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Electrical Enclosure Hydrogen Intrusion Study

Peter J. Welch and John N. Yantsios

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Peter J. Welch and John N. Yantsios
John F. Kennedy Space Center
Kennedy Space Center, Florida

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

ELECTRICAL ENCLOSURE
HYDROGEN INTRUSION STUDY

by Peter J. Welch and John N. Yantsios
John F. Kennedy Space Center

INTRODUCTION

During the Apollo, Skylab, and Apollo-Soyuz Test Project (ASTP) manned space flight programs at the Kennedy Space Center (KSC), the communications and electrical enclosures at Launch Complex 39 (LC-39) were purged with gaseous nitrogen. As a cost saving measure for the Space Shuttle program, it has been proposed that the enclosures be purged with dry air instead of gaseous nitrogen.

The purging of the LC-39 Ground Support Equipment (GSE) serves two functions: safety and corrosion control.

For safety, the gaseous nitrogen (GN_2) purge provides an inert atmosphere which minimizes the probability of electrical fires and explosions that could erupt from the infiltration of propellant vapors, such as hydrogen, into the GSE.

For corrosion control, the GN_2 purge inhibits intrusion of the salt-laden humid Cape Canaveral atmosphere into the GSE to provide a form of preventive maintenance.

The Director of Technical Support, KSC, requested that a study be conducted to determine whether hydrogen gas, being vented from the Shuttle external tank or from GSE supply lines, could diffuse into electrical enclosures and reach explosive-mixture concentrations.

To investigate the hydrogen diffusion problem, a three-step program was initiated. The first step was to conduct a literature survey on gaseous diffusion and to select an applicable model for computer simulation. The second step was to verify the model with laboratory tests. The final step was to perform a functional test of a typical electrical enclosure to determine the hydrogen concentrations which could be obtained within the electrical box under air or GN_2 purge.

HYDROGEN DIFFUSION MODEL

Gaseous Diffusion

Diffusion is defined as the process whereby particles (molecules and ions) of liquids, gaseous, or solids intermingle as the result of their spontaneous movement caused by thermal agitation, or, in dissolved substances, move from a region of higher concentration to one of lower concentration.

The hydrogen molecule at standard conditions has a theoretical average linear speed of 1.84×10^5 cm/sec (approximately 6000 ft/sec).

However, in actual practice, the hydrogen molecule will only travel a few centimeters per second because the individual molecule randomly collides with and rebounds from other molecules. The displacement of an individual molecule is identified by a probability distribution, Error Function (see Appendix).

Gas diffusion is a continuous, never-ending process which is dependent upon:

1) Physical characteristics of the gases (molecular size and weight)
2) Temperature and pressure of the gases
3) Concentrations of the gases
4) Elapsed time

Analytical Model

In the hydrogen diffusion analysis, it is assumed that the box to be purged is completely sealed except for the air supply inlet and the purge flow outlet as shown in Figure 1. It is also assumed that the box is subject to an external hydrogen atmosphere. The analytical model for this environmental condition is presented by a tube of sufficient length to be considered infinitely long (see Figure 2). In the center of the tube is a diaphragm which separates the two ends. When the diaphragm is moved at the time $T=0$, the hydrogen concentration $C(z,T)$ with respect to displacement and time can be represented as shown in Figure 3. As the time increases at $T \geq 0$, the hydrogen diffuses into the air and vice versa as shown in Figure 3.

To this point, the analytical model represents a static (no flow) system. To make the model represent the purge condition, the minimum purge flow rate required to displace the diffusing hydrogen was calculated. This is the flow which will displace the leading edge of the diffusing hydrogen back to the initial hydrogen/air interface located at $X=0$.

The mathematical formulae used in this analysis are shown in the appendix.

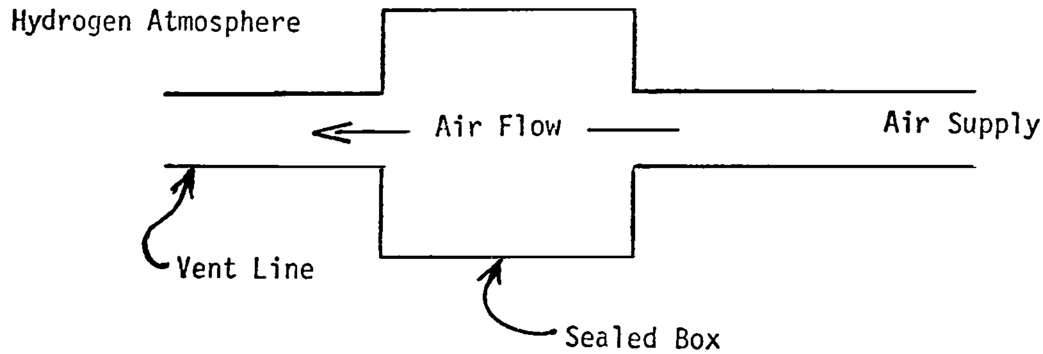


Figure 1
System condition for diffusion analysis of a box under purge

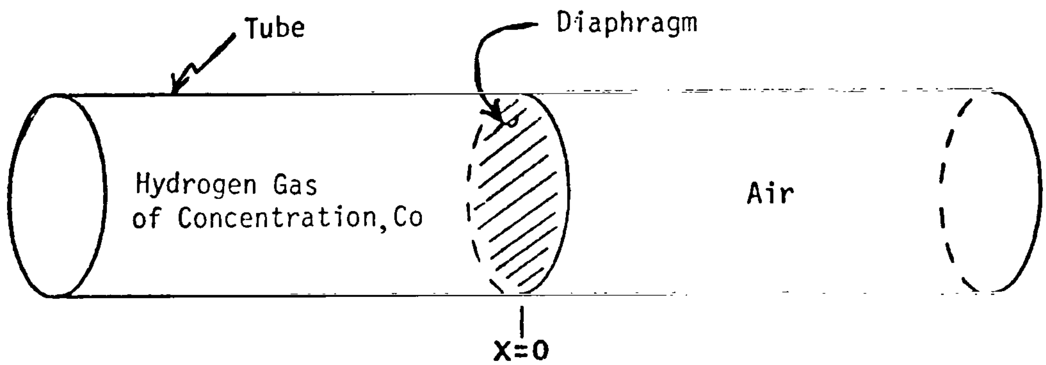


Figure 2
Hydrogen diffusion analytical model

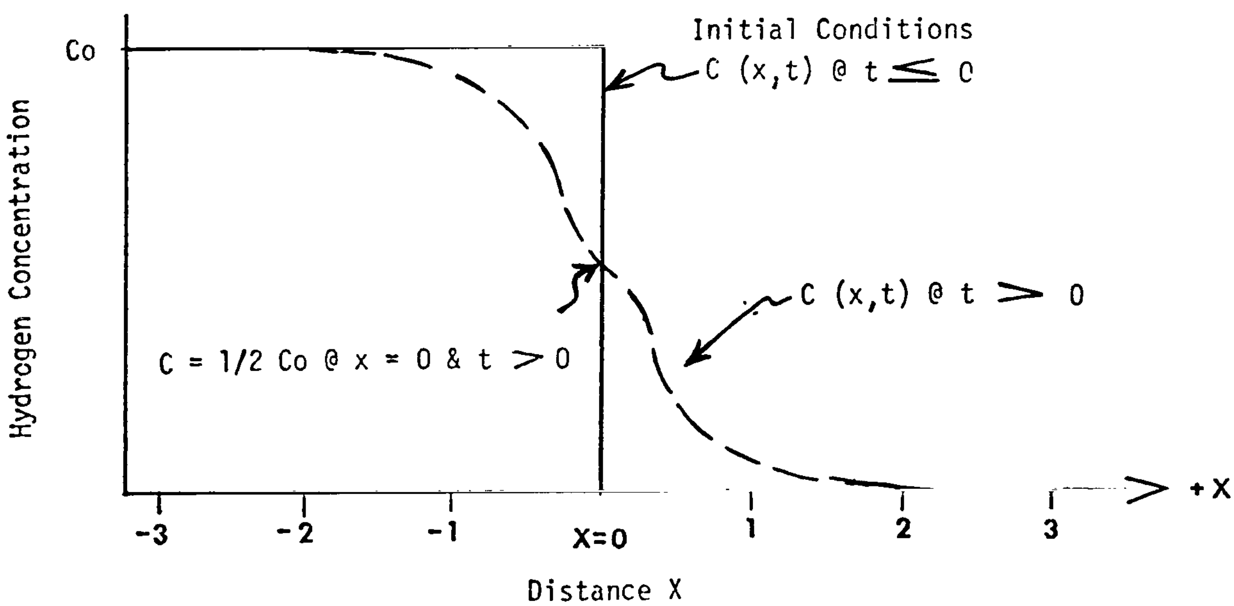


Figure 3
Hydrogen concentration profile during diffusion process

Discussion

A series of hydrogen diffusion profiles for the one dimensional model are shown in Figure 4. It can be seen that the profile does not propagate at a continuous rate. This is also illustrated in Figures 5 and 6.

The decrease in the rate of diffusion is explained by the fact that the amount of gas to diffuse into an area at any given time is dependent on the concentration of that gas in adjacent areas.

The analytical results indicate that it requires only a relatively low air purge flow rate to keep any significant quantities of hydrogen from diffusing back into the box under purge if the purge vent line is of some significant length. However, if the purge vent line is extremely short, such as in the case of seal leaks, screw holes and other openings in the box, then it is virtually impossible to prevent hydrogen from diffusing into the box. This is illustrated in Figures 6 and 7.

If we consider the displacement, X, to be analogous to the length of the vent line, or a leak path, it can be seen in Figure 6 that as the length of the flow path approaches zero, the rate of displacement (propagation) of the diffusion front approaches infinity. This would be typical where there is a leak in the box under purge. In this same case, it can be seen in Figure 7 that the purge air flow must also approach infinity to block the hydrogen diffusion into the box.

