thickness. A schematic view is given in the sectional drawing of Appendix 1. Each diffusion cylinder, in its turn, was mounted inside a cubical metal chamber having an approximate volume of 4.7 cubic feet. Thus a pair of volumes, "interior" and "exterior" were formed. The latter volume corresponded to a hazardous atmosphere and the former to the internal volume of a flame proof enclosure. The two diffusion cylinders were separated at their centres in a plane transverse to each cylinder axis, thus forming peripheral gaps of the type produced by the flanges of electrical enclosures. The

diffusion path lengths were 0.5 and 1.0 inches, which corresponded to the cylinder wall thicknesses. Gap sizes ranging from 0 to 0.020 inches were produced by plastic shims each of 0.75 inch width which were equally spaced around the periphery and held in place by 3 locating dowels. Thus the periphery of the diffusion path was reduced accordingly. The inside diameter of all the cylinders was 6.0 inches and the internal free cylinder height was 18 inches. Variation in volume was effected by installing aluminum volume reduction blocks in the top and the bottom cylinder halves to maintain volume symmetry with respect to the gap. The volumes resulting were 508, 339, and 170 cubic inches.

A "dummy" cylinder, identical to the 0.5 inch thick diffusion cylinder, was also manufactured. It was sealed at the joint in order to provide a pure quiescent air atmosphere to envelope a centrally located thermistor which served as the reference arm in a standard wheatstone bridge circuit. The active arm of the bridge circuit was an identically mounted thermistor in the diffusion cylinder undergoing the test. The pair of thermistors, designated G126, was manufactured by Fenwal Electronics.

The thermistor bridge imbalance, which was caused by methane diffusion through the gap, was registered on a microammeter (0-100 μ a). It was found that the unbalance response to methane concentration was linear within 0.2 percent methane, over the entire mixture range from 0 to 50% methane. This linear characteristic was determined by measuring the thermistor response when it was immersed in various precise methane-air mixtures prepared by the partial pressure method in a cylindrical vessel of similar proportions to the diffusion cylinders. The bridge current used was 20 milliamperes (10 milliamperes per thermistor) at which current the power dissipation rate in each thermistor was approximately 13 milliwatts. This energy dissipation rate was insufficient to initiate ignition in the explosive mixtures. The bulk of metal surrounding the thermistors acted as a sufficiently large heat sink such that the temperature variations in the diffusion and reference cylinders were negligible in spite of the thermistor heat inputs.

Thermistors were chosen therefore, because of their low power dissipation and consequent safety, their adequate output at low power consumption, their linear output with variation in methane concentration, as well as their ability to operate without the necessity of mixture circulation, thus resulting in a minimum of flow disturbance to the diffusion process.

Because direct calibration of the thermistor system was not mechanically convenient, a "Thermabridge" (thermal conductivity cell) analyzer having a repeatability of ± 1.0 percent of full scale was used to perform a calibration analysis of the internal mixture concentration after the completion of each 5 hour test. It was also used to determine the minor concentration changes of the external atmosphere. Calibration analysis probes shown in Appendix 1, were fitted inside the diffusion cylinders. The probe ends were located at the top and bottom of the internal volume. The other ends were attached to the thermabridge analyzer. Each circulation tube was a 25 foot length of copper capillary tubing (1/8 x 1/16 inches, OD x ID).

A 28 gauge chromel-alumel thermocouple was fixed in a position below and to the side of the thermistor element in both the diffusion and dummy cylinders. These were used to measure the ambient internal atmospheric temperatures in order to make minor adjustments to the diffusion coefficients used in the theoretical calculation of internal mixture concentrations, and to evaluate thermistor bridge drift due to temperature. It was determined however, that both cylinder temperatures were approximately the same and that the temperature variations from beginning to the end of the tests were minor, because of the large heat sink capacity of the metal of the cylinders and installation of the entire apparatus in a concrete pit having a metal cover which minimized the effects of ambient temperature changes.

Over the gap of the diffusion cylinder a thick rubber seal was fitted which was equipped with a clasp. The clasp-pin was abruptly removed by actuating an electric solenoid fixed to the upper half of the diffusion cylinder. The solenoid armature was connected to the clasp-pin. Removal of the pin caused the seal to drop away from the gap at the beginning of each test.

The external cubical volume was equipped with plastic hoses and valves which were used to flush the external mixture after the test completion. The external mixtures were prepared by passing commercially pure methane (99.5 percent methane by volume minimum) through a flow meter for a period of time sufficient to produce an external mixture of 50 percent ± 0.5 . Two fans mounted in the top of the external chamber thoroughly mixed the external atmosphere.

EXPERIMENTAL PROCEDURE

The various procedure steps, repeated during each diffusion test, are described in order as follows.

The thermistor bridge was turned on two hours, and the thermal conductivity analyzer a half hour before the beginning of each diffusion test. A 50 percent methane mixture was made in the preparation vessel by the partial pressure method for the purpose of calibrating the thermal conductivity analyzer. The pit cover was removed and the exterior mixture was prepared by metering in bottled methane while the thermal conductivity analyzer was being calibrated. The external mixture was then fanned to produce a uniform external concentration and then analyzed. Additional air or methane was added if this was necessary.

The pit cover was replaced and the thermistor bridge was balanced. The test was started by actuating the solenoid and removing the seal's retaining pin thus exposing the gap to diffusion of the external mixture. The starting time was noted and approximately every 15 minutes thereafter the bridge output registered on the microammeter, was noted during a period of 5 hours. Periodically, the external mixture was also rechecked as were the temperatures in the dummy and diffusion cylinders. No attempt was made to replenish the external mixture due to any losses that may have occurred, in order not to disturb the quiescent state of the gases.

At the end of the 5 hour period the thermal conductivity analyzer was used to determine accurately the inside mixture concentration. First, the inside mixture was sampled for a period of 7 minutes, at a rate of 1.0 cubic foot per hour from the bottom of the cylinder. The leads at the analyzer were then reversed to permit an estimation of the mixture gradient from top to bottom of the cylinder. The average of these two values was used as a calibrating analysis. It was then corrected for the theoretical change in concentration with time and compared to the concentration registered on the thermistor bridge microammeter for the same time. The ratio of the time adjusted calibrating value to the thermistor output value was used to adjust all the thermistor values for the test. The ratios and the adjusted values are given in the tabulations of Appendices 3 and 4 respectively.

