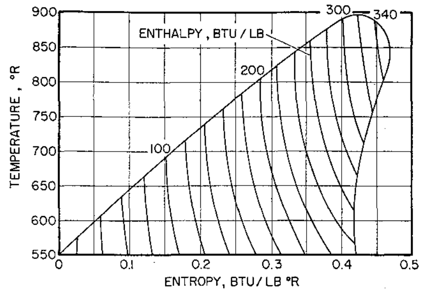

Fig. 14 Thermodynamic properties of pentaborane.

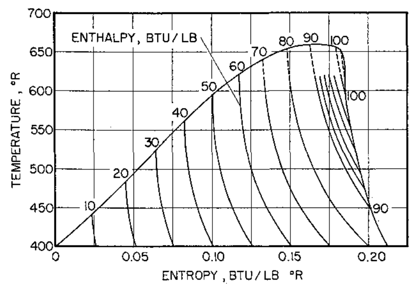

Fig. 15 Thermodynamic properties of perchloryl fluoride.

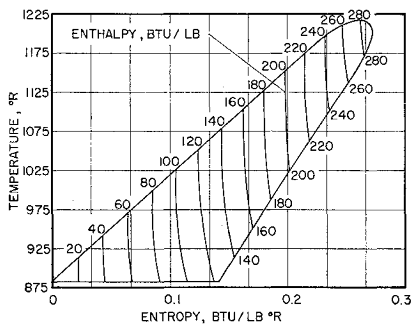

Fig. 16 Thermodynamic properties of RP-1 (H/C = 2.0).

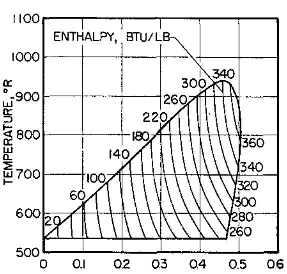

Fig. 17 Thermodynamic properties of unsymmetrical dimethylhydrazine.

This makes it possible to compute vapor entropies, and thus the temperature-entropy diagram can be constructed if liquid specific heat and heat of vaporization data are available.

The temperature-entropy diagrams computed by this method for oxygen and *n*-butane are compared with those given in the literature (Figs. 4 and 5).

The temperature-entropy diagrams of 12 liquid propellants were computed by this method and are given in Figs. 6–17.[2,3]

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Design of a High Enthalpy, Radio Frequency, Gas Discharge Volume

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A design of a highly water-cooled copper-walled discharge volume that allows radio frequency generation of high enthalpy, dense plasmas is described. It is noted that this design allows steady generation of plasmas of substantially higher enthalpy level than have previously been able to be obtained with a quartz-walled discharge volume, either cooled or uncooled.

CURRENTLY, most steady, thermal plasmas are generated by electric arc discharges. The major problems associated with this method of gas heating are well known: 1) plasma contamination with eroded electrode material; 2) limited selection of gases that may be heated due to chemical erosion of electrode surfaces; and 3) spatially nonuniform heating process.

Recently, work has begun at a few laboratories[1,2] in the United States on induction heating of plasmas. Briefly, induction heating of plasmas is based on the principle that eddy currents may be induced in an electrical conductor from an external, oscillatory circuit. These induced currents meet resistance to their flow, and joule heating of the conductor occurs. Normally a gas is a very good electrical insulator. However, upon application of a spark or introduction of a source of secondary electrons, the insulating properties of the gas begin to break down, and it becomes a fairly good electrical conductor. The electromagnetic energy being carried in an external oscillatory circuit may then couple to the small volume of conducting gas and enlarge it. Provided that the discharge is properly stabilized with respect to power level and aerodynamic cooling, a steady state discharge of high-power level will occur. This method of gas heating shows substantial promise of alleviating many of the problems associated with electric arc heating of gases.

Most of the current work in the ratio frequency heating of gases has used a quartz walled discharge volume, either with or without water cooling, to contain the heated gas. Quartz is a very good dielectric with a very low loss factor; however, its melting point and mechanical strength severely limit the enthalpy level that may be obtained in the heated gas. It has been found[1–3] that an argon plasma having an enthalpy of about 50 kcal/g-mole is about the maximum that may be generated in a quartz discharge volume before melting occurs. Adequate water cooling of the quartz is limited by its thermal conductivity and mechanical strength. Thus, it appears that a quartz wall is not feasible for containing the higher enthalpy plasmas required in hyperthermal wind tunnels, MHD power generators, electrical propulsion, and first stages of controlled fusion processes.

A novel solution to this problem is the highly water-cooled copper wall that has found extensive application in electric arc gas heaters. A highly water-cooled copper wall with its high thermal conductivity and good mechanical strength has been found to be able to contain plasmas having enthalpy levels of hundreds of kcal/g-mole. However, for rf heating of gases, the copper wall must contain a slit so as not to shield the gas, i.e., the slit prevents closed current loops from occurring in the water jacket wall which tend to dissipate all the incident electromagnetic power.