DIFFUSION MODEL VERIFICATION TEST

Objective

The objective of this series of tests was to verify the results of the diffusion analysis. In the verification tests, the concentration of helium

9

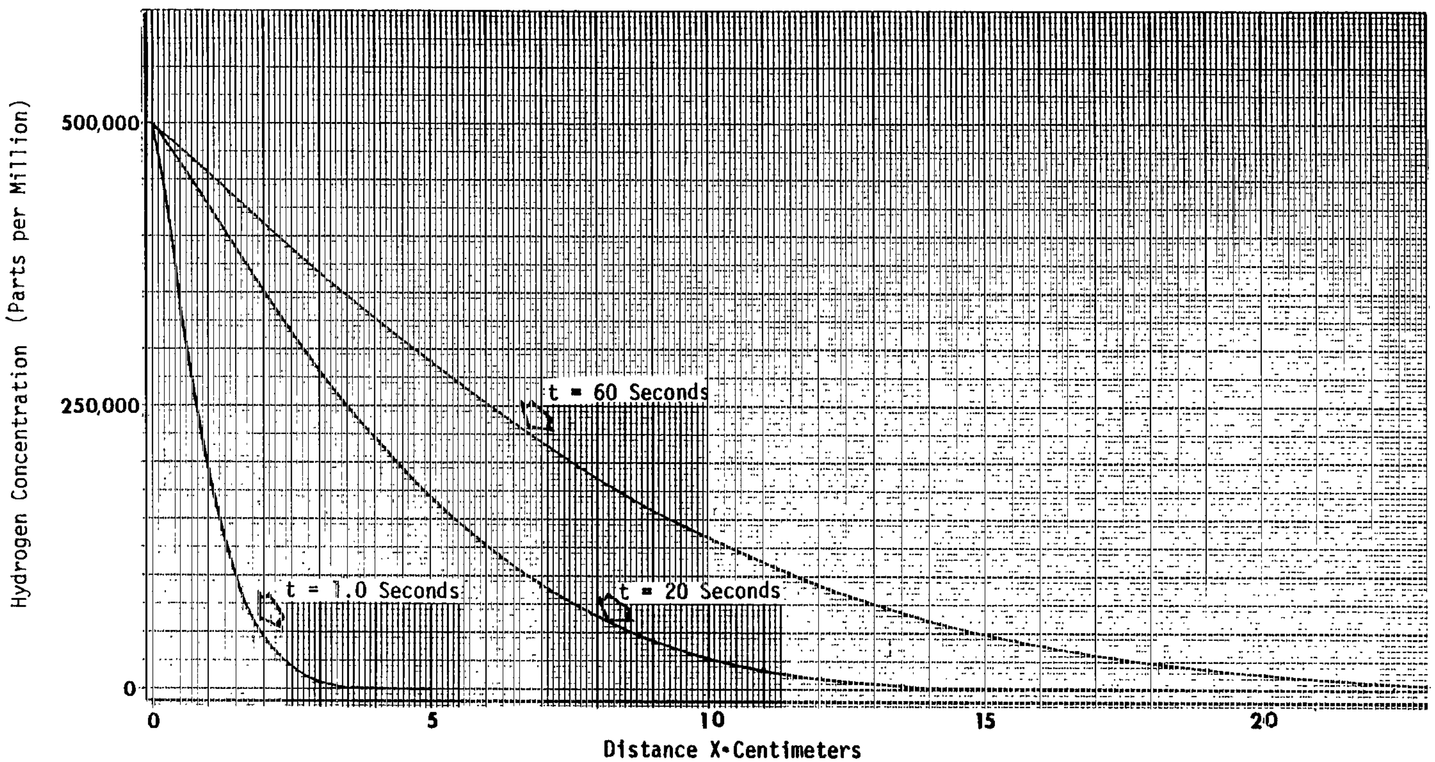


Figure 4

Hydrogen concentration profile for one dimensional diffusion under static conditions.

Analytical conditions:

Temperature = 24°C (75°F) Pressure = 1.0 Atmosphere
Second Gas = Air
Initial concentration of hydrogen = 1,000,000 PPM
@ Distance 0.0 and Time 0.0 Seconds

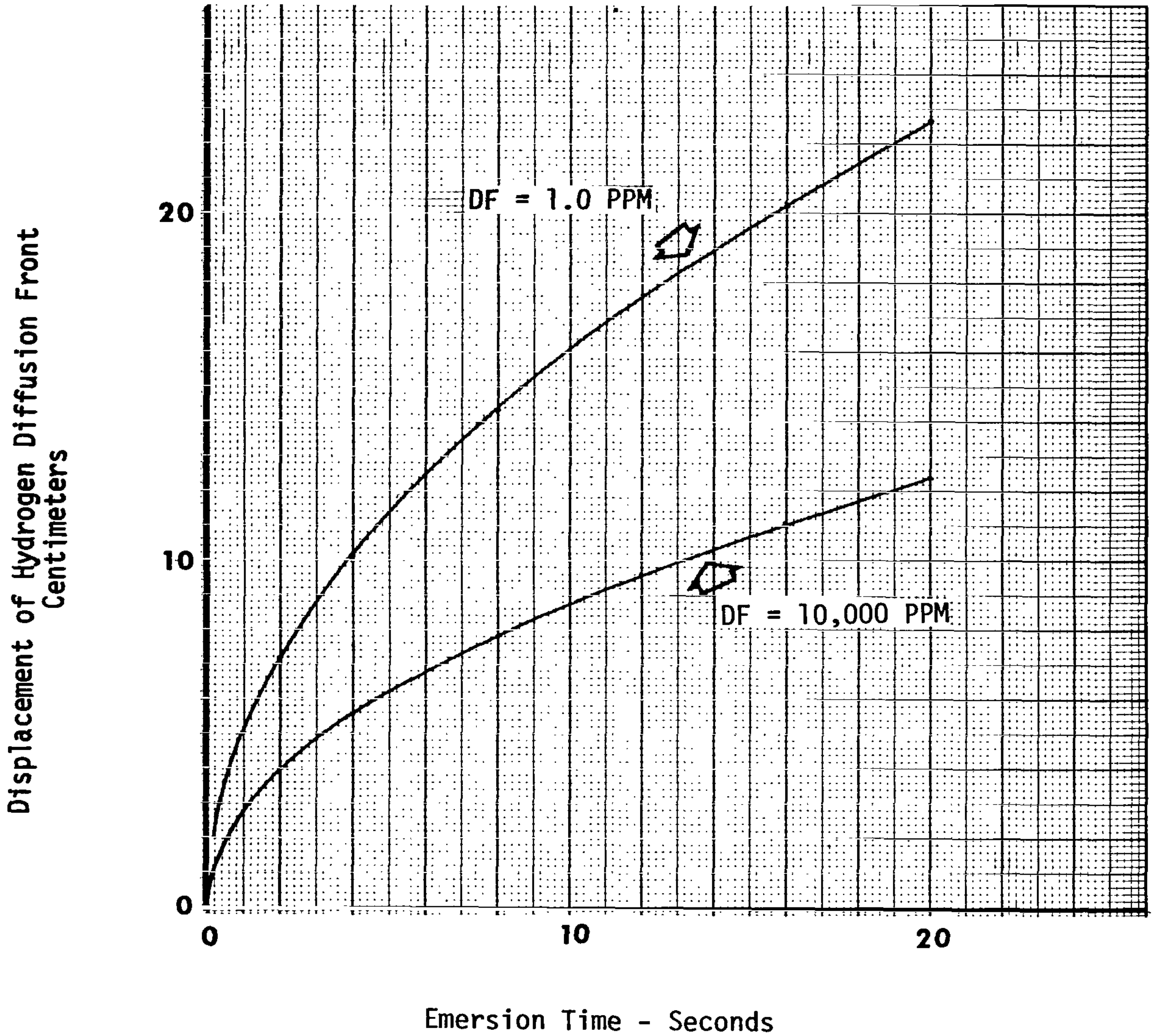


Figure 5

Displacement of the hydrogen diffusion front vs. emersion time for one dimensional model under static conditions.

"DF" indicates hydrogen concentration which defines diffusion front.

Analytical conditions:

Temperature = 24°C (75°F) Second Gas = Air
Pressure = 1.0 Atmosphere
Initial Concentration of Hydrogen = 1,000,000 PPM
@ Displacements $\leq$ 0.0 and Time $\leq$ 0.0

(Refer to Figures 4 & 5)

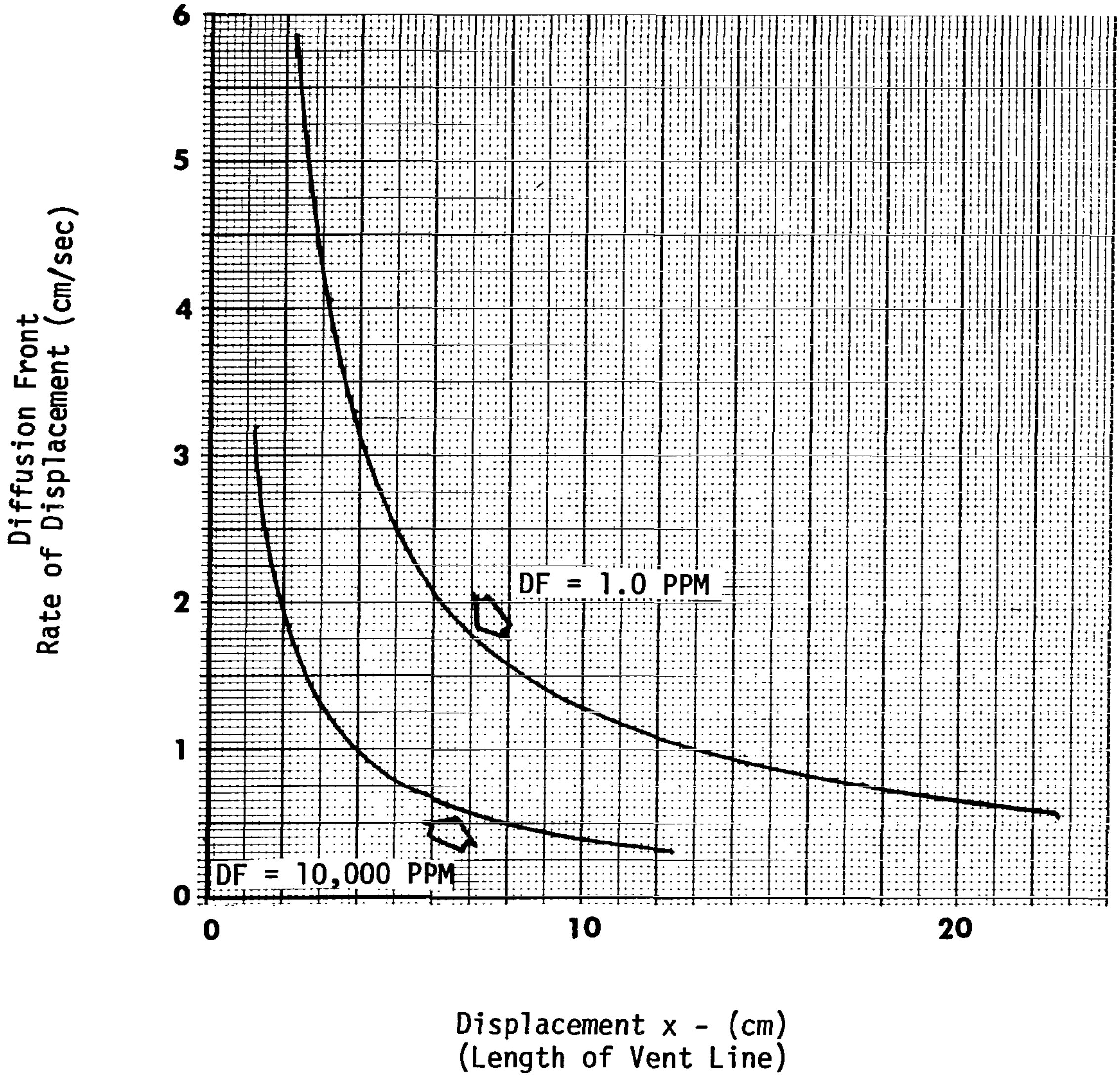


Figure 6

Diffusion front rate of displacement vs. displacement for one dimensional model under static conditions.