Calculations of methane concentration were made, as outlined in the following section, for the conditions of each of the test runs. These were recorded in Appendix 2. The calculated and experimental values of the internal methane concentration were both plotted in the figures of Appendices 5, 6 and 7, along with a representative line showing the gradual decrease in the outside concentration.

The pit cover was again removed in order to manipulate valves so that both the internal and external mixtures could be flushed with air. The external chamber was then unclamped and removed. The top half of the diffusion cylinder was lifted off and shims and volume blocks to produce the desired gap and volume for the next test, were positioned. The top of the cylinder was then replaced, the gap was checked with feeler gauges and the external chamber resealed in position. The pit top was positioned in order that thermal equilibrium of the apparatus would result during the overnight period.

This procedure was repeated a total of 10 times for varying gap size, diffusion path length (flange width), and internal volume for a nominally constant external mixture of 50 percent methane in air.

EXAMINATION OF THE THEORETICAL DIFFUSION EQUATION

The differential equation expressing unidirectional molecular diffusion is Fick's Law which parallels the Fourier equation of steady-state heat conduction. The equation is

$$\frac{dQ}{dt} = -D A \frac{dc}{dw} = V_i \frac{dc_i}{dt} \dots\dots\dots (Eq 1)$$

- where Q - moles of diffusing gas - moles
- D - diffusion coefficient- in²/sec
- A - cross-sectional area of diffusion path-in²
- c - gas concentration in diffusion path-moles/in³
- c_i - internal concentration
(uniform throughout V_i) -moles/in³
- c_o - concentration in the outside atmosphere-moles/in³
- w - length of diffusion path(flange width) -in³
- V_i - volume into which methane is absorbed -in³
- t - time - secs

When w approaches zero, then $\frac{dc}{dw}$ approaches - (c_o - c_i)/w.

Substituting this expression in Equation 1 and cross-

multiplying gives $\frac{dc_i}{c_o - c_i} = \frac{DA}{wV_i} dt \dots\dots\dots$ (Eq 2)

Integration between the limits $c_i = 0$ at time $t = 0$, and $c_i = c_i$ at time $t = t$, and assuming D is independent of c, gives

$$\frac{DA t}{wV_i} = \ln \frac{c_o - c_{i0}}{c_o - c_i}$$

or $t = \frac{wV_i}{DA} \ln \frac{c_o - c_{i0}}{c_o - c_i}$

or $t = \frac{wV_i}{DLg} \ln \frac{c_o - c_{i0}}{c_o - c_i} \dots\dots\dots$ (Eq 3)

where L is the periphery of the joint - in

and g is the gap size - in

and c_{i0} is the internal concentration at zero time - moles/in³

Equation 3 may be rearranged to express c_i as a function of time when $(DLg/wV_i) = x$, as follows:

$$c_i = \frac{c_o(e^{xt} - 1) + c_{i0}}{e^{xt}} \text{ and when } c_{i0} = 0 \text{ at time } t = 0,$$

then $c_i = \frac{c_o (e^{xt} - 1)}{e^{xt}} \dots\dots\dots$ (Eq 4)

It was assumed in the above derivation that there would be no gradient in the internal mixture i.e., that the diffusion away from the gap occurred rapidly enough to result in a homogeneous mixture throughout the internal volume. Also, it was assumed that the concentration decrease along the diffusion path of the joint gap was linear with respect to the path length - w.

Equation 4 was used to calculate the theoretical variation of the internal concentration - c_i , for variations in time, gap size, gap width, internal volume diffusion coefficient and external mixture strength. The diffusion coefficient information was derived from Reference 2 and recorded in the curve of Appendix 8.

The following is a sample calculation using Equation 4 to determine the internal concentration for the conditions of Test 1 after a period of 5 hours:

$$x = \frac{DLg}{wV_i}$$

where D = 0.03375 in²/sec for a temperature of 58°F

L = the logarithmic mean periphery less shim allowance

$$= \frac{(D_o - D_i)}{\ln D_o/D_i} - 3 \times 0.75$$

$$= \frac{(7 - 6)}{\ln 7/6} - 2.25 = 18.2 \text{ inches}$$

g = 0.020 inches

w = 0.50 inches

V_i = π x 6² x 18 - volume of thermistor etc.

= 509 - 1

= 508 cubic inches

$$\text{Therefore, } x = \frac{0.03375 \times 18.2 \times 0.020}{0.50 \times 508} = 0.0000483$$

$$= \frac{1}{20,700}$$

Therefore, when a time of 5 hours = 18000 seconds elapses and the exterior concentration is 46.2%, the predicted inside concentration is

$$C_i = \frac{46.2 (e^{18,000/20,700} - 1)}{e^{18,000/20,700}}$$

$$= 46.2 \times \frac{1.385}{2.385}$$

$$= 26.8\% \text{ methane}$$

The results of the calculations for each set of test conditions are tabulated in Appendix 2 and plotted by the black dots on the curves of Appendices 5, 6, and 7.

DISCUSSION OF THE RESULTS

The experimental results are recorded in the tabulation of Appendix 4, and plotted in Appendices 5, 6 and 7.

The ratio method of calibration of the thermistors automatically compensated for the effects of the bridge zero drift as well as calibrating the

thermistor circuit. The maximum zero drift encountered was approximately linear and was equivalent to an average value of 0.27% CH₄ per hour. This was determined by a grease test during which no diffusion occurred. However, the bridge output returned to zero in a majority of cases after flushing of the internal volume with air.

The gap size measurements were made by feeler gauges. It was found that the gaps were not always uniform around the periphery. This is attributed to the snug fit of the cylinder pins in their locating holes. The tolerance on the gap measurements was assumed to be a maximum of ± 0.0005 inches.

The external mixture decreased from the beginning of the test to the end. These variations were smoothed and the values at integral periods of elapsed time are given in the tabulation of Appendix 2. Each value is within the thermal conductivity analyzer tolerance of 1.0 percent of the indicated reading i.e. ± 0.5 percent methane. An average rate of decrease is shown on the graphs of Appendices 5, 6 and 7 to show the tendency of the internal and external methane concentrations to converge.

