It is interesting to note that the effective sky temperatures were found to increase only slightly with increasing plate inclination. The effect of surface temperature on the effective sky temperature is shown for the JPL atmospheric model. The Viking Project atmospheres were published for only a single surface temperature.

The normal variations in altitude and temperature that a Martian lander would expect to encounter would have a greater effect on the effective sky temperature than the effect of vehicle surface inclinations.

References

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[2] Schmitz, R. A. and Soffen, G. A., "Viking 75 Project Mars Engineering Model," M75-125-0, March 13, 1970, Viking Project Office, NASA.

[3] Jet Propulsion Laboratory Lunar and Planetary Sciences Section Staff, "Mars Scientific Model," JPL Document 606-1, Vol. 1, July 1968, Jet Propulsion Lab., Pasadena, Calif., Sec. 5.1, pp. 1–13, Sec. 5.2, pp. 1–11, Sec. 5.3, pp. 1–22.

Ignition of Metal Powders in Gaseous ClF_3

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IN Ref. 1, data were presented on the hypergolic ignition of metals in gaseous and liquid ClF_3 and ClF_5, in respect to their use as spacecraft chemical heaters. Since ClF_3 has also been proposed for use in the primary combustors of air-augmented rockets, the hypergolicity of gaseous ClF_3 with several additional metal powders has now been investigated. Preliminary tests were performed by passing gaseous ClF_3 over the metal powders contained in a small porcelain crucible at ambient conditions. The materials of most interest were tested for spontaneous ignition on a surface mixing burner (Fig. 1). The metal powders were entrained in a stream of N_2 gas in the mixing chamber A of the powder-dispersing device B of an S. S. White abrasive cutting machine. The suspended material was then transported into the center tube of the burner D. The ClF_3 was introduced through the bundle of tubes surrounding the center tube and mixed rapidly with the dust cloud at the surface of the burner. The tubes were $\frac{1}{8}$-in.-o.d. stainless steel, and the body of the burner was 1-in. i.d. Dust concentrations up to 300 mg/l of N_2 were attainable, and the normal procedure was to vary the concentration from zero to the maximum.

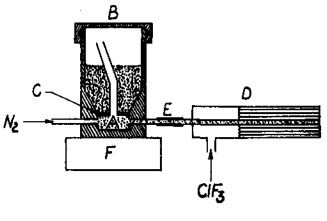

Fig. 1 Surface mixing burner apparatus: A, mixing chamber; B, powder dispersing unit; C, orifice plate; D, surface mixing burner; E, "Tygon" tubing; and F, vibrating table.

Table 1 Ignition of materials with gaseous ClF_3 (crucible tests)

Material	Ignition	Comments
Cabot carbon black, Sterling MTX	Yes	Glowed, no vigorous burning
Acheson graphite (Dag Ultrafine, 4–5 μ)	Yes	
Valley Metallurgical H-30 Al[a] (30 μ)	No	
Valley Metallurgical H-5 Al[a] (5 μ)	No	
Kawecki boron, Grade I, Lot 362 × 18, neutralized (2–4 μ)	Yes	
Boron carbide, Fisher Cat. B-377	Yes	
Magnesium, 44 μ	Yes	Vigorous, self-sustaining flame
Nickel, 200 mesh, C B 528, 311187, The Matheson Co., Inc.	No	
Zinc dust, Merck 41598, 90% Zn	Yes	Bright flash
Molybdenum, lot MO-1501, grade 150–250, Sylvania Electric Products Inc.	Yes	
Iron filings	Yes	Very reactive
Steel wool, Federal Grade O	Yes	Very reactive
Tungsten, 2 μ	Yes	
Zirconium hydride	No	
Zirconium, 5 μ	Yes	Self-sustaining flame

[a] The hypergolic ignition of aluminum reported in Ref. 1 could be accounted for by the presence of small amounts of a reactive impurity, such as moisture or a hydrocarbon, or by an experimental configuration which more effectively reduced heat loss.