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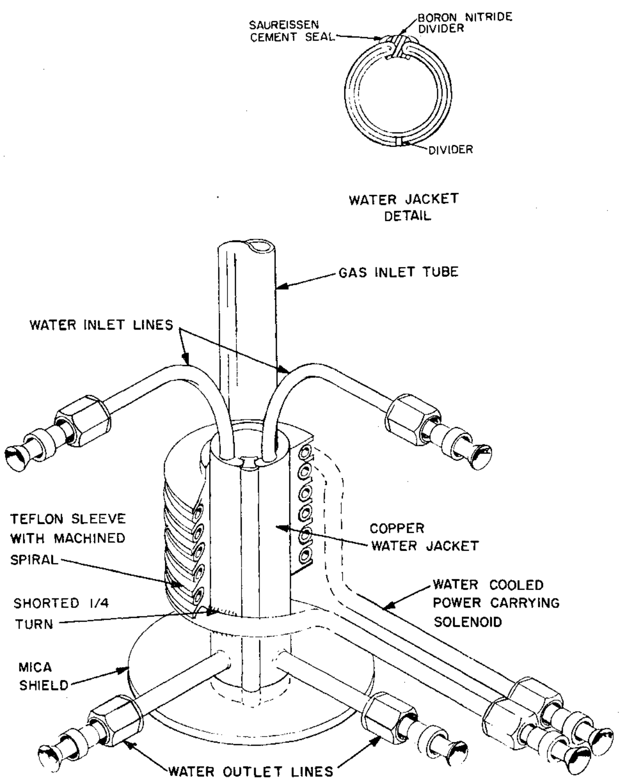

Fig. 1 Schematic of rf gas discharge volume.

Figure 1 shows a design of a water-cooled copper discharge volume. The jacket is formed from a single piece of copper sheet (0.035 in.) and contains a divider opposite the slit; thus, each half of the jacket is separately cooled. All joints are silver soldered for low electrical resistance and for high strength. Cooling water at about 500 psi is pumped through the water jacket in order to insure adequate cooling of the copper wall; the annular cooling passage gap is about 0.035 in. The first turn of the copper solenoid ($\frac{3}{16}$-in. tubing) is shorted to the jacket's outer wall, and the remainder of the turns are embedded in a Teflon sleeve containing a $\frac{3}{16}$-in. machined spiral in its outside surface; the Teflon prevents arcing between adjacent coils and between the coil and the jacket walls. The slit in the water jacket is sealed with boron nitride, a high temperature electrical insulator, which is carefully machined to fit the slit. The boron nitride separator is made gas tight by sealing both outer edges which are in contact with the cold outer jacket wall with high temperature Sauereisen cement. The mica disk on the bottom of the jacket shields the Teflon sleeve from any free convective flow of heated gas.

The gas is injected with a tangential component of motion through three critical flow orifices into the discharge volume. The tangential injection provides a swirling motion to the heated gas which tends to stabilize the discharge; the critical flow condition allows simple metering of the gas mass flow rate by measuring only the injection manifold pressure. The gas injection assembly is separated from the discharge volume by about 10 in. of connecting glass tube. This separation is necessary in order that the gas injection assembly does not act as an electrode causing an "E" type discharge and thereby absorbing some of the incident power.

Figure 2 shows the copper water-jacketed discharge volume in operation. An argon plasma having an enthalpy of about 100 kcal/gm-mole is being generated which discharges to atmospheric pressure. The enthalpy at atmospheric pressure corresponds to an equilibrium gas temperature of about 12,000°K. This water jacket design has been operated at this enthalpy level for times of an hour with no noticeable wall erosion.

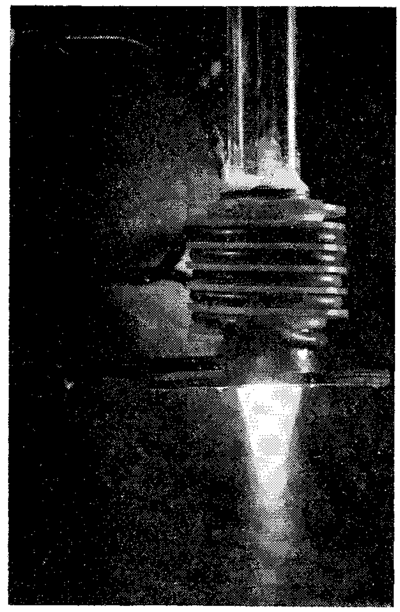

Fig. 2 Argon plasma, 100 kcal/g-mole at 1 atm.

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Coning Effects Caused by Separation of Spin-Stabilized Stages

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Nomenclature

I_L = longitudinal moment of inertia of body
I_T = transverse moment of inertia of body
$\bar{M}$ = total momentum vector
M_L = longitudinal momentum
M_T = transverse momentum
m = mass of body
μ = reduced mass of configuration = $m_1m_2/(m_1 + m_2)$
l = separation between center of masses of body 1 and body 2 prior to separation
ω_L = longitudinal angular speed
ω_T = transverse angular speed
θ = coning angle = $\tan^{-1}(M_T/M_L)$

Subscripts

1 = body 1, payload
2 = body 2, booster

For spin-stabilized booster-payload configurations that are coning, it has been observed that the coning angle of the payload after separation is appreciably different from that of the combination. At first, it seems logical to blame the separation mechanism for introducing a tip-off condition. However, it is physically possible for the coning angle to change even with a perfect separation mechanism. As shown

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