The degree to which these experiments and the theory agree is seen by inspection of the graphs referred to above. Examination of the experimental results of reference 2, showed that there was an experimental spread in the quoted values of diffusion coefficient for various gas systems ranging up to ± 10 percent, but the value was more frequently of the order of ± 5 percent. In addition, methane mixture preparation and calibration analysis each could contribute a maximum of ± 1 percent spread to the experimental values of concentration in the calibrated mixture. Gap size measurements also contributed to the spread to the extent of the maximum tolerance of ± 0.0005 inches, or, ± 5 percent of a gap having a value of 0.010 inches. Considering all other sources of experimental spread to be small compared to these, calculations were made of the maximum and minimum internal concentrations resulting from the application of the above tolerances as follows: external mixture - 50 percent ± 0.5 , gap size - 0.010 inches ± 0.0005 , gap width - 0.5 inches, internal volume - 339 cubic inches, gap periphery - 18.2 inches, diffusion coefficient - 0.0342 square inches per second ± 0.00171 at a temperature of 62°F, all after an elapsed time of 5 hours from the beginning of diffusion. The result was a spread from 22.7 percent to 25.7 percent methane in the internal mixture, i.e. a 3 percent total differential, or,

an average mixture tolerance of ± 1.5 percent. All of the experimental results fell within this tolerance except that of test number 1, the experimental concentration of which exceeded the calculated value by + 1.8 percent methane. The average differential corresponding to an elapsed time period of 5 hours was + 0.74 percent methane relative to the calculated value of internal concentration.

As predicted by equation 3, the time to reach a given internal mixture for a given outside mixture was found to be directly proportional to the internal volume. For example, the times to reach a mixture of 20 percent methane for enclosure volumes of 508, 339, and 170 cubic inches (a relationship of 3:2:1), were 3, 2, and 1 hours respectively, when all other factors remained the same (see curves for tests 1, 5, and 7 in Appendices 5, 6, and 7 respectively).

It was established that a small positive gradient existed from the bottom to the top of the enclosed volume. These measurements cannot be considered absolute because the sampling method accuracy, and sampling time resulted in a disturbed mixture with a reduced gradient relative to the undisturbed condition. The gradient measured however, was small having a maximum value of 0.7 percent methane at an internal mixture of approximately 10 percent methane for the largest internal volume of 508 cubic inches after a 5 hour diffusion period.

The first readings of each test up to an elapsed time period of one hour were considerably lower than the values indicated by the trend of the later measurements and those calculated by the theory. The values are recorded in the tabulation of Appendix 4. Because these low values made it difficult to visually differentiate the curve for one set of test parameters from the curve of another, they were omitted from the plotted curves of Appendices 5, 6 and 7. It is thought that the reasons for this effect were, firstly, due to the time lag required for the first of the diffused molecules to reach the central location of the thermistor from the gap, and secondly, due to a buoyant effect causing the methane to rise initially and by-pass the thermistor resulting in the slight gradient discussed above.

In spite of these difficulties, however, the theory adequately predicts the average concentration for known conditions of gap geometry, internal volume and ambient temperature.

Experiments with no apparent gap were made previously by the authors employing hydrogen diffusing into three commercially-made enclosures in the field of industrial safety. The results of this work were reported in reference 1. It was found that some diffusion occurred in spite of the zero nominal gap however, because the flanges in the bolted condition had minor irregularities resulting in estimated average gaps of the order of 0.0006 inches. For example, 10 percent internal concentration of hydrogen resulted after a period of 3.5 hours by diffusion from a 44% external mixture into an enclosure having an internal volume approximately symmetrical with respect to the flanges, of 109 cubic inches, a flange periphery of 22.6 inches, a flange width of 0.5 inches, 6 retaining bolts and a flange surface roughness of approximately 40 μ -inches. It would have taken methane approximately 10 hours to diffuse to the same internal concentration under the same enclosure conditions with no intentional gap.

It is apparent that considerable time is required for mixtures frequently of lesser external concentration than those considered here, to diffuse into enclosures with no intentional gaps and having relatively large internal volumes typical of coal mine equipment. As a result of this observation it was considered that greased flanges would be a simple means of effectively preventing the diffusion from occurring at all. Brief experiments with greased flanges are described in the following section.

THE EFFECTS OF FLANGE GREASE ON DIFFUSION

Four tests were carried out in the same fashion and with the same equipment as described above, except that a silicone grease (designated as "Dow Corning 44 Grease" of medium consistency) was applied to the flanges so that the effectiveness of the grease seal in preventing diffusion could be determined. The results of these tests are shown in the following tabulation.

Grease Test Number	Gap Size (inches)	Test Condition	Total Elapsed Time (hours)	CH ₄ Inside (%)
		External Mixture 50% CH ₄ 508 in ³ Internal Volume		
1	0.0018	Light smear of grease	5	0.6
2	0.0018	Gap filled with grease	5	0
3	0.0018	Gap filled with grease	5	0.7
4	0.0068	Gap filled with grease	3.6	0

The reason for the presence of methane in test 3, small as it was, could not be determined. It is concluded in spite of this however, that a gap filled with grease is entirely effective in preventing diffusion.

Greases can be manufactured with widely varying characteristics such as viscosity, inertness, water-resistance etc. Therefore, it appears likely that a grease can be found or developed which would be suitable for use in prevention of diffusion through joints over extended periods of time and under mine environmental conditions.

The cyclic use of electrical equipment in hazardous atmospheres leads to the phenomena of "breathing". That is, a cyclic inhalation and exhalation of the hazardous exterior mixture occurs, due to the thermal variations produced by a cyclic electrical load. If the joints of an enclosure were sealed by grease such thermal variations would result in internal pressure fluctuations. A test was done with a greatly exaggerated vacuum of 186 mm of mercury (0.246 atmospheres) inside the diffusion cylinder having 1.0 inch flanges, a shimmed gap of 0.0055 inches completely filled with grease and an internal volume of 508 cubic inches. The largest volume was chosen for the maximum "pumping effect". The test was stopped after 72 hours had elapsed. Removal of the top half of the cylinder showed that there was no movement of the grease toward the inner edge and there was no loss of internal vacuum during that period. Consequently, the viscosity of the grease, which was specified as 960 poises at 68°F, was sufficient to enable the grease to resist movement in spite of the exaggerated pressure differential which was applied across the seal, and in spite of the exaggerated gap size. Consequently, it is considered that the simple precaution of greasing the flanges and any other small openings of an enclosure would prevent the presence of an explosive mixture inside the electrical enclosure.

