modified and used. The basic assumptions of the Talbot theory are that completely frozen flow exists throughout the boundary layer and that ambipolar diffusion exists outside of the sheath. The validity of both assumptions are discussed by Talbot.[7] Talbot did not take into account the presence of negative ions. However, when the presence of negative ions is included, the basic analysis remains virtually unchanged.

Apparatus and Experimental Procedure

A plasma torch was used to generate a 3-in.-diam subsonic stream of argon plasma, exhausting into a water cooled vacuum tank which is 3 ft diam and 4 ft long. The tank was evacuated by a mechanical vacuum pump. A gate valve was placed between the pump and the tank to regulate the tank pressure. The electrostatic probe was housed in a $\frac{3}{4}$ in. outside diam copper tubing and was water cooled. The collecting electrode was steel, 0.060 in. diam and was insulated from the remainder of the probe by a glass insulator. The probe was shaped like a flat ended cylinder and the collecting electrode was located at the center of the flat end. During the experiments, the probe was placed in the center of the plasma stream with the flat end perpendicular to the flow direction.

A mixture of UF_6 and argon was injected into the plasma stream through two $\frac{1}{32}$-in.-o.d. stainless steel tubes placed at the nozzle exit perpendicular to the plasma flow. The UF_6 feed rate was controlled by valves between the UF_6 feed tank and the tubes. The argon flow rate and the torch current were set to predetermined values to produce desired plasma enthalpies. Before each run, argon was added to a UF_6 feed vessel to pressurize the vessel to 15 psia. The UF_6 feed rate were calculated using the recorded rate of pressure drop in the feed tank during each run and the concentration of UF_6 in the feed mixture.

Results and Discussions

The current-voltage characteristics of the electrostatic probe were obtained at static pressures of 15 and 30 torr and enthalpies up to 1.5×10^3 cal/g for the argon plasma with and without the addition of UF_6. For each set of experimental conditions, the ion temperature of the plasma was evaluated from the probe characteristics independently. The results were within 5% of each other. The typical probe characteristics given in Fig. 1 demonstrate that a small addition of UF_6 suppresses the electron saturation current by more than a factor of 100. The reduction in electron number density as a function of the ratio of UF_6 concentration to free electron concentration prior to UF_6 addition is shown in Fig. 2. It is seen that the addition of UF_6 in a number density equal to the free electron number density prior to UF_6 addition reduces the electron concentration by as much as 98%. Further reductions in electron concentration require much larger additions of UF_6.

During some experimental runs, a deterioration of the probe collecting electrode was detected. This deterioration was traced to the dissociation of some of the UF_6 molecules, resulting in chemically reactive products. These products react with the collecting electrode and cover the electrode with a resistive film. By lowering the effective collecting area of the probe, the resistive film led to erroneous number density results. In general, this deterioration is important only when the probe is strongly positively biased and the plasma enthalpy and the UF_6 feed rate are both high. Under these conditions, a large negative ion current (on the order of 50 ma) reaches the collecting electrode and the probe deteriorate rapidly after a relatively short period (on the order of 10 sec). To insure that the coating action does not significantly influence the probe characteristics, the probe traces were taken rapidly, the positive voltage ranges were swept in less than $\frac{1}{2}$ sec. For cases where some coating action were suspected, several traces were taken consecutively and compared with one another so as to ascertain that no significant deterioration of the collecting electrode had taken place during a given run.

The experimental data obtained in the present investigation show that uranium hexafluoride is electrophilic. In view of this finding, the use of uranium hexafluoride as the nuclear fuel in the gas core reactor–MHD generator system is probably impractical. In particular, the electron attachment and the possible subsequent detachment are known to depend on the electron energy as well as the pressure and the temperature of the plasma. Further experiments at temperatures and pressures appropriate to the gaseous nuclear core as well as to the MHD generator would be useful.