Results and Discussion

The results of the simple crucible tests presented in Table 1 are self-explanatory. The surface mixing burner experiments are summarized in Table 2. The B and B_4C powders ignited spontaneously very close to the surface of the burner at all dust concentrations investigated and burned with a steady flame. The Al powder ignited intermittently 1 or 2 in. from the burner surface, but a steady flame could not be established. Graphite showed no evidence of reaction, even though it ignited in the crucible tests (Table 1); apparently the reaction is very slow, and heat losses in the burner experiments preclude ignition. At low dust concentrations the B/Al mixture behaved as if the B and Al were burning independently; i.e., the boron flame was readily established, but the aluminum ignited intermittently. At higher dust concentrations, the heat released by the combustion of the boron was sufficient to promote rapid ignition of the aluminum, and a steady, very bright flame resulted.

These results indicate that B, B_4C, and B/Al mixtures should ignite spontaneously with ClF_3 in the primary combustors of air-augmented rockets even when introduced as the

Table 2 Ignition of powdered materials with gaseous chlorine trifluoride (surface-mixing burner tests)

Material	Ignition	Comments
Amorphous boron, Kawecki Grade I, 4–5 μ diam	Yes	Stable flame established
Boron carbide, Norton Grade 6 (0.2 μ diam)	Yes	Stable flame established
Spherical aluminum Valley Metallurgical H-5 (5 μ diam)	Yes	Intermittent combustion
Graphite, Acheson "Dag Ultrafine" (4–5 μ diam)	No	No evidence of reaction
60 wt % Kawecki boron/40 wt % Valley Metallurgical Al H-5 (5 μ diam)	Yes	Stable flame at high dust concentrations (see text)

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pure metal powders. The ignition of graphite (carbon) will probably depend on the presence of other fuel components. Aluminum may be hypergolic with ClF_3 under some conditions.

Reference

[1] Rhein, R. A., "Ignition of Metals With ClF_3 and ClF_5 for use as Spacecraft Chemical Heaters," *Journal of Spacecraft and Rockets*, Vol. 6, No. 11, Nov. 1969, pp. 1328–1329.

Phase Change Solidification Dynamics

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Nomenclature

C_p = specific heat
h = total height of n-hexadecane in test cell
h_a = dimensionless spatial increment = Δz
H_f = heat of fusion, cal/g or Btu/lb
K = thermal conductivity
k_a = dimensionless time increment = $\Delta\tau_o = \Delta\tau$
N = total number of spatial nodes
p = k_a/h_a^2
R = number of completely solidified space nodes
S = dimensionless height of solid phase formed
T, T_a = temperature and ambient temperature, respectively
T_e = equilibrium temperature of solidification
t = time, sec or min
t^* = time interval from start of cooling to the start of solidification at the bottom plate
x_j = fraction of partly-solidified node that is solid, by the jth time step
Y = height of solid phase formed, cm or in.
y = spatial coordinate
z = dimensionless spatial coordinate
α = thermal diffusivity
λ = dimensionless constant = α_S/α_L
ρ = density, g/cm³ or lb/ft³
τ_0, τ = dimensionless times, presolidification and solidification
$\tau_0{}^*$ = dimensionless time corresponding to t^*
θ = dimensionless temperature

Subscripts

i,j = finite spatial and time increments, respectively
Lo = presolidification problem (liquid)
L,S = liquid and solid phases

Introduction

CANDIDATE phase-change materials for thermal control systems for spacecraft should have equilibrium melting temperatures that are close to the acceptable range for the design media for electronic equipment, 40°F–150°F, with heats of fusion ≥ 100 Btu/lbm, and they should be noncorrosive, nontoxic, chemically inert and stable, with low vapor pressures, small volume changes, and negligible subcooling. Normal (long-chain) paraffins with even numbers of carbon atoms are most widely considered.