CONCLUSIONS

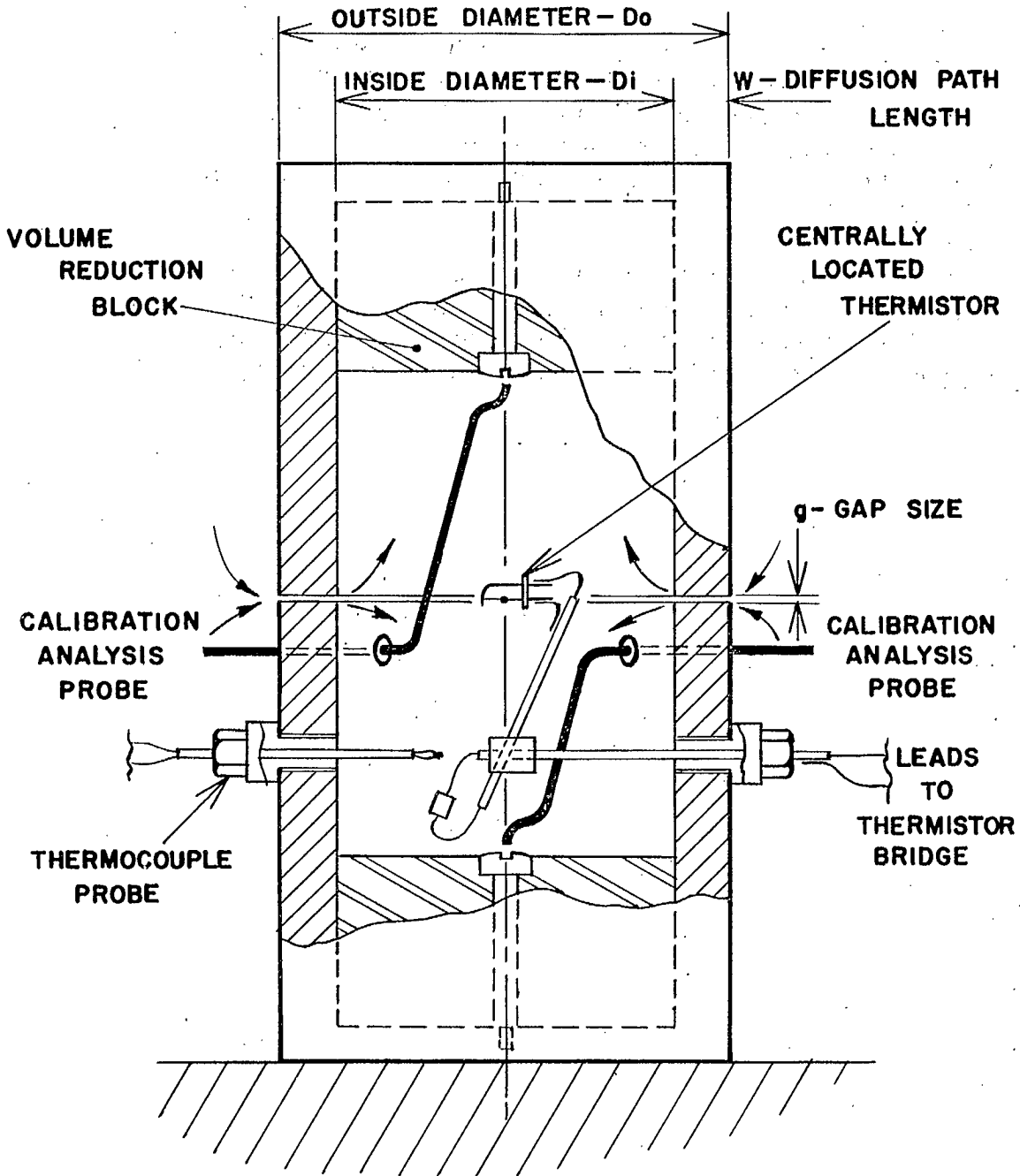
1. The slope of the theoretically calculated curves of diffusion variation with time closely duplicated the trends of the experimentally determined concentrations. The experimental values were an average of 0.7 percent methane above the corresponding calculated values at the end of a diffusion time period of 5 hours. Therefore, the theoretical equation adequately predicted the experimental facts and may be used for a calculation of diffusion for any known set of conditions.
2. A small mixture gradient was present, the maximum measured value of which was 0.7 percent methane higher at the top than the bottom of the internal volume of the apparatus used.
3. The time to reach a given internal mixture for a given outside atmosphere is directly proportional to the internal volume. Large free volumes, common in many flameproof enclosures, would require hours of immersion in high concentration methane atmospheres to attain an explosive internal mixture because of the normally close-fitting joints with no intentional gap. As the volumes decrease, the time to reach an explosive internal mixture decreases and small joint gaps which can occur in all enclosures due to flange unevenness are more serious. The diffusion hazard may be reduced by application to the joints of a suitable grease (one which would not harden with age and prevent proper closing of the joint). Such an application also appears to be effective in preventing the inhalation of the exterior mixtures into enclosures due to thermally-induced pressure changes resulting from cyclical electrical loading.

ACKNOWLEDGEMENTS

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REFERENCES

1. Brown, G.K. and Dainty, E.D. and Silver, S. -
Laboratory Investigations of Hydrogen Explosion
Phenomena Relating to Electrical Apparatus.
Chapter 7 of Mines Branch Research Report R 182
Department of Mines and Technical Surveys, Ottawa,
April 1966.
2. Fuller, E.N. and Schettler, P.D. and Giddings, J.C.-
A New Method for Prediction of Binary Gas Phase
Diffusion Coefficients. Volume 58, number 5, May
1966, pp 19-27 of Industrial and Engineering Chemistry.



