# Joule Heating Effects in MHD Generator Boundary Layers

R. Kent James* and Charles H. Kruger†
*Stanford University, Stanford, California*

**Experimental measurements were performed of temperature and electron number density profiles on a laboratory-scale MHD generator. Comparisons between calculations from a two-dimensional theory and measurements for cases without current generally showed good agreement when the turbulence model properly accounted for the effects of freestream turbulence, although small discrepancies were observed between theory and experiments for the overall profile shape. Comparisons of experimental temperature profiles without current to profiles with current showed a marked temperature increase in the boundary layer due to Joule heating. The magnitude of the increase was well predicted by the two-dimensional boundary-layer theory. Measured temperature profiles with current and magnetic field did not agree with predictions. The predicted profile in the inner region of the boundary layer for a case with current and magnetic field was above a similar case without current, whereas measurements for anode boundary layers were below control profiles without current. A cathode boundary layer behaved oppositely to the anode boundary layers. Three-dimensional recirculation induced by nonuniformities in axial current could explain the discrepancies.**

## Nomenclature

| | |
|---|---|
| $B$ | = magnetic field intensity |
| $c$ | = speed of light |
| $e$ | = electron charge |
| $h$ | = Plank's constant; also stagnation enthalpy |
| $J$ | = current density |
| $k$ | = Boltzmann's constant |
| $l$ | = half the distance between opposing electrodes |
| $m_e$ | = electron mass |
| $N_e$ | = electron number density |
| $p$ | = pressure |
| $Pr$ | = Prandtl number |
| $q$ | = heat flux |
| $Re$ | = Reynolds number |
| $\dot{R}_e$ | = electron recombination rate |
| $u,v,w$ | = velocity components in the $x$, $y$, and $z$ directions, respectively |
| $x,y,z$ | = orthogonal coordinates |
| $\alpha$ | = electron recombination rate coefficient |
| $\delta_l$ | = boundary-layer displacement thickness |
| $\lambda$ | = wavelength |
| $\mu$ | = viscosity |
| $\mu_e$ | = electron mobility |
| $\mu_i$ | = ion mobility |
| $\rho$ | = density |
| $\sigma$ | = electrical conductivity; also Stefan-Boltzmann constant |

## Introduction

MAGNETOHYDRODYNAMIC (MHD) electric power generation is being vigorously developed as an alternative to presently used forms of energy conversion, as MHD generators are expected to provide a substantial improvement in the efficiency of electric power generation. Many loss mechanisms which significantly affect the generator performance occur in the electrode wall boundary layer of an MHD generator, for example, electrode voltage drop, heat transfer, axial leakage, and axial breakdown.

Received Oct. 10, 1981; revision received July 9, 1982. 

*High Temperature Gasdynamics Laboratory; presently Process Improvement Engineer, Energy and Environment R&D, Weyerhaeuser Co., Tacoma, Wash. Member AIAA.

†Professor and Chairman, Department of Mechanical Engineering, High Temperature Gasdynamics Laboratory. Member AIAA.

While in many ways the electrode wall boundary layer is similar to extensively studied boundary layers in applications such as turbine blades or rocket nozzles, unique effects can occur in the electrode wall boundary layer which have not been extensively studied. In the present work, the role of these effects is assessed by performing experimental measurements of temperature profiles in a small-scale MHD generator, and comparing these profiles to predictions from a two-dimensional numerical model of the electrode wall boundary layer.

Early theoretical work on the gasdynamic aspects of MHD generators was done by Kerrebrock and co-workers in the early 1960s. They developed solutions for insulator and electrode wall boundary layers for a restricted set of laminar MHD flows.[1,2] After the development of finite difference methods for the solution of boundary-layer equations in the late 1960s, several papers appeared that used these methods to solve MHD boundary-layer flows.[3-10] These computations demonstrated that electron recombination kinetics, electron temperature nonequilibrium, and Joule heating can be important in the electrode wall boundary layer, and that $\boldsymbol{J}\times\boldsymbol{B}$ effects can be important in the insulating wall boundary layer.

Although some comparisons of the existing models to experiments have been made, generally the limits of the models have not been established. Parameters which govern the models, such as turbulence parameters and kinetic constants, are not well established for MHD conditions. Uncertainties exist in the modeling of physical phenomena such as three-dimensional effects, nonuniformities, turbulence damping, and MHD-driven instabilities. With these unknowns, it is important that the theoretical models be compared to experiments before placing excessive confidence in the theoretical results.

Experimental boundary-layer research in combustion MHD generators has been more limited than theoretical research. Experimental verification of the role of the thermal boundary layer in determining electrode voltage drops was provided by Kessler.[11] Measurements of turbulent boundary-layer profiles in combustion MHD generators have been made by Daily,[8] Kirillov et al.,[12] and Rankin,[9] but no measurements of the thermal boundary-layer profiles in a combustion MHD generator have been made under conditions where the boundary layer was noticeably affected by the current interactions. Particularly lacking are experimental data for plasma profiles measured under conditions where current interactions are important.