Analytical Conditions:

Temperature = 24°C (75°F)
Pressure = 1.0 Atmosphere
Second Gas = Air
Initial Concentration of Hydrogen = 1,000,000 PPM
@ Displacement X <0.0 and Time ≤ 0.0

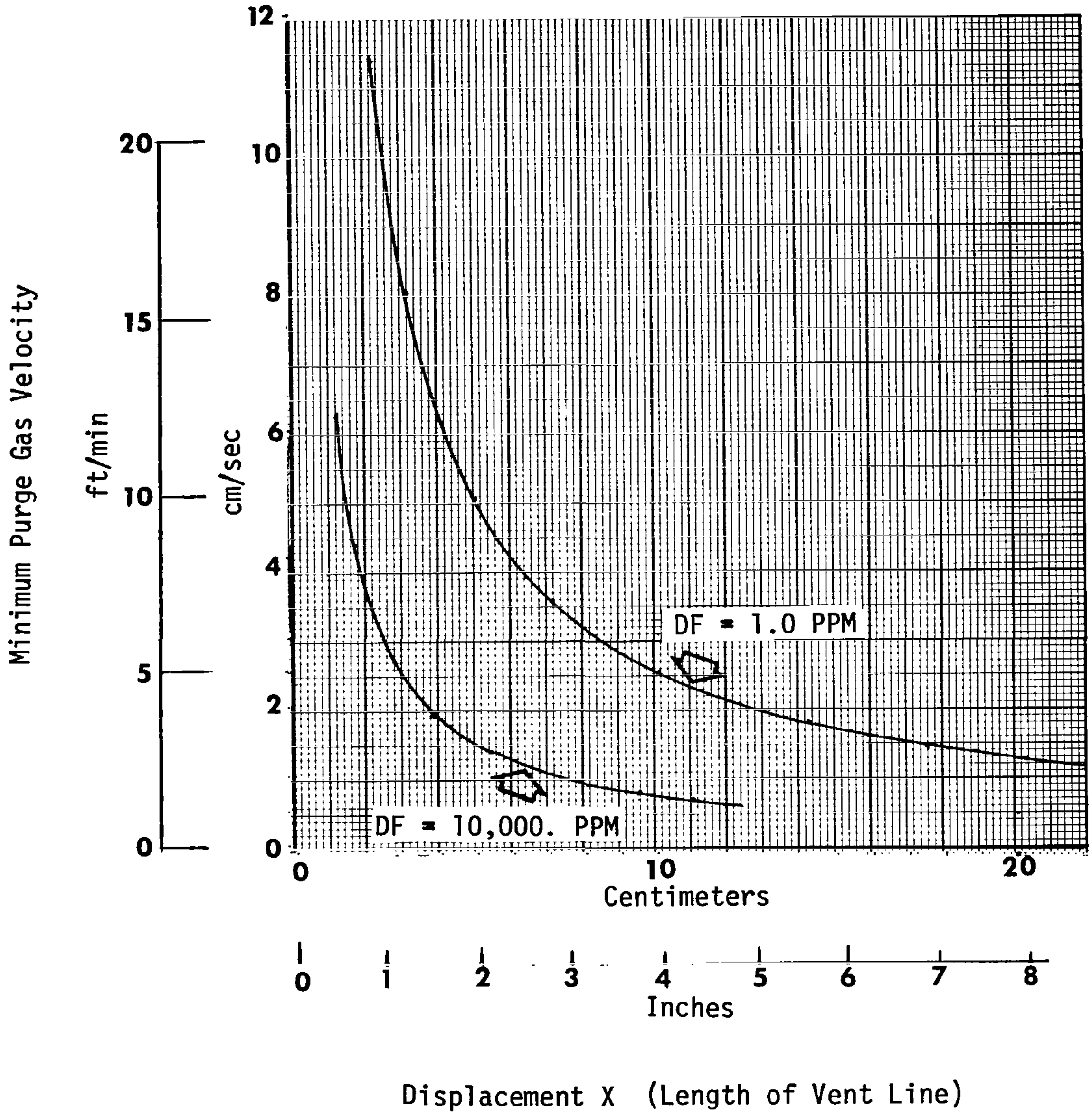


Figure 7

Minimum Purge Gas (Air) Velocity vs. Displacement
Analytical conditions:

Temperature = 24°C (75°F)
Pressure = 1.0 Atmospheres

diffusing through a static or dynamic stream of nitrogen was measured at various positions along the tube. The test results were then compared with the analytical model.

Helium was used as the diffusing medium to eliminate the hazards posed by hydrogen. In the analytical model, a helium/argon system was selected due to the lack of available helium/nitrogen diffusion information.

Test Configuration

A schematic drawing of the test set-up is illustrated in Figure 8. In the test set-up, the test box (an electrical distribution box) was used to contain the diffusion gas, helium.

The helium concentration was measured with a helium leak detector. The detector probe was located at various distances, "L", from the end of a horizontal, nitrogen-filled 1/2-inch tube which was exposed to the helium environment in the test box.

During the tests, which approximated the analytical model under static conditions, the helium leak detector probe was positioned at four locations along the 1/2-inch tube. The probe locations were 3 1/2, 7 1/2, 10 1/4, and 21 inches from the test port inlet to the test box. The static test results, which are an average of from two to four similar test runs, are shown in Figure 9. Dynamic tests were performed with the probe located 1 3/8 and 3 inches from the test port opening. The dynamic test results are shown in Figures 10 and 11.

A second series of tests was performed with a calibrated bleed fitting (P/N 75M02048-2) similar to those installed on the electrical boxes under purge (see Figure 12). The fitting was attached to a 3/8-inch bulkhead fitting with a 3/8-inch elbow and tube. In this configuration, the probe was located 8 inches (measured along tube center line) from the face of the bleed fitting. The static and dynamic test results are shown in Figures 13 and 14.

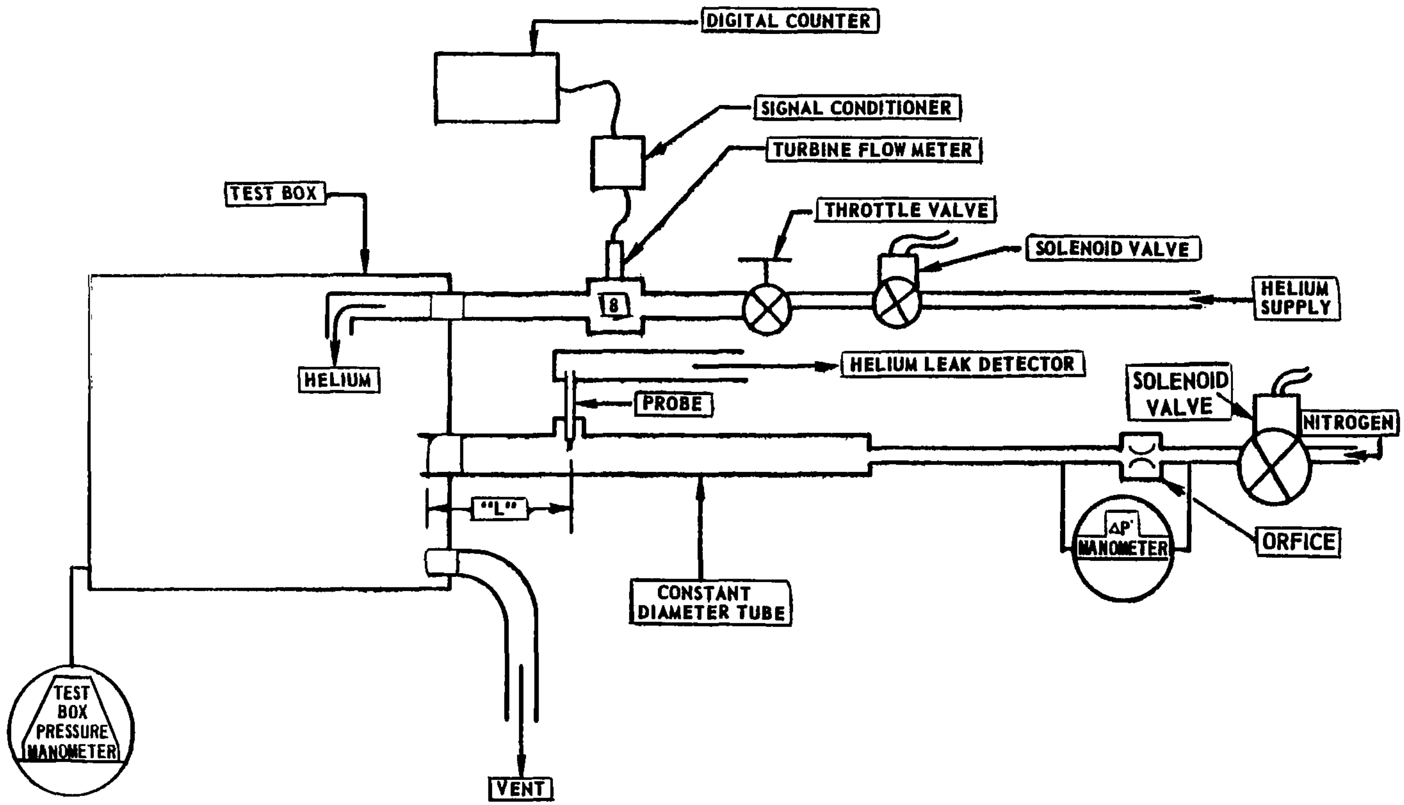


Figure 8

Schematic Drawing of Helium Diffusion Test Setup

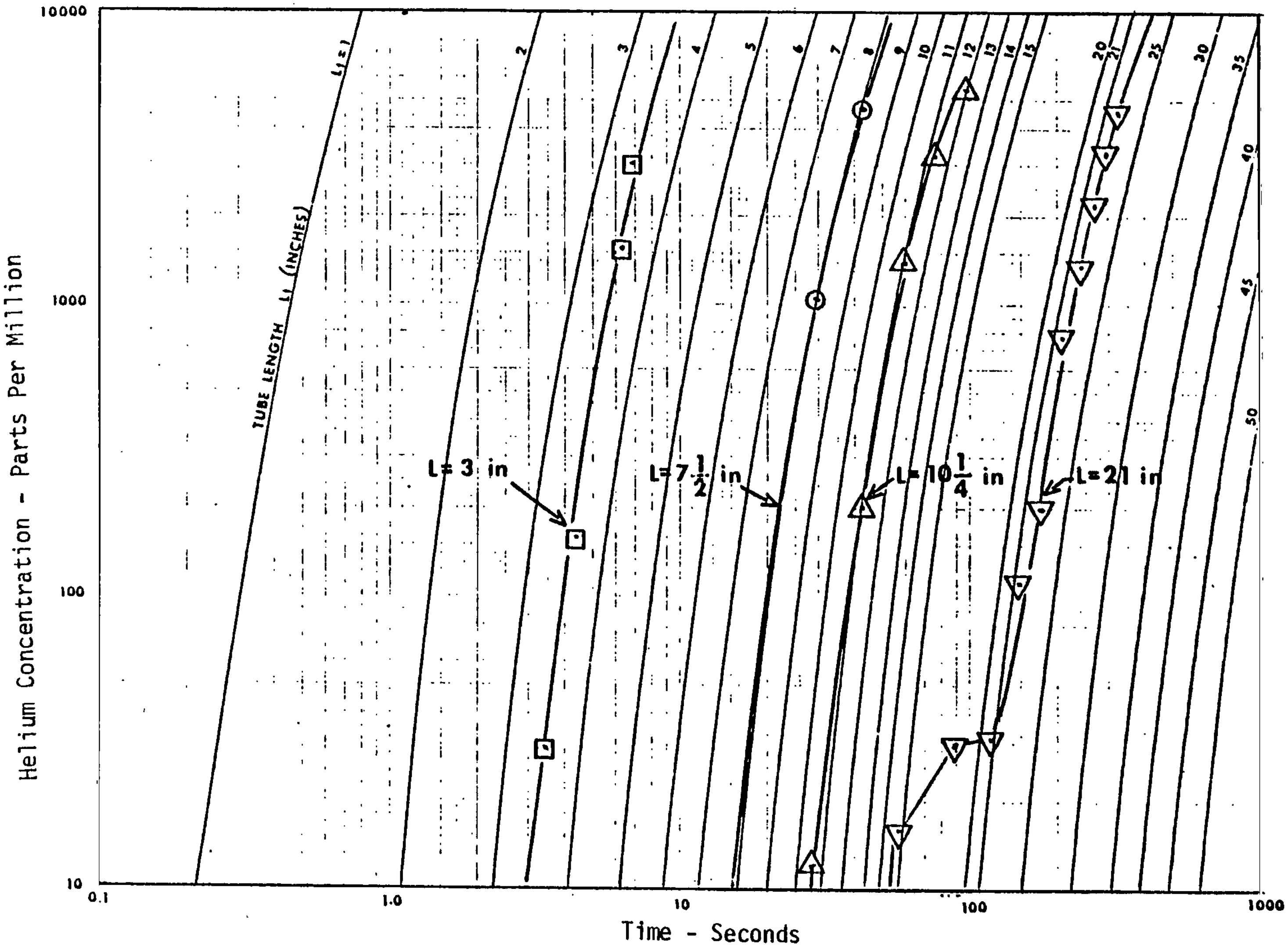


Figure 9

Static diffusion test results for helium diffusing up a straight (horizontal) tube filled with nitrogen where:

Lt - Analytical tube length
L - Test data for lengths 3, 7 1/2, 10 1/4, and 21 inches.