APPENDIX I - SCHEMATIC DRAWING OF DIFFUSION CYLINDER AND INTERNALS

APPENDIX 2 - TABULATED THEORETICAL INTERNAL METHANE CONCENTRATIONS

Test	Internal Volume (in ³)	Gap Width (in)	Gap Size (in)	Ambient Temperature (°F)	Diffusion Coefficient (in ² /sec)	Gap Periphery (in)	OUTSIDE (Co) AND INSIDE (Ci) METHANE CONCENTRATIONS - % CH ₄							
							Time (hrs)	0	1.0	2.0	3.0	4.0	5.0	6.0
								Co	Ci	Co	Ci	Co	Ci	Co
1	508	0.50	0.020	58.0	0.0338	18.2	Co	50.0	49.2	48.5	47.7	47.0	46.2	45.4
							Ci	0	7.86	14.3	19.3	23.6	26.8	29.4
2	508	0.50	0.011	63.5	0.0342	18.2	Co	50.0	49.6	49.2	48.8	48.4	48.0	47.6
							Ci	0	4.57	8.64	12.3	15.5	18.4	20.9
3	508	0.50	0.0068	63.5	0.0342	18.2	Co	50.0	49.5	49.0	48.5	48.0	47.5	47.0
							Ci	0	2.84	5.46	7.91	10.1	12.2	14.1
4	508	0.50	0.0018	63.5	0.0342	18.2	Co	50.0	49.1	48.2	47.3	46.5	45.6	44.7
							Ci	0	0.75	1.46	2.13	2.77	3.38	3.95
5	339	0.50	0.020	63.0	0.0342	18.2	Co	50.0	49.6	49.3	48.9	48.6	48.2	47.8
							Ci	0	11.5	20.2	26.7	31.8	35.4	38.0
6	339	0.50	0.011	61.0	0.0340	18.2	Co	50.0	49.5	49.0	48.5	48.0	47.5	47.0
							Ci	0	6.64	12.3	17.0	21.0	24.4	27.2
7	170	0.50	0.020	63.0	0.0342	18.2	Co	49.8	49.4	49.1	48.7	48.3	48.0	47.6
							Ci	0	20.2	31.9	38.6	42.3	44.5	45.6
8	170	0.50	0.0108	62.5	0.0341	18.2	Co	49.9	49.4	48.9	48.4	47.9	47.4	46.9
							Ci	0	12.2	21.1	27.7	32.6	35.8	38.3
9	170	1.00	0.0105	63.0	0.0342	19.6	Co	50.2	49.9	49.6	49.3	49.0	48.8	48.5
							Ci	0	6.9	12.8	17.4	21.9	25.6	28.6
10	170	1.00	0.005	62.0	0.0349	19.6	Co	50.5	50.1	49.7	49.3	48.9	48.5	48.1
							Ci	0	3.6	6.9	10.0	12.7	15.2	17.5

