v used was from +20 to +45 V, ev was very much greater than kT in all cases; therefore, thick sheath electric probe theory applied. In determining these number densities from the bell jar Langmuir probe, at least 12 values of the square of the current at applied bias voltages between +20 and +45 V were fitted with a least square linear relation. This gave a rms deviation, for all points, of less than 2%.

From the results presented in these figures, the computed current agrees within a factor of ~3 with that measured for Kapton H. It is larger by approximately a factor of 4 for that obtained with FEP, and larger by approximately a factor of 10 for the quartz measured current, the magnitude being on the order of microamperes. As previously stated, the current calculated using a Laplace field in the space surrounding the hole yields an upper current limit for a planar probe in a plasma. Therefore, the apparent agreement between theory and experiment for Kapton H is probably due to phenomena not considered in the theory. One phenomenon that may enhance the experimentally measured current is sputtering of the dielectric material. Sputtering produces a gas cloud near the hole. As some of the plasma electrons travel toward the hole, they make ionizing collisions with the gas cloud particles creating more electrons. These ejected electrons along with the original electrons now travel toward the hole, thereby enhancing the measured current. If sputtering is present, the results indicate that Kapton H is sputtered the most, FEP next, and quartz is sputtered the least.

Although the magnitude of the computed current differs from the measured current, the variation of the current with voltage is in agreement with experimental trend. This suggests that the theory may be used to estimate the drainage current at higher voltages than those presented here. However, it is expected that sputtering and other effects may become more severe at higher voltages for some materials.

Conclusions

Parker's method for calculating the current through holes in dielectric covering of probes satisfactorily predicts the trends in experimentally measured current in a dilute plasma for voltages up to 2000 V. A Laplace field was used to numerically predict an upper limit for the drainage current. For holes in quartz and FEP, the theoretical current was larger than the measured current for all valtages presented. For Kapton H the theoretical current and the measured current were approximately in agreement over the full range of voltages presented. Since the computed current is the theoretical maximum current, this agreement suggests that other phenomena may be occurring near the hole enhancing the measured current.

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Helium Absorption into Nitrogen Tetroxide (NTO) and Aerozine-50 (A-50)

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Nomenclature

A = liquid gas interface area, m^2
K_G = mass convection coefficient, moles/hr m^2 atm
$\dot{N}_c$ = mass convection rate of helium into the propellant, moles/hr
$\dot{N},\dot{N}_0$ = mass convection rate (and at $\theta = 0$), moles/hr
P,P_0 = total pressure of the ullage gas (and at $\theta = 0$), atm
P_s = total pressure of the ullage gases when the propellant is saturated with helium, atm
p = partial pressure of helium above the saturated propellant, atm
R = universal gas constant
V = total volume of the ullage gases, m^3
Z = compressibility factor for helium $= P/\rho RT$
δ = partial derivative of
Δ = change of or delta, $\Delta P = P - P_s$
η,η_0 = number of moles of helium gas in the ullage (and at $\theta = 0$)
θ = time, hr

Introduction

THE solubility limits of helium into NTO and A-50 propellants have been identified, but the mechanism describing helium absorption between the limits has not. A simplified, yet unique, analytical technique has been developed and is provided in this note for simulating the absorption phenomena under closed storage conditions. The model developed has been used to evaluate propellant conditions for Apollo missions. A study was initiated to predict Service Propulsion System (SPS) tank pressures because Apollo flight data indicates that ullage pressure decays were a direct result of helium being absorbed into the propellants. The results of this analysis were compared with Apollo 8–12 and 14 flight data and were found to closely agree with the flight data.

Helium Absorption Mechanism

The formulation developed here requires the use of the mass convection analogy, Dalton's law of partial pressures and Henry's law for fluid solubility. This development was initiated by assuming the following. 1) The system was closed; i.e., no flow or leakage exists. 2) All diffusion is normal to the gas/liquid interface. No cross-diffusion or propellant vaporization exists.

$$\dot{N}_c = -K_G A \Delta P \tag{1}$$

mass convection at the interface. 3) The driving force (ΔP) at all times is

$$\Delta P = P - P_s \tag{2}$$

where the saturation pressure (P_s) can be expressed as

$$P_s = p + VP_{\text{propellant}} \tag{3}$$

The concentration (C) of helium in the gas can then be equated to pressure as follows:

$$C = \eta/V = p/(ZRT) \tag{4}$$

For very low absorption rates, the assumptions that the ullage gases are isothermal ($dT = 0$) and that the gas behavior is pseudo-ideal ($dZ = 0$) are justifiable. With these assumptions, the concentration gradient within the ullage can be simply expressed as

$$dC = dp/ZRT \tag{5}$$

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so that for a closed system

$$\delta C/\delta\theta = (1/ZRT)\,\delta p/\delta\theta = (1/ZRT)\,\delta P/\delta\theta \qquad (6)$$

Combination of Eqs. (1) and (6) results in the following:

$$\delta P/\delta\theta = -K_G ZART(P-P_s)/V \qquad (7)$$

which will now be integrated assuming either constant or nonconstant ullage volume.