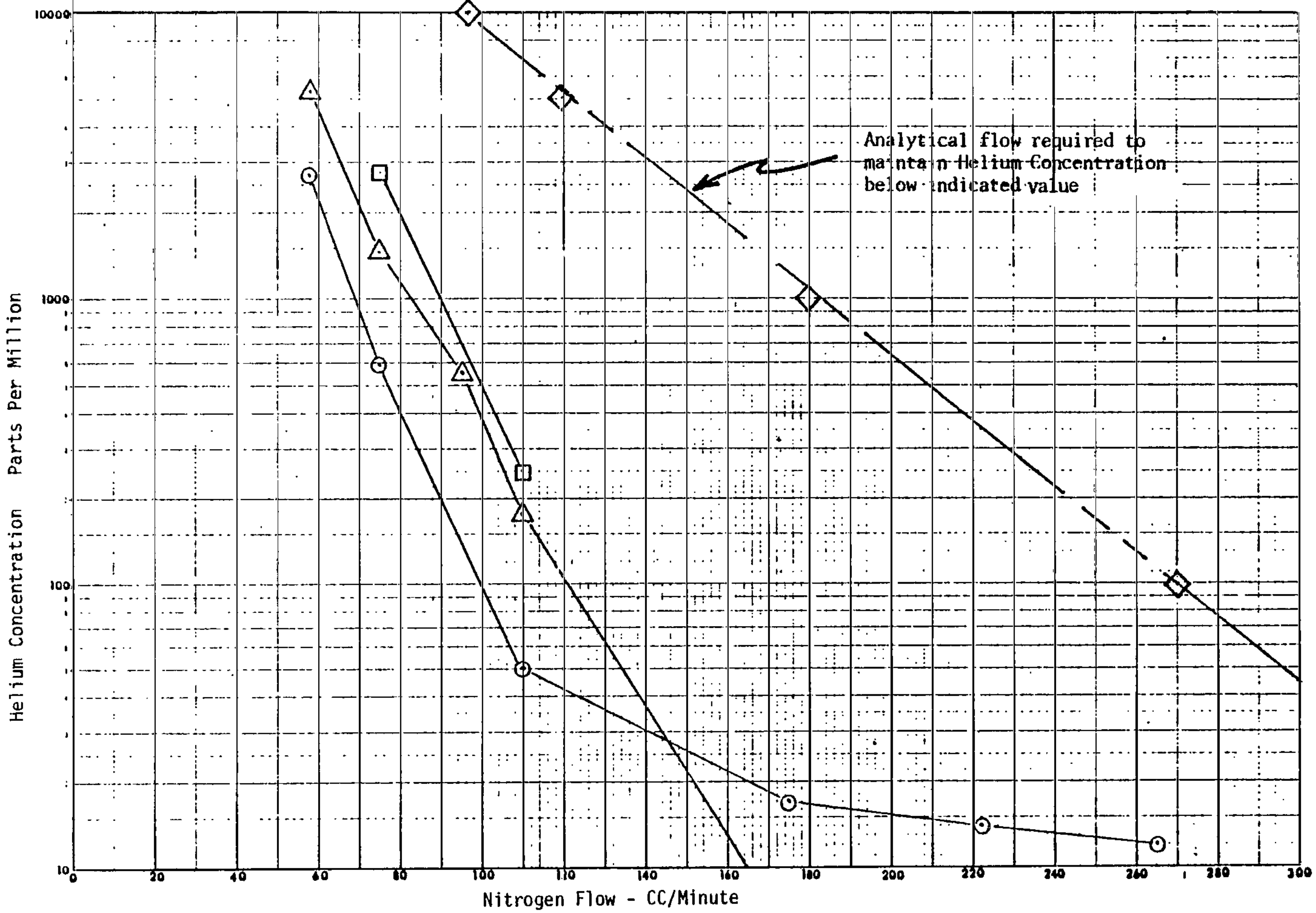


Figure 10

Dynamic diffusion tests results for helium diffusion up a flowing nitrogen stream in a 1/2" tube (0.391 inch inside diameter) at a distance of 1 3/8 inches.

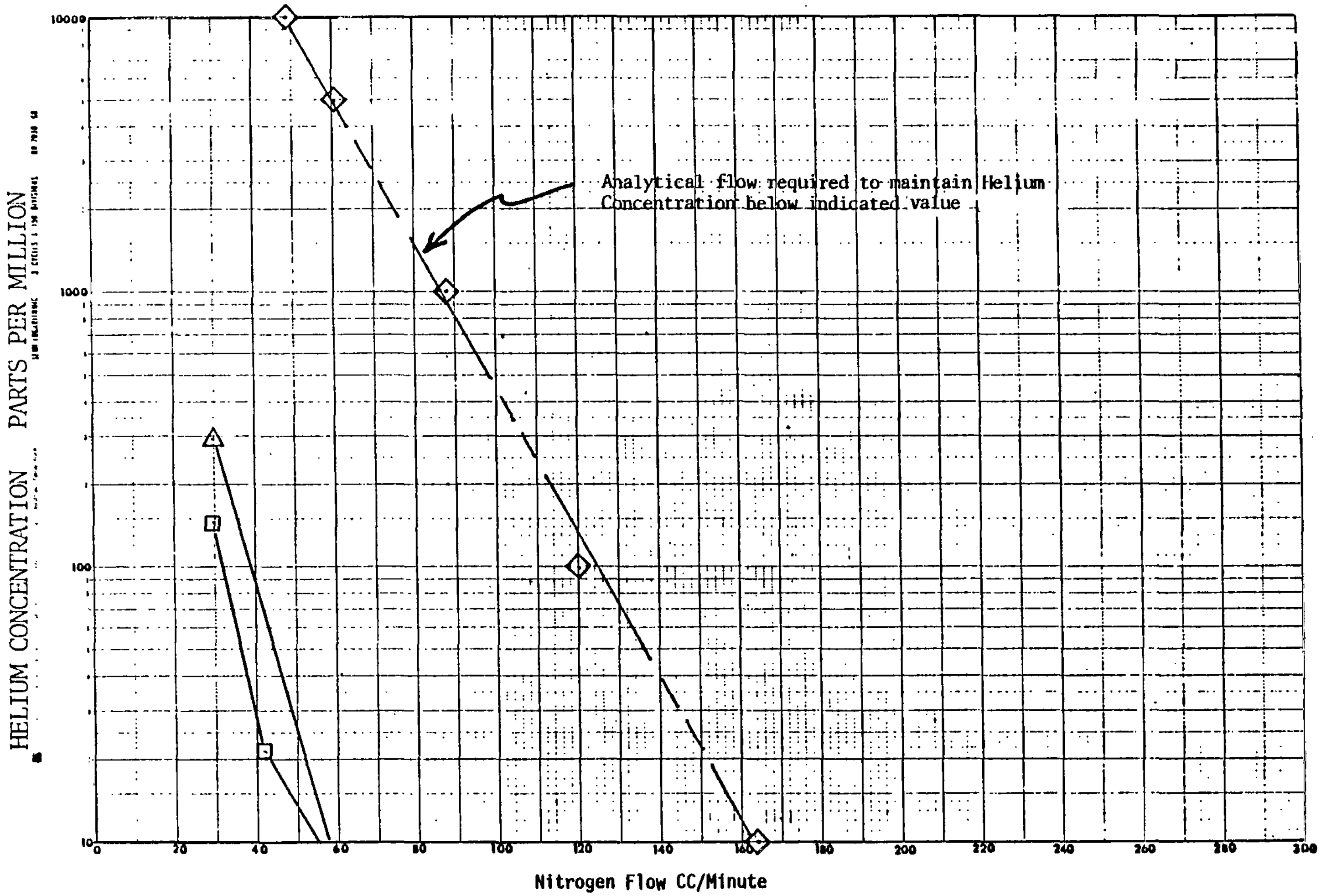


Figure 11

Dynamic diffusion tests results for helium diffusion up a flowing nitrogen stream in a 1/2" tube (0.391 inch inside diameter) at a distance of 3 inches.

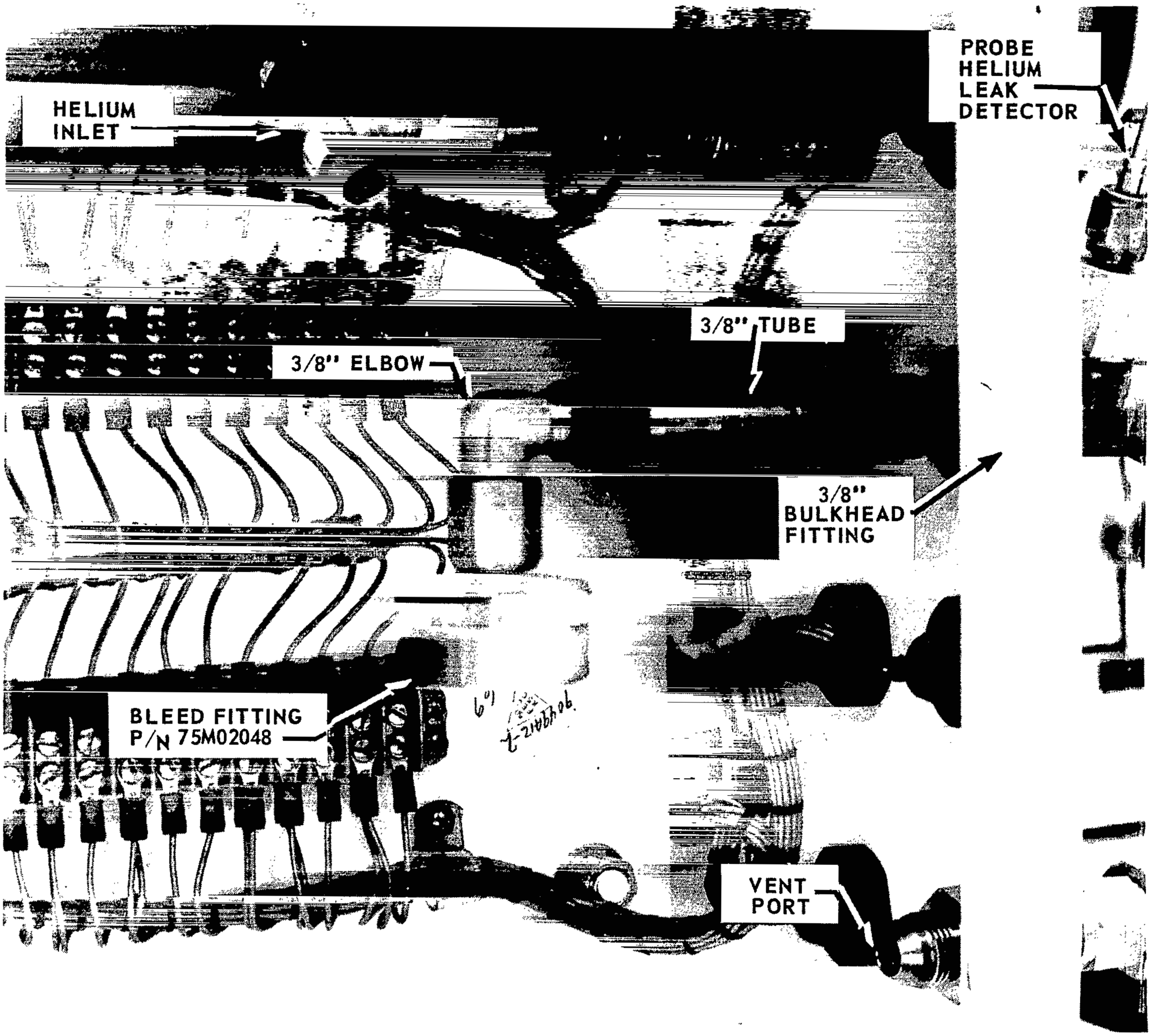


Figure 12

Test box configuration for tests using calibrated bleed fitting.