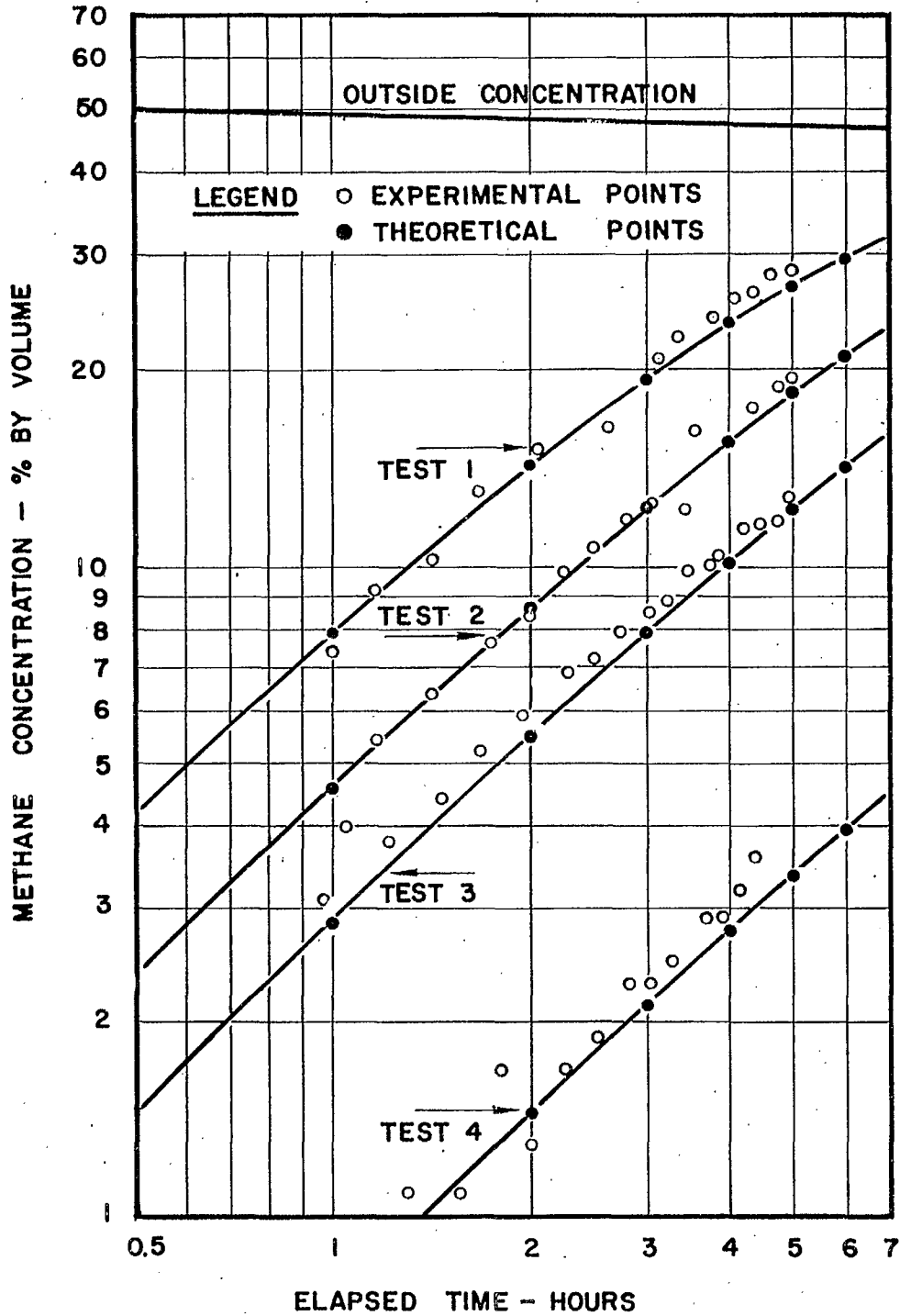
APPENDIX 3 - TABULATED INTERNAL MIXTURE CALIBRATION DATA

Test	Calibration Analysis			Average Calibration Analysis Corrected to 5 hours (% CH ₄)	Thermistor Bridge Output at 5 hours (μa)	Calibration Correction Ratio
	Item	Bottom	Top			
1	Time (hrs) % CH ₄	5.15 29.0	- -	28.6	29.6	0.967
2	Time (hrs) % CH ₄	5.13 19.7	- -	19.3	18.0	1.072
3	Time (hrs) % CH ₄	5.15 12.7	5.25 13.3	12.8	13.5	0.948
4	Time (hrs) % CH ₄	4.5 3.5	4.67 3.7	3.88	3.44	1.128
5	Time (hrs) % CH ₄	5.18 35.6	5.28 36.0	35.3	32.5	1.085
6	Time (hrs) % CH ₄	5.35 25.9	5.42 26.4	25.1	23.2	1.082
7	Time (hrs) % CH ₄	5.58 43.8	5.70 44.0	43.3	41.5	1.042
8	Time (hrs) % CH ₄	4.88 36.6	4.93 36.6	36.9	33.5	1.100
9	Time (hrs) % CH ₄	5.10 27.4	5.17 27.6	27.1	24.6	1.100
10	Time (hrs) % CH ₄	5.12 16.7	5.18 16.8	16.4	19.2	0.853

APPENDIX 4 - TABULATED EXPERIMENTAL INTERNAL CONCENTRATIONS
(Gaps to the nearest 0.001 inch)

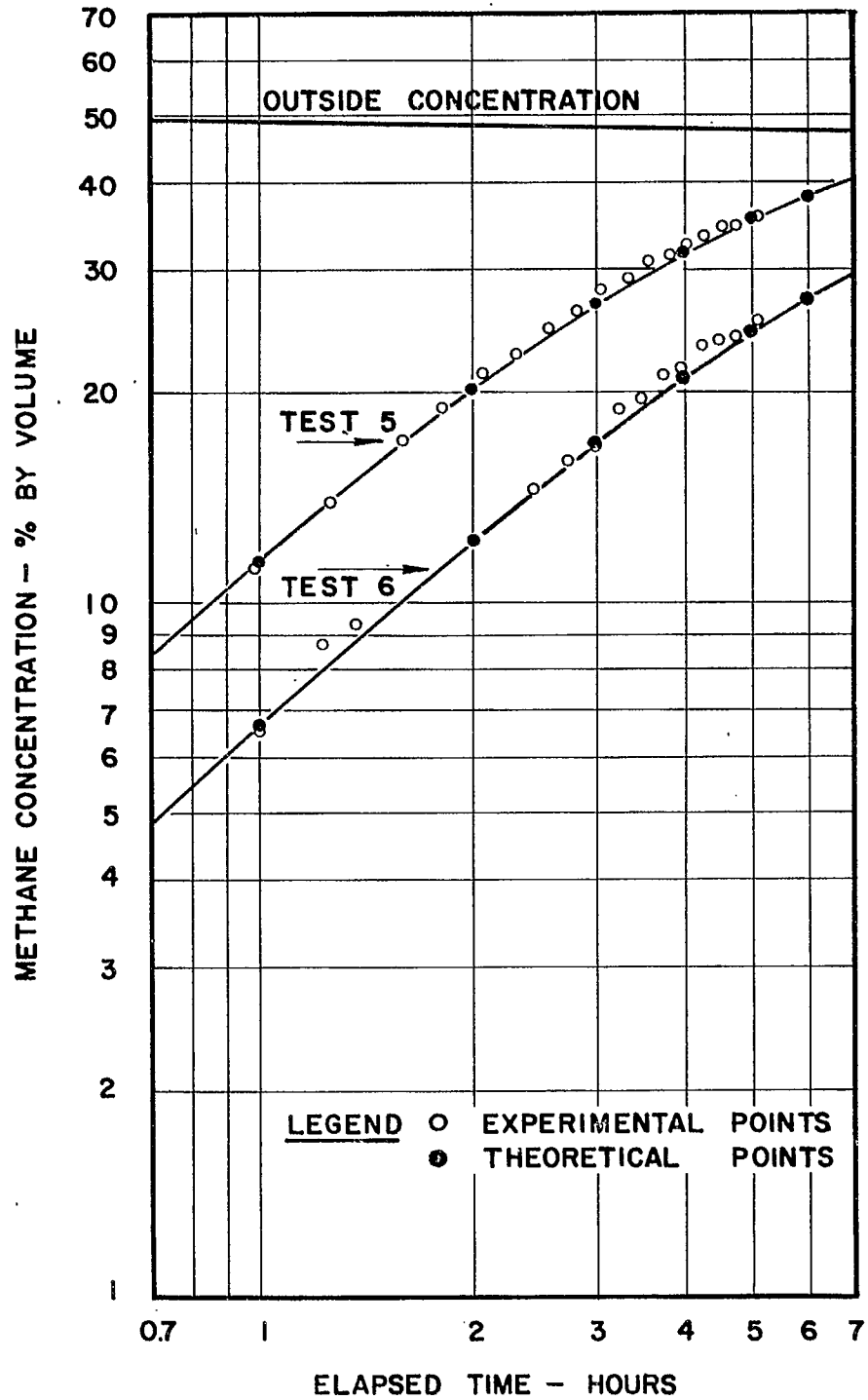
TEST		1	2	3	4	5	6	7	8	9	10
VOLUME*		508	508	508	508	339	339	170	170	170	170
PERIPHERY		18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	19.6	19.6
GAP WIDTH		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0
GAP SIZE		.020	.011	.007	.002	.020	.011	.020	.011	.011	.005
1	TIME	0	0	0	0	0	0	0	0	0	0
	%CH4	0	0	0	0	0	0	0	0	0	0
2	TIME	0.25	0.25	0.25	0.25	0.25	0.25	0.28	0.25	0.25	0.25
	%CH4	1.0	1.3	0.38	0	2.2	0.43	4.9	2.5	2.0	0.6
3	TIME	0.50	0.50	0.50	0.58	0.50	0.48	0.53	0.50	0.50	0.50
	%CH4	3.5	1.9	1.7	0	2.7	2.6	10.2	6.1	4.1	1.7
4	TIME	0.75	0.75	0.75	0.80	0.73	0.73	0.75	0.75	0.75	0.75
	%CH4	5.6	3.5	2.2	0.11	8.7	4.4	14.6	8.8	5.0	2.8
5	TIME	1.00	1.05	0.97	1.08	0.98	0.98	1.03	1.00	1.00	1.00
	%CH4	7.4	4.0	3.1	0.23	11.2	6.6	18.5	11.3	7.4	3.8