Case 1. Assume that the ullage volume and the propellant volume are constant, then

$$\delta P/(P-P_s) = (-K_G ZART/V)\,\delta\theta \qquad (8)$$

integrating from $P=P_0$ to P and $\theta=0$ to θ provides the following result:

$$(P-P_s)/(P_0-P_s) = \exp(-K_G ZART/V)\theta \qquad (9)$$

Case 2. The propellant and ullage volumes are not held constant for this case but are allowed to change in accordance with the ideal gas law for the residual ullage gases

$$V = Z\eta RT/P$$

Assuming that a constant convection rate $\dot{N}$ exists, the residual ullage gas can be determined as $\eta = \eta_0 - \dot{N}\theta$. Substitution for V in Eq. (7) and rearrangement results in the following:

$$\delta P/[P(P-P_s)] = -K_G A\delta\theta/\dot{N}(\eta_0/\dot{N}-\theta) \qquad (10)$$

Integrating over the same limits gives

$$[P(P_0-P_s)]/[P_0(P-P_s)] = (1-\dot{N}\theta/\eta_0)^{-K_G A P_s/\dot{N}} \qquad (11)$$

A comparison of Eqs. (9) and (11) was made by calculating a typical pressure decay with each equation and comparing the results. The results showed a difference of less than 0.4%, indicating that the constant volume assumption is adequate. In addition, it may be deduced from this comparison that the helium absorption process occurs with little change in the ullage and propellant volumes.

White Sands Test Facility (WSTF) data; was used to calculate a mass transfer coefficient (K_G) for A-50 and NTO absorption. The calculated K_G values varied from 3.18×10^{-5} to 3.35×10^{-5} moles/hr m^2 atm. Consequently, an average K_G value of 3.27×10^{-5} was used for both propellants in conducting this study and was also employed in the resulting computer program.

Use of the technique for describing the helium absorption mechanism shown in this note was made in developing a helium absorption computer program.[2] The use of this program has helped to better understand propellant tank pressure behavior during Apollo missions. Figures 1 and 2 show a comparison of the average Apollo mission tank pressures and the corresponding program predictions. The program has also been used for multiple burn missions.

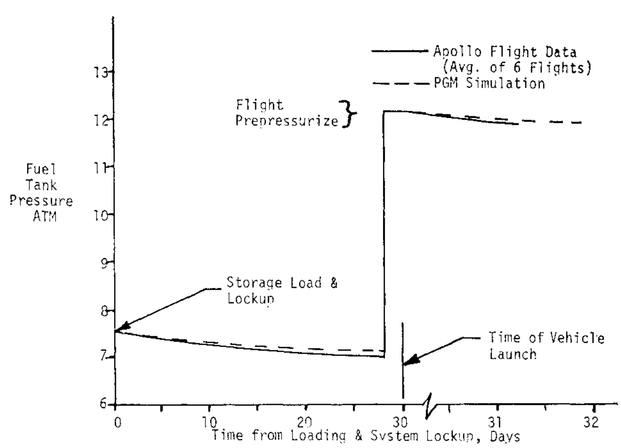

Fig. 1 Apollo fuel tank pressure history.

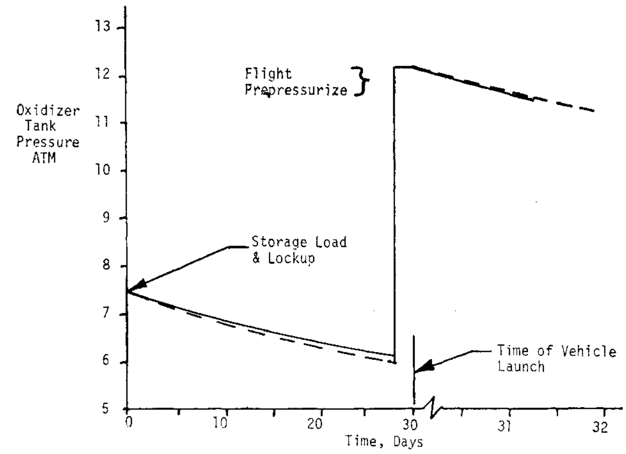

Fig. 2 Apollo oxidizer tank history.

Conclusions

1) Volume changes for the ullage or the propellant are negligible during the helium absorption process. 2) The rate of helium absorption into NTO and A-50 can be adequately simulated as

$$\dot{N}_c = 3{\cdot}27 \cdot 10^{-5}\,(P-P_s)A, \text{ moles/hr}$$

3) The pressure decay of A-50 and/or NTO propellant tanks pressurized with helium can be adequately predicted with Eq. (9)

$$(P-P_s)/(P_0-P_s) = \exp(-K_G ART/V)\theta \qquad (9)$$

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An Approximation to Midcourse Correction Direction Errors

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In the statistical analysis of midcourse execution errors, the covariance of $(\bar{v}/v)$, where $\bar{v}$ is the three-dimensional midcourse velocity vector and v is its magnitude, must be determined.[1] This covariance occurs for cases of errors dependent on the direction of the correction velocity vector but independent of its magnitude. The covariance matrix may be determined accurately by numerical integration and in most cases mission analysts resort to this technique. Schmidt[2] gives an exact procedure requiring diagonalization of Cov($\bar{v}$)

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