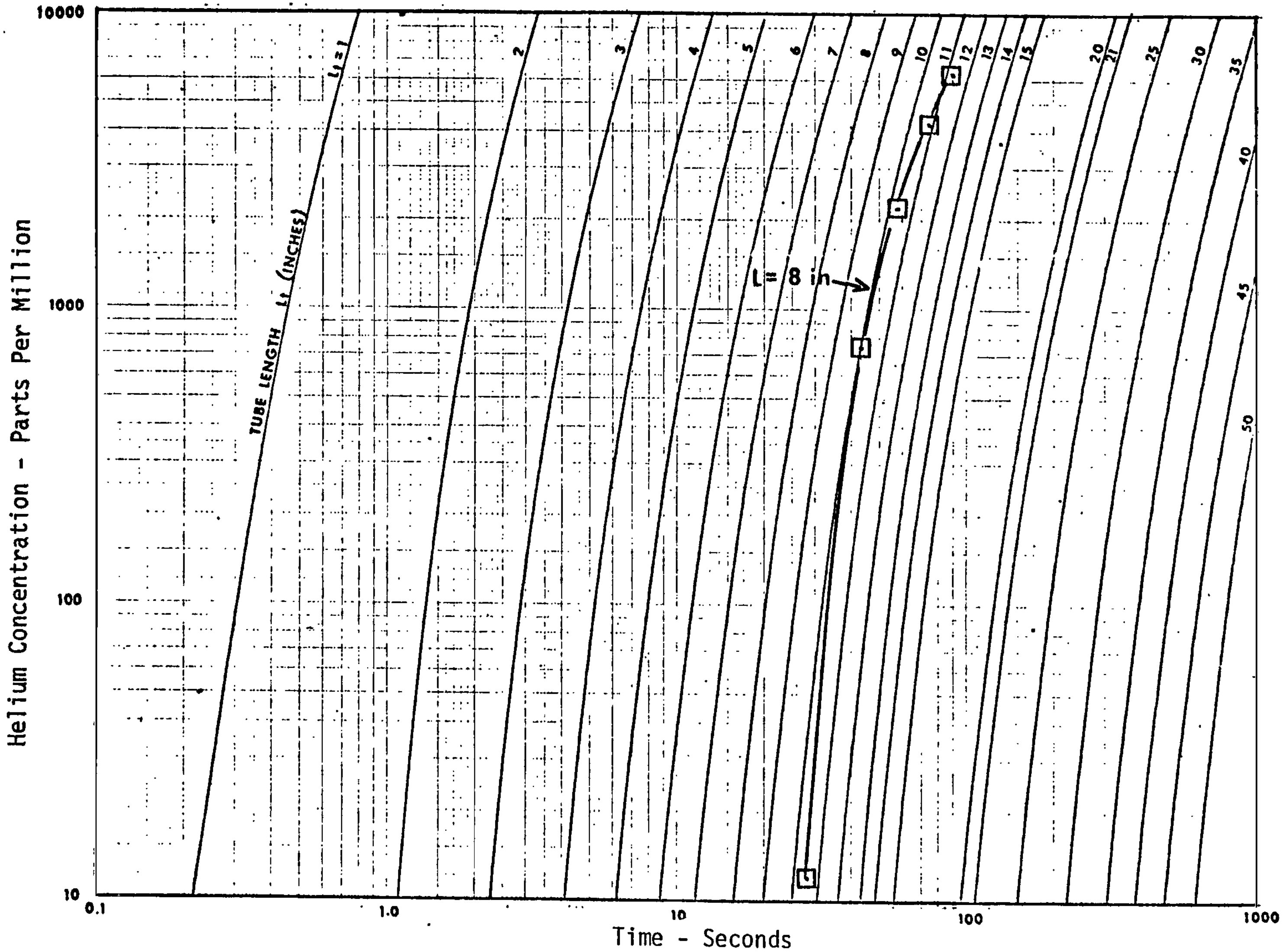


Figure 13

Static diffusion test results for helium diffusing up a tube with a calibrated bleed fitting installed where:

Lt Analytical tube lengths
L Test data for tube centerline length of 8 inches

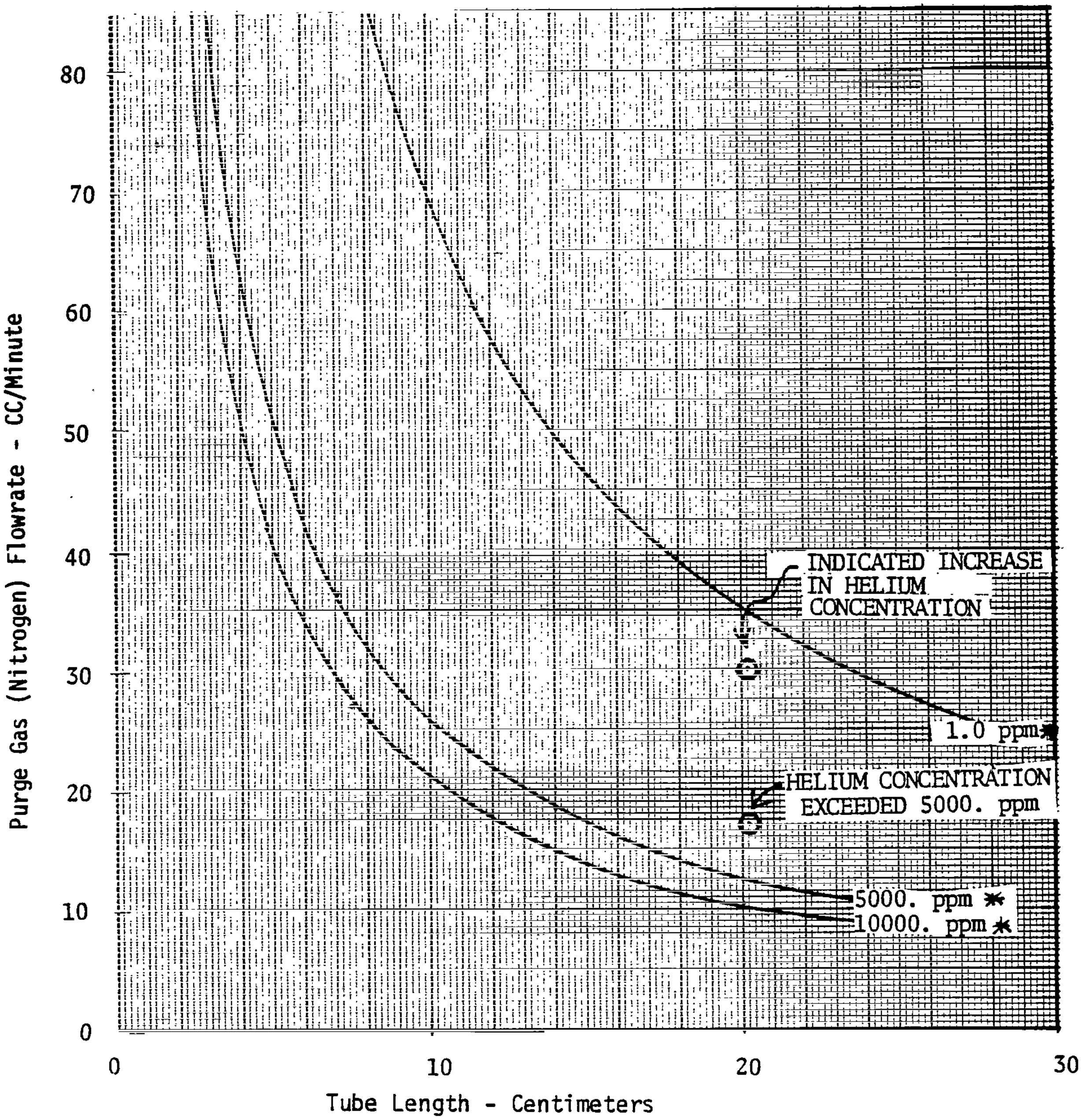


Figure 14

Test results of Dynamic Diffusion Test for bleed fitting configuration where the tube length = 8 inches (20.3 cm)

Analytical Conditions:
- Temperature = 75°F
- Pressure = 1.0 Atmospheres
- Diffusing Media: Helium/Argon

* Lines marked 1.0, 5000., & 10000. PPM indicate analytical purge flow required to maintain He concentration below the indicated value.

Discussion

The test results shown in Figure 10 tend to verify the analytical diffusion model under static conditions. With the probe located so that the tube length, L = 3 inches, the test data corresponded to the analytical length, L = 3 1/2 inches. In the other three cases where L = 7 1/2, 10 1/4, and 21 inches, the data corresponded respectively with analytical lengths of L = 8, 11 1/2, and 23 inches.

In the dynamic tests shown in Figures 11 and 12, the detected helium concentrations remained below the maximum concentration predicted for a given purge gas flow at a particular point in the test tube.

In the static diffusion test with the bleed fitting attached to the test port, the bleed fitting appears to add 2 1/2 inches to the effective length of the tube (see Figure 13). The center line tube length (L) from the face of the fitting to the probe was 8 inches and the test data corresponds to the analytical length of 11 inches. When compared with the results of the other tests (Figure 10), the effective length of the bleed fitting configuration is increased by 2 1/2 inches.

In the dynamic test of the bleed fitting configuration (Figure 14), no increase in helium concentration was detected until the purge gas flow dropped below that flow predicted to maintain the diffusion gas concentration below 1 PPM. However, the helium concentration exceeded 5000 PPM at a gas flow above that predicted to maintain the diffusing gas concentration below 5000 PPM.

It is suspected that the irregular (bending) configuration of the set-up caused turbulence and counter flows in the flow stream which allowed a higher than predicted upstream concentration of helium.