6	TIME	1.17	1.40	1.22	1.30	1.26	1.23	1.28	1.25	1.25	1.25
	%CH4	9.2	5.4	3.8	1.1	13.9	8.7	21.6	15.2	8.8	4.9
7	TIME	1.42	1.50	1.47	1.56	1.60	1.37	1.55	1.48	1.50	1.50
	%CH4	10.2	6.4	4.4	1.1	17.1	9.3	25.2	17.3	10.7	5.8
8	TIME	1.67	1.75	1.68	1.80	1.82	2.45	2.68	1.73	1.75	1.75
	%CH4	13.1	5.6	5.2	1.7	19.0	14.6	35.3	19.5	11.9	6.7
9	TIME	2.05	2.00	1.94	2.00	2.07	2.74	2.94	1.98	2.00	2.00
	%CH4	15.1	8.4	5.9	1.3	21.2	16.0	36.6	21.8	13.5	7.6
10	TIME	2.62	2.25	2.27	2.25	2.32	2.98	3.17	2.24	2.25	2.25
	%CH4	16.2	9.8	6.9	1.7	22.6	17.3	37.8	23.8	15.0	8.4
11	TIME	3.13	2.50	2.50	2.53	2.57	3.23	3.42	2.48	2.50	2.50
	%CH4	20.9	10.7	7.2	1.9	24.6	18.9	39.1	25.7	16.5	9.0
12	TIME	3.37	2.80	2.74	2.80	2.82	3.48	3.67	2.74	2.75	2.75
	%CH4	22.5	11.8	7.9	2.3	26.2	19.5	40.6	27.1	17.7	9.9
13	TIME	3.80	3.03	3.02	3.02	3.07	3.73	3.92	2.98	3.00	3.00
	%CH4	24.1	12.5	8.5	2.3	28.0	21.1	41.1	28.7	18.7	10.7
14	TIME	4.07	3.42	3.22	3.27	3.32	3.98	4.17	3.24	3.25	3.25
	%CH4	25.9	12.2	8.8	2.5	29.0	21.7	41.5	30.2	19.7	11.5
15	TIME	4.37	3.55	3.47	3.70	3.57	4.23	4.41	3.48	3.50	3.50
	%CH4	26.5	16.2	9.8	2.9	30.4	23.3	41.7	31.4	20.9	12.1
16	TIME	4.62	4.33	3.72	3.90	3.82	4.49	4.66	3.74	3.75	3.75
	%CH4	28.1	17.4	10.0	2.9	31.4	23.7	42.5	32.7	22.0	12.9
17	TIME	5.00	4.75	3.85	4.15	4.03	4.72	4.91	3.98	4.00	4.00
	%CH4	28.6	18.7	10.4	3.2	32.5	23.9	43.2	33.6	22.9	13.6
18	TIME	-	5.00	4.20	4.38	4.29	4.97	5.17	4.23	4.25	4.25
	%CH4	-	19.3	11.4	3.6	33.6	24.6	43.6	34.7	24.1	14.1
19	TIME	-	-	4.45	4.45	4.53	5.10	5.41	4.47	4.50	4.50
	%CH4	-	-	11.6	3.6	34.5	25.4	43.8	35.5	25.3	15.0
20	TIME	-	-	4.72	-	4.76	-	-	4.89	4.75	4.75
	%CH4	-	-	11.7	-	34.7	-	-	36.2	26.3	15.5
21	TIME	-	-	4.95	-	5.02	-	-	-	5.00	5.00
	%CH4	-	-	12.7	-	35.3	-	-	-	27.1	16.5