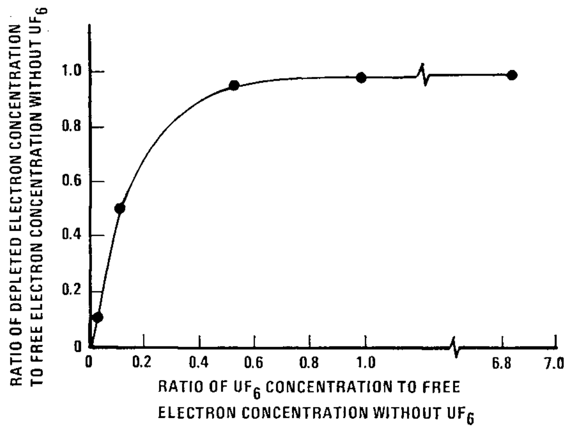

Fig. 2 Effectiveness of UF_6 as an electrophilic compound.

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Detection of Crystals in CO_2 Jet Plumes

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APPLICATION of jet systems for attitude control and propulsion of spacecraft is the primary reason for investigation of freejets exhausting into vacuum. Since the jet

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plume field practically always contains a surface at which the gas state crosses the saturation line, the question arises as to what degree phase transition by means of homogeneous nucleation actually will occur. In the case of nucleation, clusters can be produced; among other quantities (such as number density and surface energy), the knowledge of their phase and size is necessary to determine the amount of energy transferred to the gas. Other applications requiring a detailed understanding of the production mechanism and physical properties of the clusters are contamination and electrical propulsion studies.

Probably the only method to determine the phase of clusters is by means of electron diffraction.[1] The average size can also be determined by this method from the half widths of the peaks if the clusters are solid and their radii are smaller than about 100Å. In the following, a simple experiment using electron diffraction techniques will be described which has the advantages (as compared to mass spectrometric methods) of being less expensive and not requiring skimmers and additional pumping stations. In addition, the measurement is made at the point in the flow where the electron beam interferes with the clusters.

Carbon dioxide was expanded through a model nozzle (throat diam $d^* = 0.056$ cm, half angle 11°, and exit to throat area $D^2/d^{*2} = 40$) into a vacuum of approximately 10^{-4} torr. As shown in Fig. 1, an electron beam crossed the jet axis, and a detector consisting of two slits and a Faraday cage could be rotated around an axis perpendicular to the beam axis. Both slits had a width of 0.063 mm, and the angular resolution of the detector was $0.65 \cdot 10^{-3}$ rad. The electron beam of 30 kv was produced by a Fernfokus-type gun which is especially suited for producing a beam of small divergence. No additional focusing was used. The instrument width was determined by measuring the half width of the beam signal in high vacuum.

A typical Debye-Scherrer pattern, as detected by the described apparatus, is shown in Fig. 1 where five superimposed peaks are clearly identified on the gas scattered background. The appearence of these peaks indicates the solid state of the clusters. Scans were made at various points along the jet axis for different stagnation conditions. Within the resolution of the measurements, no change in cluster size could be detected along the jet axis for $z/D > 5$. This is in agreement with light scattering measurements.[2] Figure 2 shows the average cluster size on the jet axis as a function of stagnation pressure P_0. These data are corrected for the width of the detector. For comparison, a calculated curve shows the cluster size at the nozzle exit. The present results indicate larger cluster sizes than those obtained by a similar investigation[3] where molecular beam and mass spectrographic time-of-flight techniques (MSTOF) were used. This was unexpected, since possible influences causing errors in the diffraction technique, such as beam divergence or lattice imperfections, will always yield a particle size that is too small. If one excludes slight differences in the nozzle shape as a possible cause for different cluster size, there remain the specific effects of MSTOF techniques where cluster distributions seem to be reduced to smaller average sizes due to electron impact.[3] But even if this influence were negligible, the assumption of close packed spherical clusters as made here in order to reduce the MSTOF data[3] might be idealized and yield average sizes that are too small. The present data could not be compared with the measurements of Rouault and Audit,[4] who used a molecular beam technique with photographic recording of diffraction patterns, because of their different type of jet source.

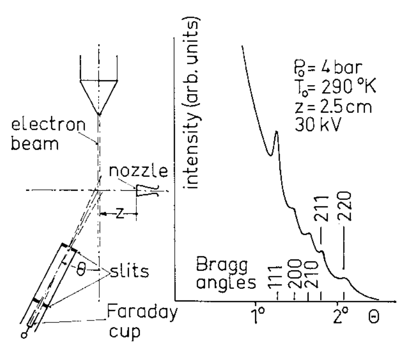

Fig. 1 Schematic and typical test results; (a) arrangement of electron beam, nozzle, and rotating detector, (b) typical electron diffraction pattern.