ELECTRICAL ENCLOSURE HYDROGEN INFILTRATION TEST

Objective

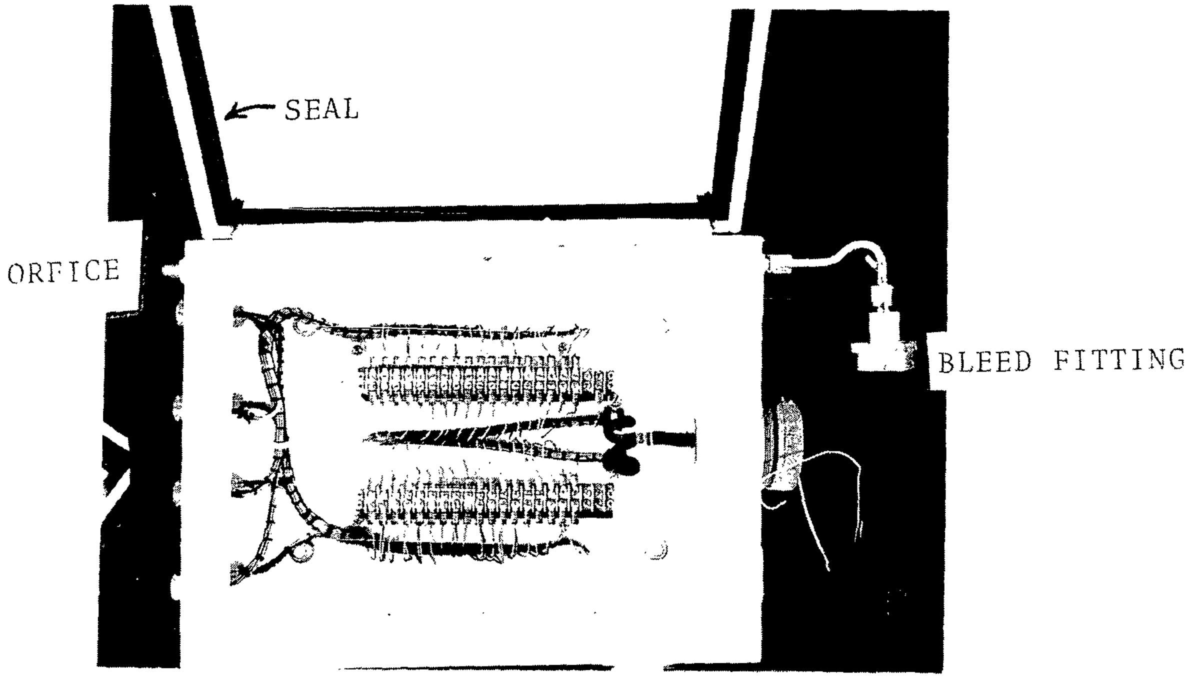
The objective of this series of tests was to determine whether an electrical enclosure under purge is subjected to hydrogen infiltration while surrounded by a hydrogen atmosphere. The Design Technical Instruction for Hazard-proofing and Environmental Protection of Equipment by Purge, DTI-M-23, was used to define the electrical enclosure configuration.

DTI-M-23 requires that hazardproofing purges be maintained at 0.5 to 1.0 scfm through the enclosure, and that a minimum positive pressure of 0.5 inch of water be maintained within the enclosure. These requirements are met by providing an orificed purge gas supply sized to provide the required flow, and providing a purge bleed assembly to vent the purge gas while maintaining the appropriate positive pressure within the enclosure.

Test Configuration

An electrical enclosure, crossover distributor number 9049A12-2 that had been used at LC-39, was obtained for the tests. This enclosure (see Figure 15), which measured approximately 16 inches by 12 inches by 7 inches, was configured to meet the DTI-M-23 flow and vent requirements. A calibrated orifice, 75M0465-2, and calibrated bleed fitting, 75M02048-2, were installed.

A glove box, measuring approximately 30 inches by 18 inches by 18 inches, was used as a container for the hydrogen atmosphere.



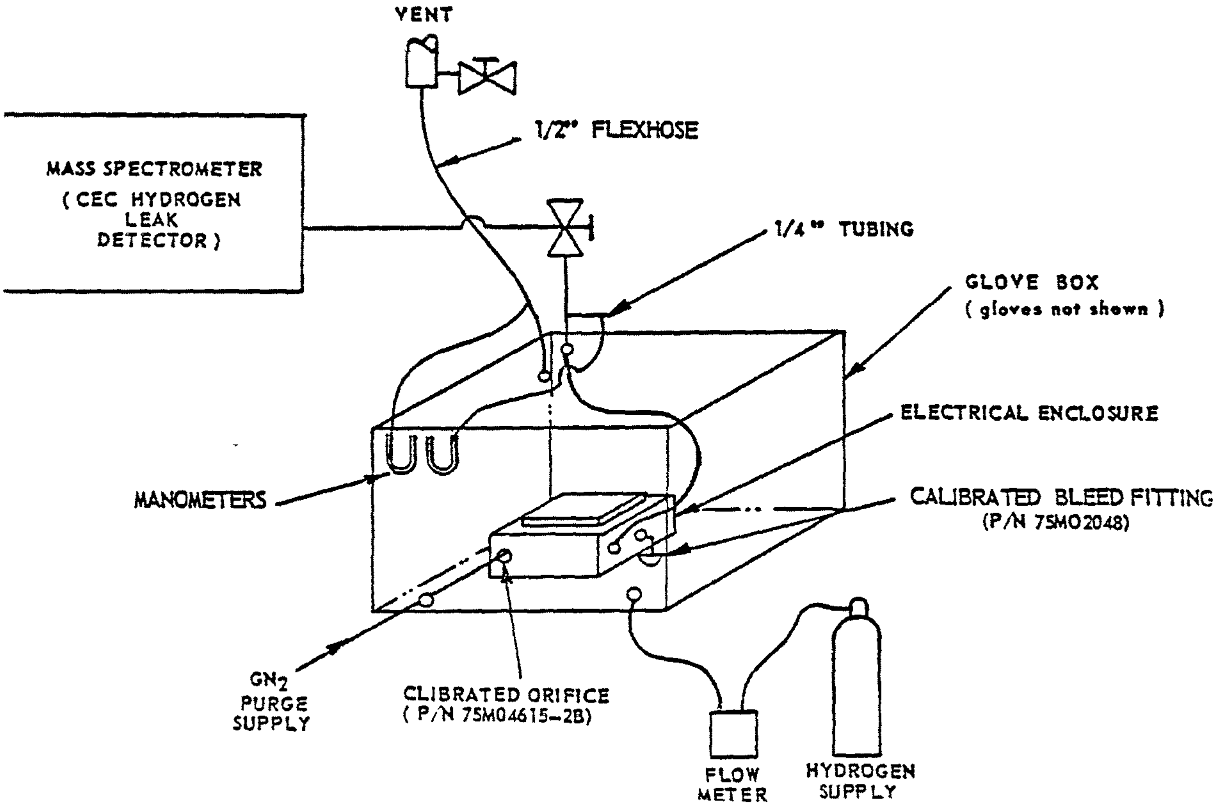


Figure 15

The electrical enclosure,Crossover Distributor Number 9049A12-2, is shown with the calibrated orfice,P/N 75M04615-2B and the bleed fitting,P/N 75M02048-2,installed (top). A schematic drawing of the test system is shown (below).

Calibration tests were made on the purge supply fitting (P/N 75M04615-2B) to determine the upstream pressure required to flow 0.5 scfm GN_2 through the fitting. This pressure was determined to be 28 psig. Normal system pressure in this application is 50 psig, which would flow approximately 0.7 scfm GN_2 through the fitting. Prior to each test, the enclosure cover was adjusted to maintain 0.5 inch of water pressure at 0.5 scfm GN_2.

Sample ports were installed in the enclosure to measure the internal hydrogen concentration. A mass spectrometer was used to measure the concentration of the diffusing hydrogen vapor. The hydrogen concentration within the electrical enclosure was measured with the enclosure in several configurations; gaseous nitrogen was used as the purge medium throughout these tests rather than air due to the hazards involved with air/hydrogen mixtures.

For the first hydrogen infiltration test, the electrical enclosure was placed horizontally in the glove box with the cover facing upward (see Figure 15). A single sample probe was placed in the electrical box, 2 inches below the cover. The purge supply orifice and bleed fitting ports were also located 2 inches below the cover.

The electrical box nitrogen purge was maintained at 0.5 scfm while the hydrogen flow was kept at 1.0 scfm for the 3 1/2 hour test period. The results are shown in Figure 16.

Before the second test, the glove box vent port was moved to the bottom of the box (See Figure 17) and during the test, the glove box hydrogen flow was increased to 1.5 scfm. The results of Test No. 2 are shown in Figure 18.

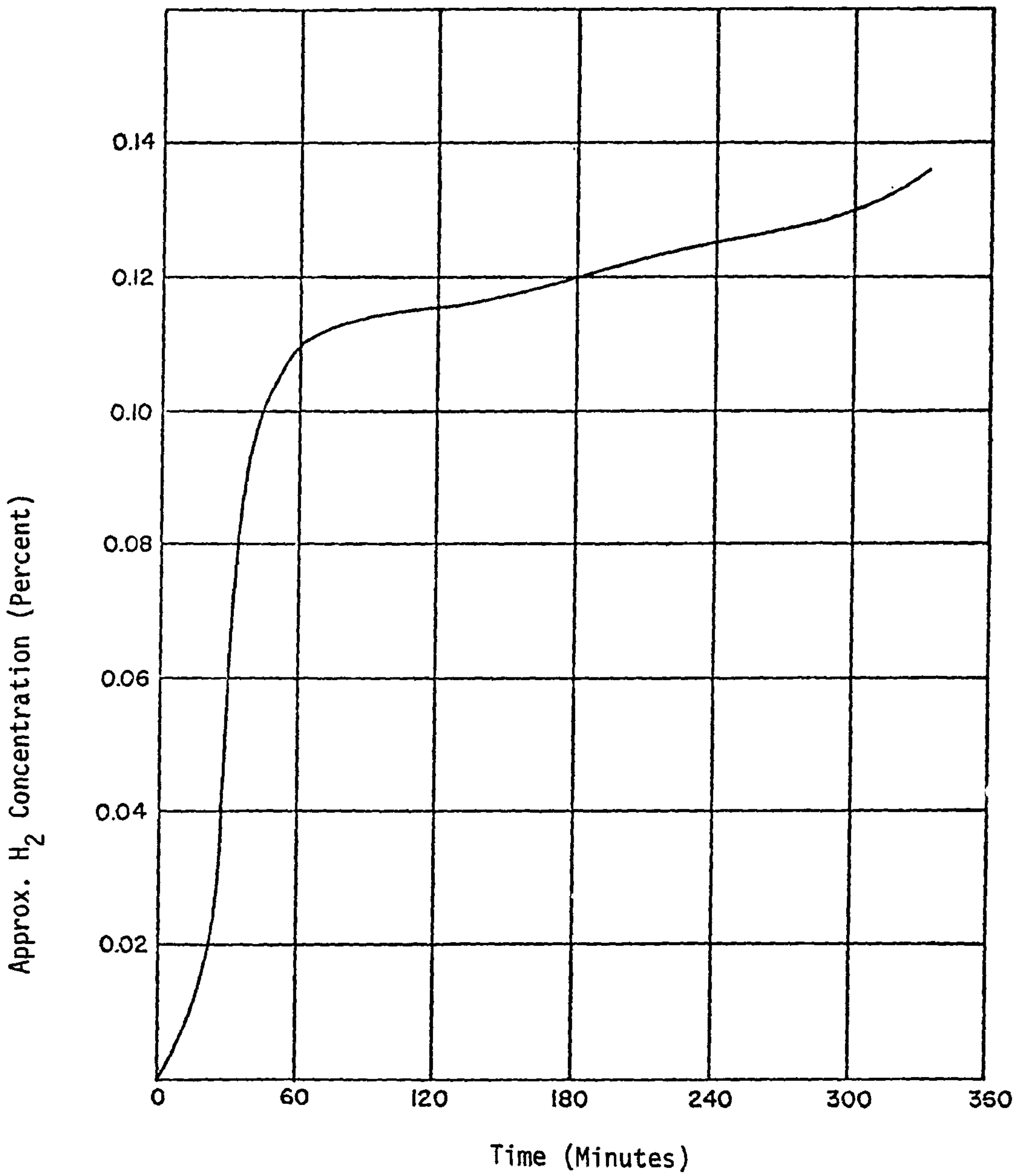


Figure 16

Results of hydrogen infiltration test No. 1

Test Conditions:

Bl. box position: Horizontal
El. box purge flow: 0.5 scfm GN_2 @ 0.6 in. H_2O
Glove box flow: 1.0 scfm H_2 @ 0.1 in. H_2O
Instrumentation: Mass spectrometer

Note: The glove box was vented from the top.