*UNITS: Volume (in³), Joint Dimensions (in), Time (hr).



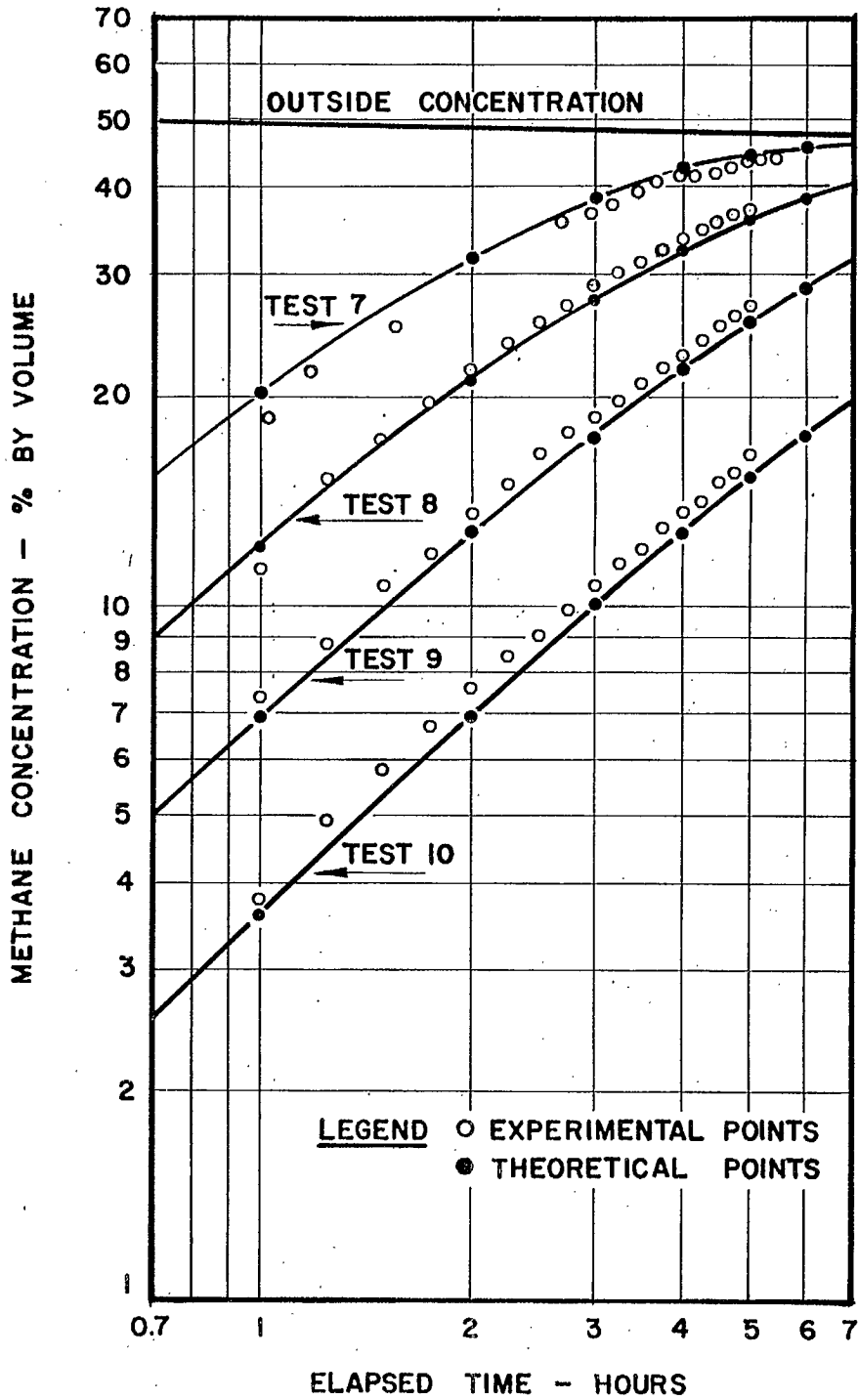
TEST	GAP (IN)	WIDTH (IN)	PERIPHERY (IN)
1	0.020	0.5	18.2
2	0.011	0.5	18.2
3	0.0068	0.5	18.2
4	0.0018	0.5	18.2

**APPENDIX 5 - RESULTS OF METHANE DIFFUSION INTO
THE 508 CUBIC INCH. CYLINDRICAL VOLUME**



TEST	GAP (IN)	WIDTH (IN)	PERIPHERY (IN)
5	0.020	0.5	18.2
6	0.011	0.5	18.2

APPENDIX 6 - RESULTS OF METHANE DIFFUSION INTO THE 339 CUBIC INCH CYLINDRICAL VOLUME

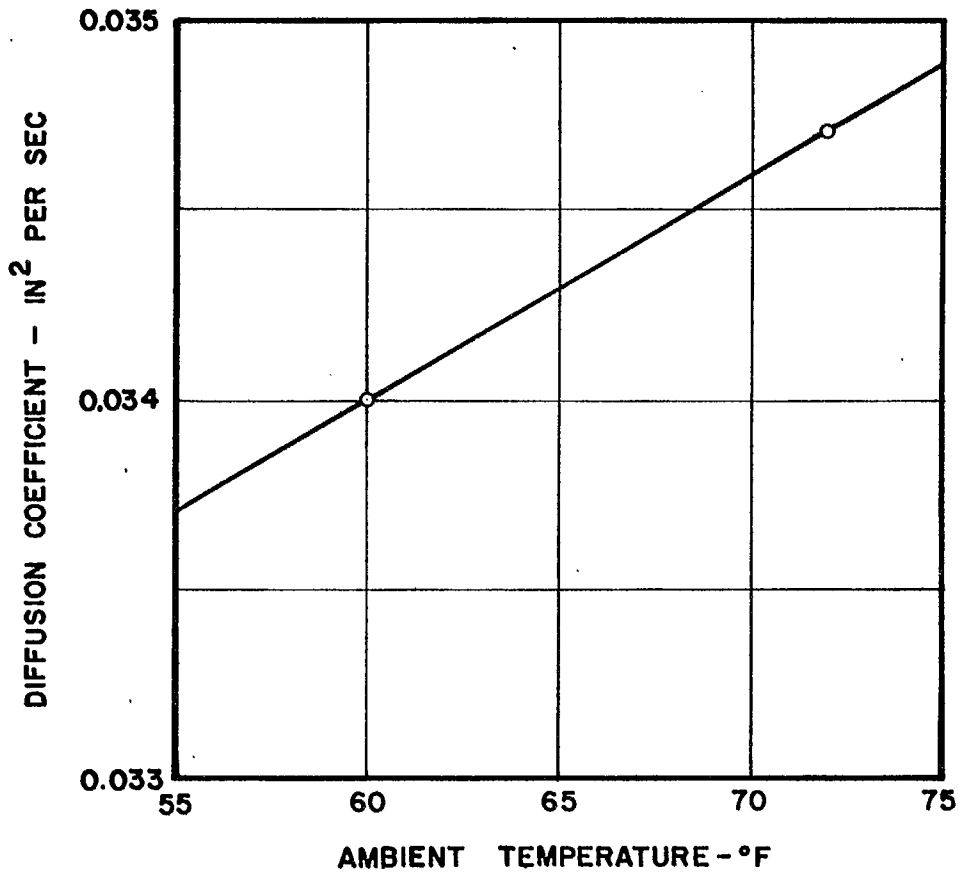


TEST	GAP (IN)	WIDTH (IN)	PERIPHERY (IN)
7	0.020	0.5	18.2
8	0.0108	0.5	18.2
9	0.0105	1.0	19.6
10	0.005	1.0	19.6

APPENDIX 7 - RESULTS OF METHANE DIFFUSION INTO THE 170 CUBIC INCH -CYLINDRICAL VOLUME

NOTE: 1. DATA SUITABLE FOR ATMOSPHERIC PRESSURE.

2. PLOTTED VALUES SHOWN ARE GIVEN IN REFERENCE 2.



APPENDIX 8 - DIFFUSION COEFFICIENT VARIATION
WITH TEMPERATURE FOR THE
METHANE-AIR SYSTEM