Carslaw and Jaeger[1] pointed out the basic nonlinear nature of phase-change problems. A survey of phase-change problems and the experimental study of different test cells are presented in Ref. 2. Bannister[3] emphasized the need to study nucleation theory as a basis for the study of subcooling phenomena in solidification problems. An approximate one-dimensional mathematical model, neglecting the effects of convection was presented by Pujado, Stermole, and Golden.[4] Ehrlich[5] gave the implicit finite-difference equations for the one-dimensional melting problem with a variable heat flux or heat input specified as a function of time. Grozka[6] included the effects of gravity, magnetic and electric fields, and convective currents; she pointed out that the pure-conduction problem with phase change is valid so long as the liquid phase remains stable, and that natural convection must be considered after the Rayleigh number reaches 1720 for a layer of fluid either heated from below or cooled from above. Many other papers are reviewed in a survey by Muehlbauer and Sunderland.[7] This Note is based on Ref. 8, in which implicit finite-difference equations were obtained for the one-dimensional model of the solidification of n-hexadecane and were put into tridiagonal matrix forms and solved by Gauss elimination and back substitution.

Theoretical Analysis

The problem to be studied is the solidification of n-hexadecane in a cell of height h (between plates) and constant cross-sectional area in the plane perpendicular to the axis, y of the cell (Fig. 1). The temperature profile and the rate of solidification are to be determined using a one-dimensional model along the y axis and assuming that unsteady state conditions obtain. The effects of convection are assumed to be negligible, because mixing that occurs when solidification takes place is minimized by having the cell cooled from the bottom, so that the solid formed at the bottom of the cell remains there, and ρ_S and ρ_L are nearly equal for n-hexadecane between 262°K and 310°K, so that the net velocity of the interface between the solid and the liquid phases is near zero. It is further assumed that the cell and its content are at ambient temperature T_a initially,

$$T_{Lo}(y,0) = T_a \text{ at } t = 0 \text{ for } 0 \leq y \leq h \tag{1}$$

and the temperatures of the inside faces of the bottom and the top plates of the cell are functions, $f_1(t)$ and $f_2(t)$, of time, respectively:

$$T_{Lo}(0,t) = f_1(t) \text{ at } y = 0 \tag{2}$$

$$T_{Lo}(h,t) = f_2(t) \text{ at } y = h \tag{3}$$

With these definitions, knowledge of the temperature profiles of the inside faces of the two plates, say by polynomial fits of

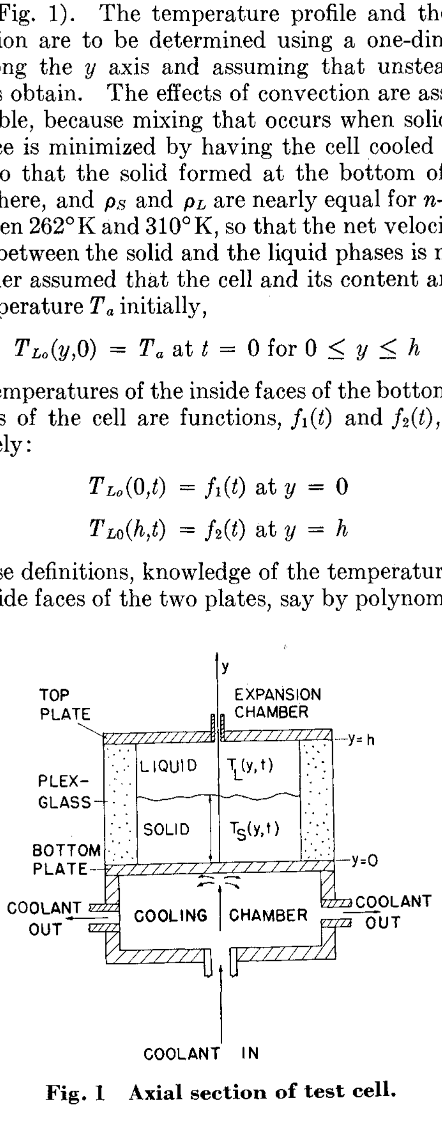

Fig. 1 Axial section of test cell.

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