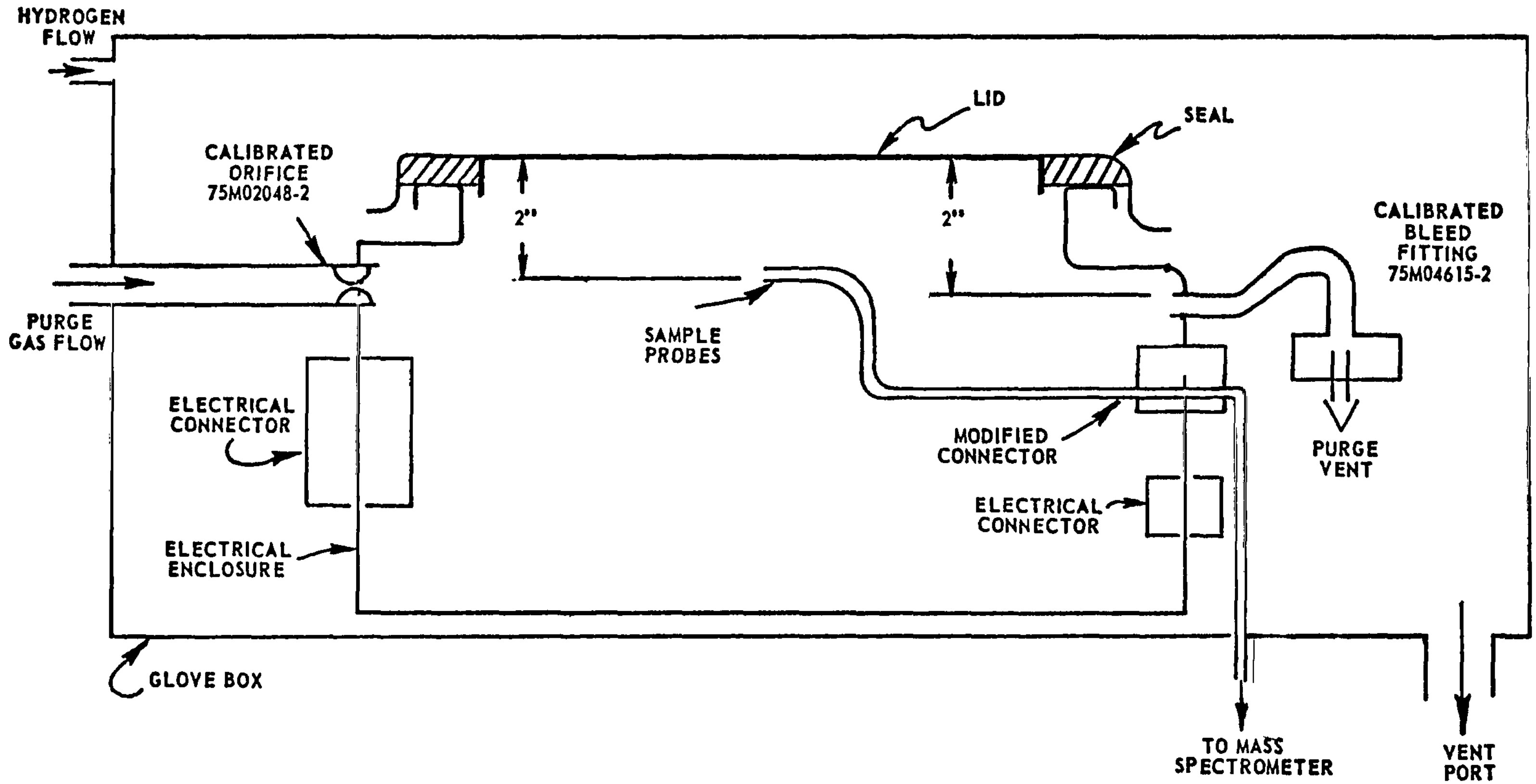


Figure 17

Schematic drawing of hydrogen infiltration test 2 setup.

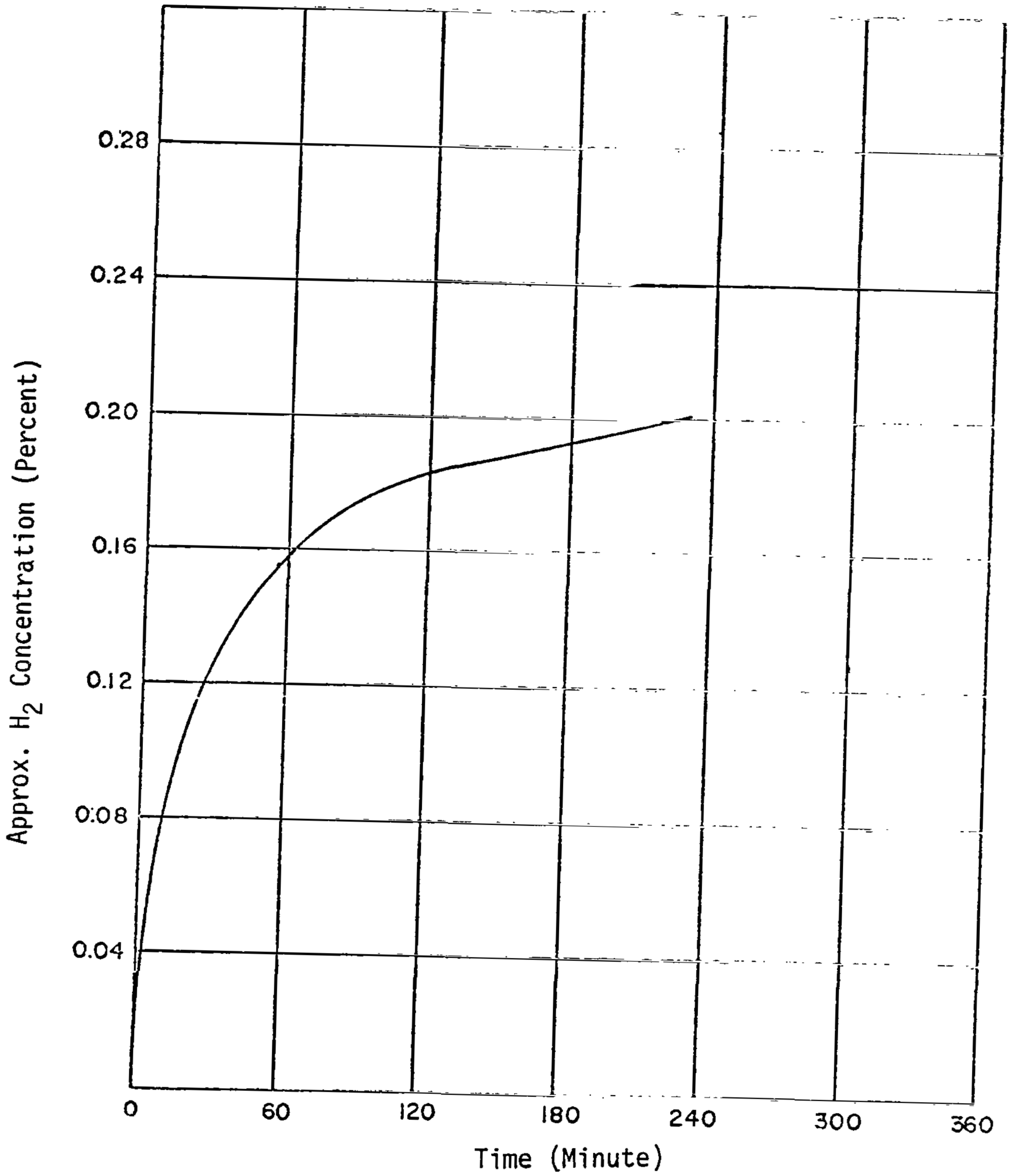


Figure 18

Results of hydrogen infiltration test No. 2

Test Conditions:

Bl. box position: Horizontal
El. box purge flow: 0.5 scfm GN_2 @ 0.6 in. H_2O
Glove box flow: 1.5 scfm H_2 @ 0.1 in. H_2O
Instrumentation: Mass spectrometer

Note:The glove box was vented from the bottom.

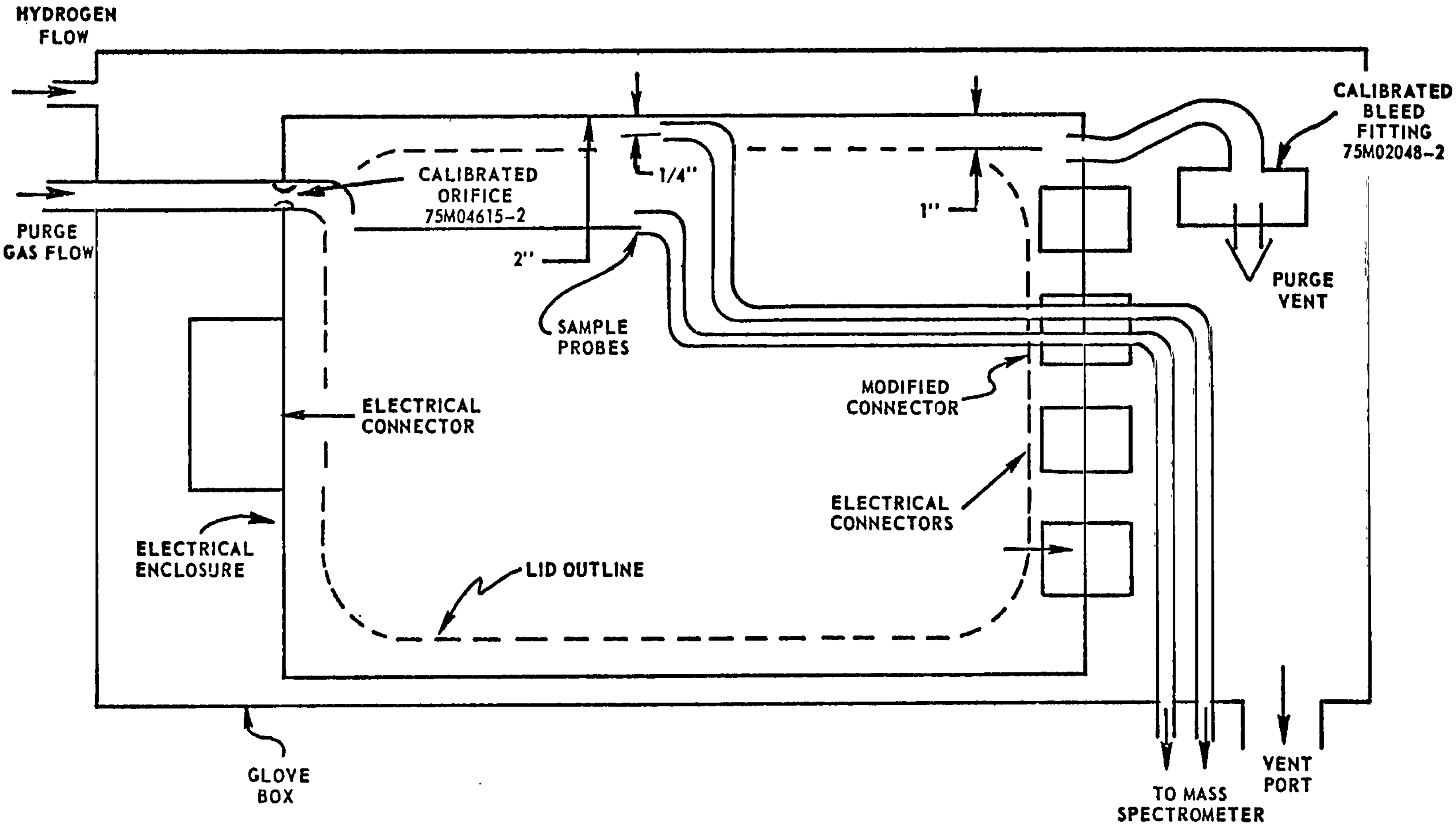


Figure 19

Schematic drawing of hydrogen infiltration Test No. 3 setup.