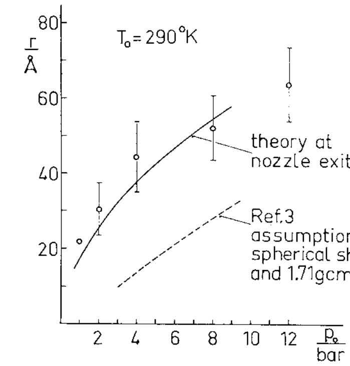

Fig. 2 Comparison of average CO_2 cluster size with one-dimensional theory at nozzle exit.

The apparent lack of growth of the clusters along the jet axis can be explained as a rarefaction effect. Using a Lagrange type of description, the balance of mass and energy for a cluster moving with a velocity v which shall be equal to the gas velocity in the jet yields

$$dg/dz = (s_g/v)(a_c\beta - \alpha_g) \tag{1}$$

$$de_g/dz = (s_g/v)(a_e E^+ - E_g^-) \tag{2}$$

where g is the number of molecules in a cluster, e_g is its internal energy, s_g is the cluster surface, a_c and a_e the accommodation coefficients for sticking and energy transfer, respectively, β/α_g the mass flow rate to/from the surface, and E^+/E_g^- the energy flow rate to/from the cluster surface. In this simple model β and E^+ are dependent upon the gas density n and the temperaure T as follows:[5] $\beta \sim n(T)^{1/2}$, $E^+ \sim \beta T$. The parameter α_g and E_g^- are exponentially dependent[6] upon the sublimation energy ϵ_g and the cluster temperature T_g

$$\alpha_g, E_g^- \sim \nu \exp(-\epsilon_g/kT_g)$$

with ν being the frequency of a molecule bound in the lattice, and k = Boltzmann's constant. With decreasing gas density and temperature, β and E^+ are reduced, and in the extreme case of $n \to 0$ (which especially applies to molecular beam sampling), the cluster size and temperature adjusts by means of evaporation cooling on an extremely rapid scale to their final values that are essentially determined by ϵ_g and the initial cluster size g_0. Equations 1 and 2 were solved numerically, and Fig. 3 shows, as an example, the behavior of the cluster temperature T_g as a function of time. The final temperature is not dependent upon the initial temperature.

In conclusion, it has been shown that the electron diffraction technique is a simple and inexpensive tool for the study of condensation effects in low density flows. It is expected that the sensitivity and the resolution of the detector can be considerably increased by using electron multipliers and by increasing the slit distance.

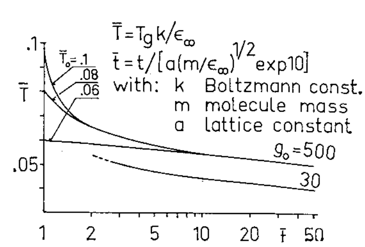

Fig. 3 Cluster temperature decay with time (initial time = 1, $g = g_0$ and $T_g = T_0$).

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Draining of a Fluid from a Rotating Cylindrical Tank

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Introduction

PREVIOUS investigations have shown that in draining a low-viscosity liquid from a stationary tank, there exists a fluid level at which a dip on the free surface extends almost instantaneously into the drain.[1–5] The height at which this occurs, referred to as the critical height,[5] has been shown to be a function of the ratio of inertial forces to body forces, a Froude number, here defined as $Fr = \bar{U}^2/gR$, where $\bar{U}$ is the average free-surface velocity, g the acceleration of gravity, and R the tank radius. However, there are no data on a similar occurrence when the tank is rotated with constant angular velocity ("rigid body" rotation). It is the purpose of this Note to present quantitative data and qualitative observations on the occurrence of a critical height in a uniformly rotated flow. These data and observations should lend insight into the nature of the flow, so that a mathematical model of the problem can be constructed.

The problem investigated is shown in Fig. 1. A low-viscosity fluid (i.e., water) in a closed and continually pressurized cylindrical tank, filled at the centerline to an initial height H_i, is rotated uniformly about its central axis. At time = 0, flow is initiated through a symmetrically placed drain of radius $a(a/R \ll 1)$. At some later time > 0, rotation other than rigid body can be detected. As the fluid height decreases, the deviation from uniform rotation increases; the free surface is no longer parabolic but has a depression at the center. The free surface eventually reaches a critical height, H_c, at which the depression extends to the drain almost instantaneously and a vortex is formed.

