NASA TECH BRIEF

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Computation of Laminar Heat Transfer from Gaseous Plasmas in Electromagnetic Fields

Electrode erosion in plasma-propulsion and power-generation devices can be caused by intense heat flux, especially at the anode. In the past, methods for computing anode heat fluxes were limited to boundary-layer flows of high-temperature gaseous plasmas in the absence of magnetic fields; much of the earlier work relating to plasmas was confined to reentry problems.

A comparatively general analysis of heat transfer for a two-temperature gaseous plasma in the presence of electromagnetic fields has been developed; it is available in report form. The analysis is based on laminar flow of a singly-ionized, quasineutral plasma with variable properties. The total velocity of the electrons is considered to be the sum of the mass-averaged directed velocity of the gas mixture plus an ambipolar-diffusion velocity resulting from the concentration gradient of the electrons plus a field velocity of the electrons in an electromagnetic field; the field velocity for ions is assumed to be negligible. It is shown that the Nusselt number is a function of six different dimensionless parameters compared to two parameters for a nonionized, low-temperature gas flow without applied electromagnetic fields. The total heat flux to the wall consists of the convective heat flux (which can be computed from Nusselt's relations) plus additional terms representing energy loss or gain at the sheath edge near the surface.

A sheath analysis is described for a species (1) in an accelerating field, (2) in a decelerating field, (3) emitted from the wall, and (4) recombining at the wall. Expressions for energy loss or gain terms are then obtained for special cases of a cathode, an anode, and some other surfaces. To show the importance of different nondimensional parameters on convective heat flux, a simple heat-transfer model consisting of flow between parallel flat plates is then considered. The current is assumed to be uniformly distributed, and thermophysical properties are assumed to be constant; additionally, the temperatures of each of the species are taken to be equal. The distribution of the gas temperature between electrodes is found to be dependent upon a dimensionless variable which is proportional to the current, and on another dimensionless variable which is inversely proportional to the cathode temperature and directly proportional to the ratio of thermal to electrical conductivity.

The ratio of the anode-to-cathode surface temperatures is important; for a typical value of the ratio of these temperatures, it is shown that an independent adjustment of the value of both the dimensionless variables noted above leads to a reversal in the sign of the convective heat transfer at the cathode. In the physical sense, the reversal in the convective heat flux to and from the cathode is brought about by a change in the joule heating which influences the temperature gradient at the surface.

Note:

The following document may be obtained from:

National Technical Information Service
Springfield, Virginia 22151
Single document price $6.00
(or microfiche $0.95)