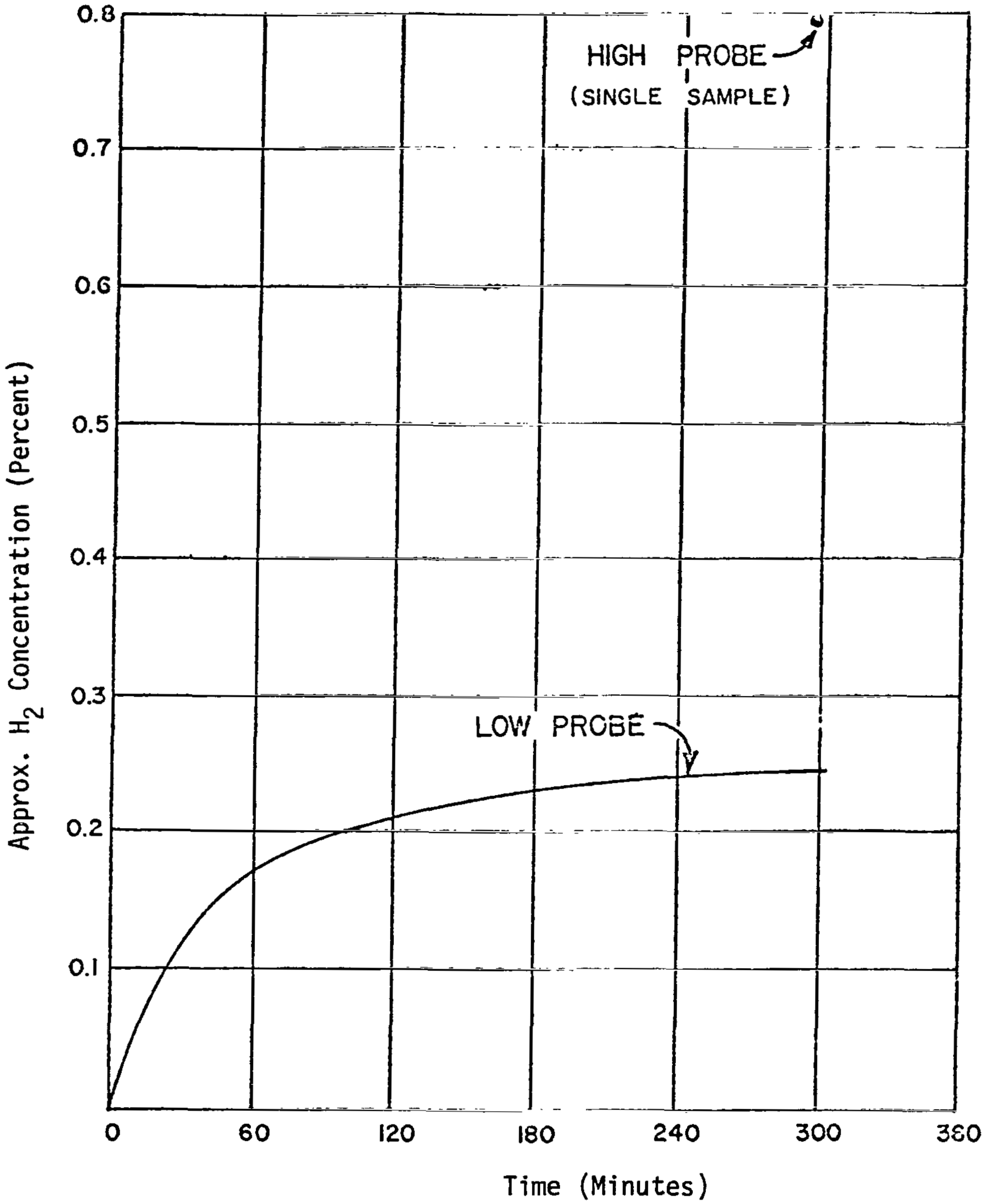


Figure 20

Results of hydrogen infiltration test No. 3

Test Conditions:

Bl. box position: Horizontal
El. box purge flow: 0.5 scfm GN_2 @ 0.6 in. H_2O
Glove box flow: 1.5 scfm H_2 @ 0.1 in. H_2O
Instrumentation: Mass spectrometer

Note:The glove box was vented from the bottom.

The final test was performed after reconfiguring the test set-up. The electrical box was placed in a vertical position with the purge bleed fitting and the vent port located 2 inches from the top of the electrical box and at the opposite end. The low probe was located 2 inches from the top of the box and the high probe approximately 1/2 inch below the top (see Figure 19). The results of Test No. 3 are shown in Figure 20.

Discussion

The infiltration test results show that hydrogen will infiltrate/diffuse into an electrical enclosure which is under purge. After 5 hours of tests, a hydrogen concentration of approximately one percent was obtained at the high point in the electrical box.

The first two tests verified that hydrogen can infiltrate the electrical box, and the third test showed that a higher concentration of hydrogen will accumulate at the high point above the bleed port.

Although the hydrogen concentration within the electrical box did not reach the lower explosive limit (LEL) of hydrogen, 4%, a hazardous condition could still exist. In this series of tests, the purge flow entered the box 2 inches from the top, while the Specification DTI-M-23 shows the purge flow entering the box close to the bottom of the box. In the test configurations, the purge flow probably creates some turbulence at the top of the box which may have lowered the hydrogen concentration in the pocket at the top of the box.

CONCLUSIONS

In the tests, a hydrogen concentration of approximately 1% was obtained at the high point in the electrical enclosure. It is possible that in an operational environment under some unforeseen circumstance, a hydrogen concentration which exceeds the lower explosive limit of 4% could be obtained unless the electrical enclosures are specifically designed to prevent or minimize diffusion into the units.

To prevent the accumulation of hydrogen at the high point in the electrical enclosures, the vent port should be located at the high point to bleed off the hydrogen buildup, or a portion of the purge gas flow should be directed into the high point to create turbulence and prevent the hydrogen pocket from forming.

The diffusion analysis indicates that most of the hydrogen intrusion probably occurred at the points which present short leak paths, such as the door seal.

Nitrogen should be used as the purge gas for the presently installed electrical enclosures. More stringent electrical enclosure design requirements should be imposed before air is used to purge the enclosures in a potentially hazardous (hydrogen) environment.

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APPENDIX

FORMULAE OF DIFFUSION ANALYSIS

The diffusion in this analysis is represented by the equation: (2)

$$C(x,t) = \frac{Co}{2} \operatorname{erfc}\left(\frac{x}{2\sqrt{(Dt)}}\right)$$

Where:

$C(x,t)$ = Concentration of diffusing gas (parts per million, PPM) at any location (x), cm and time (t), seconds.

Co = Initial concentration of diffusing (PPM) gas at all values of $x \leq 0$ and $t = 0$

x = Location in one dimensional system (cm)

t = Time (seconds)

D = Diffusion coefficient (cm^2/sec)

erfc(N) = A standard mathematical function referred to as the error-function compliment which represents the gas distribution probability (Table 1).

Diffusion coefficient (3)

$$D = Do\left(\frac{T}{To}\right)^{M}\left(\frac{Po}{P}\right)$$

Where:

D = Diffusion coefficient @ t, p

T = Temperature (°K)

P = Pressure (ATM)

M = Constant (theoretical)

Do = Diffusion Coefficient @ To, Po

To = 273° K

Po = 1.0 ATM

Minimum purge flow

$$\dot{V} = A \frac{\Delta x}{\Delta t}$$

Where:

$\dot{V}$ = Flow Volume (cc/sec)

A = Flow Area (sq cm)

Δx = Distance of hydrogen diffusion (cm)

TABLE 1

ERROR FUNCTION COMPLEMENT TABLE

$$\operatorname{erfc}(N) = \frac{2}{\sqrt{\pi}} \int_N^{\infty} e^{-t^2} dt = 1 - \frac{2}{\sqrt{\pi}} \int_0^N e^{-t^2} dt = 1 - \operatorname{erf}(N)$$

N	erfc N	2i erfcN	N	erfc N	2i erfcN
0	1.00000	1.1284	1.00	0.15730	0.1005
0.05	0.94363	1.0312	1.1	0.11980	0.0729
0.10	0.88754	0.9396	1.2	0.08969	0.0521
0.15	0.83200	0.8537	1.3	0.06599	0.0366
0.20	0.77730	0.7732	1.4	0.04772	0.0253
0.25	0.72367	0.6982	1.5	0.03390	0.0172
0.30	0.67137	0.6284	1.6	0.02365	0.0115
0.35	0.62062	0.5639	1.7	0.01621	0.0076
0.40	0.57161	0.5043	1.8	0.01091	0.0049
0.45	0.52452	0.4495	1.9	0.00721	0.0031
0.50	0.47950	0.3993	2.0	0.00468	0.0020
0.55	0.43668	0.3535	2.1	0.00298	0.0012
0.60	0.39614	0.3119	2.2	0.00186	0.0007
0.65	0.35797	0.2742	2.3	0.00114	0.0004
0.70	0.32220	0.2402	2.4	0.000689	0.0002
0.75	0.28884	0.2097	2.5	0.000407	0.0001
0.80	0.25790	0.1823	2.6	0.000236	0.0001
0.85	0.22933	0.1580	2.7	0.000134	
0.90	0.20309	0.1364	2.8	0.000075	
0.95	0.17911	0.1173	2.9	0.000041	

The error function and its complement are mathematical functions which are used to describe the probability distribution for diffusion and heat transfer processes (6).

STANDARD TITLE PAGE

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		14. Sponsoring Agency Code

15. Abstract

A program was conducted at the Kennedy Space Center (KSC) to evaluate the problem of hydrogen diffusion into an electrical enclosure under purge. In the past, nitrogen has been used as the purge gas at Launch Complex 39, to minimize the probability of fire and explosions which could erupt from propellant vapor (hydrogen) diffusion into the electrical enclosures. The present study was undertaken to determine the feasibility of substituting a dry air purge for the nitrogen to effect a cost savings.

It was concluded that: (1) Hydrogen concentrations of approximately 1% were obtained in an electrical enclosure under design purge conditions. (2) Hydrogen concentrations exceeding the lower explosive limit, 4%, could probably be obtained within the enclosure under worst case conditions. (3) Most of the hydrogen intrusion into the enclosure probably occurred at the point with the shortest leak path, such as the door seal. (4) More stringent electrical enclosure design requirements should be imposed before air is used as a purge gas.

16. Key Words Diffusion, Hydrogen, Purge, Electrical Enclosure	
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