As explained by Morton,[6] in a flow with externally imposed rotation, the effects of rotation are controlled by the Rossby number (ratio of inertial to Coriolis forces). In the present case, the Rossby number is defined as $Ro = \bar{U}/\Omega R$

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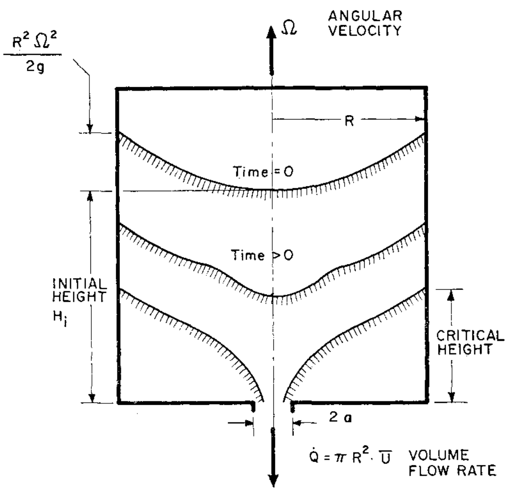

Fig. 1 Free-surface profiles.

where Ω is the rate of angular rotation of the tank. Various investigators have shown that two distinct flow patterns can occur in a uniformly rotated flow, depending on the value of Rossby number. Of these investigations, those of Stewartson,[7] Barua[8] and Long[9] are applicable to the present study.

Stewartson[7] and Barua[8] both investigated the streamline pattern obtained at values of $Ro \ll 1$ for a point sink in a uniformly rotating flow. They showed that the flow was directed toward the sink as a cylindrical jet surrounded by a uniformly rotating flow. Long[9] obtained a mathematical solution for sink flow from a rotating cylinder of infinite length. The validity of the solution was limited to values of $Ro \geq 0.522$. The solution showed that as Ro decreased from infinity (no rotation) to this limit, the sink drew an ever-increasing amount of flow from a region near the axis of rotation. Long hypothesized that for values of Ro below this limit, the flow might be unsteady and inertial waves could exist in the flow. This limiting value of Ro is of the same order of magnitude as that discussed by Greenspan,[10] ($Ro \simeq 2/\pi$), below which rotating flow could exhibit columnar motion.

Thus, H_c should be a function of Ro as well as Fr, and qualitative differences in the flow should be apparent at $Ro \sim 0.5$. However, whereas in the nonrotating case ($Ro \to \infty$, $1/Ro \to 0$) H_c was independent of H_i, at values of $Ro < 0.5$ the hypothesized unsteady nature of the flow should indicate some dependence, on H_i.

Apparatus

The experimental setup is shown schematically in Fig. 2. To calculate the three dimensionless groups H_c/R, Fr and $1/Ro$, H_c, $\bar{U}$ and Ω must be measured. A turbine flow meter was used to measure the volume flow $Q = \pi R^2 \cdot (\bar{H}_i - \bar{H})$, where $\bar{H}_i$ and $\bar{H}$ are average values, and the volume rate of flow $\dot{Q} = \pi R^2 \cdot \bar{U}$, both as functions of time. The value of $\bar{H}c$ ($\simeq Hc$ for the values $1/Ro$ and Fr obtained in the experiments) was determined by a visual sighting of the point of free-surface extension, and by electrically interrupting the flow meter signal at this point. Measurement of Ω was accomplished by an electronic counter activated every tank revolution by a cam-microswitch arrangement on the tank turntable.

The test procedure was as follows: First, the tank was filled to the desired $\bar{H}_i$ and kept stationary for a time to damp out any residual vorticity. Then rotation was started. Spinup times were calculated from the analysis of Wedemeyer.[11] The applicability of his results was verified by a series of tests to determine the time it took a ½-in. diam paddle-wheel float, supported at the centerline and starting from rest, to attain the angular velocity of the tank. Upon completion of spinup the tank was pressurized. The pressure was held constant during draining, and the critical height was recorded.