SOME STUDIES OF SEEDING AND CURRENT CONDUCTION IN MHD COMBUSTION PLASMAS

by

SUNIL CHANDRA SHARMA

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Centre for Energy Studies
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
Hauz Khas, New Delhi-110016
INDIA

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TO MY PARENTS

CERTIFICATE

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(Signature) 27/11/86
Supervisor of the Candidate

Address Dr R.P. Dahiya
Asstt Professor
Centre of Energy Studies

(Signature) 27/11/86
Chairman, D.R.C.

Department of Centre of Energy Studies
I.I.T., Delhi.

P.T.O.

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SC Sharma

(Sunil Chandra Sharma)

PREFACE

Magnetohydrodynamic (MHD) power generator in combination with a steam bottoming plant has the potential to give an overall efficiency upto 50 per cent. In an open cycle MHD power generator, fossil fuel is burnt with oxygen enriched air and the desired level of electrical conductivity of the combustion products is attainded by adding a low ionization potential material, which is known as seed. Potassium carbonate is considered suitable for seeding the working fluid of open cycle MHD power generators.

In the present thesis, combustion and current condution processes in seeded combustion plasma have been investigated under different physical conditions which may be relevant to gaseous fuel fired open cycle MHD power generators. Aqueous solution of potassium carbonate has been injected with the help of a two fluid pneumatic atomiser in the combustion products of liquefied-petroleum-gas (LPG, $C_{3.7}H_{8.8}$) and oxygen. The transport properties of potassium carbonate seeded combustion plasma, viz. composition, combustion temperature and electrical conductivity have been studied by incorporating the moles of water and potassium carbonate present in the aqueous seed solution. Investigations have also been made for the seed drop size distribution obtained from a pneumatic atomiser. It has been observed that the mean drop size gets lowered and distribution becomes more uniform on increasing the relative velocity between the aqueous seed solution and atomising oxygen at the interaction zone. The level of seed ionization has been observed to be influenced by the mean drop size.

The boundary layers developed over the copper and stainless steel (304) electrodes have been investigated for different sets of physical parameters, viz., electrode temperature, electrode surface conditions, applied voltage and seeding ratio (weight per cent of potassium). The alkali seed material present in the seeded plasma has been found to get adsorbed on the relatively cool electrode surfaces. A composite layer of low work function ($\sim$ 2.13 ev) has been observed

to be formed over the copper cathode facilitating thermionic emmission of electrons. In diffusive mode of conduction, the anode potential drop, the cathode potential drop and the current density have been investigated as function of electrode (cathode/anode) temperature. For planar copper electrodes current density typically of 2400 amp/m^2, for an applied voltage of 100 V has been achieved when the temperature of both the electrodes is around 1220 K. The current density has been observed to increase further up to 2800 amp/m^2 when matrix cathode with sharp multiple points is used under similar operating conditions. Experiments have also been conducted by using stainless steel (304) electrodes which are capable of sustaining temperatures higher then those of copper electrodes. The thermionic emmission of electrons form the seed laden stainless steel cathode has been observed to give current density of the order of 3500 amp/m^2, for electrode temperature of 1500 K and an applied voltage of 60 volts. Under these conditions, a potential drop of 25 volt has been observed to appear in anode electrostatic sheath, after seven hours of channel run time.

Temporal behaviour of the matallic electrodes has been investigated as a function of channel run time. When we start with the fresh copper electrodes, their surfaces get coverage of seed compound over a period of time. Adsorption of potassium is uniform on both the electrodes but the cathode surface get enhanced seed coverage due to additional contribution made by positively charged potassium ions drifting towards it from the plasma core. The anode potential drop then increases appreciably. It has been observed that after 16 hours of channel run time, 70 per cent of applied voltage drops in anode boundary region.

The composite surfaces formed on the electrodes are investigated by Auger Electron Spectroscopic, Differential Thermal Analysis and Scanning Electron Microscopic techniques. The material adsorbed on the electrode surfaces has been found to be primarily potassium carbonate.

LIST OF FIGURE

LIST OF TABLES

NOMENCLATURE

English letter symbols

A	Richardson's constant
A_1	Area of cross-section of atomising tube
A_2	Area of cross-section of atomising tube at nozzle
A_p	Effective area of probe for current conduction
b_1 to b_4	Constants
B	Magnetic field
C_0	Concentration of aqueous seed solution (initially)
C_i	Concentration of ith species
C_s	Concentration of the Saturated Solution
C_{p0}	Specific heat of aqueous seed solution at constant pressure
C_{p1}	Specific heat of solid K_2CO_3 at constant pressure
C_{p2}	Specific heat of liquid K_2CO_3 at constant pressure
d	Seperation between the probes
d_{vs}	volume to surface ratio of total droplets in a spray, i.e. sauter mean diameter

e	Electronic Charge
E	Electric field
f	Fractional radius (= r/r_0)
f_1	The ratio of the saturatod seed droplet radii to mean radii ($=r_S/r_0$)
f_2	The ratio of the melted K_2CO_3 droplet radii to mean radii (r_M/r_0)
f_3	The ratio of the evaporated droplet radii to mean radii (r_E/r_0)
F(v)	A function of velocity
H_i	Peak to peak height of Auger emission
J	Total current density
J_e	Electronic current density
J_i	Ionic current density
k	Thermal conductivity of combustion products
k_B	Boltzmann's Constant
k_{el}	Thermal conductivity of electrode material
k_i	Thermal Conductivity of ith species
K_L	Loading parameter
l	Characteristic length

L_1	Latent heat of fus. ion of solid K_2CO_3
L_2	Latent heat of vaporisation of liquid K_2CO_3
L_s	Latent heat of saturated solution
m_0	Mass of the 15% aqueous K_2CO_3 solution
$\dot{m}$	Mass flow rate per min
m	Amount of water present in the seed solution
m_e/m_i	The ratio of electron to potassium ion mass
n	Total number of species in a mixture
n_e	Electron density
n_i	Ion density
n_{is}	Ion current density assuming local saha equilibrium
$n_{i\delta}$	Random ion current density at cathode - sheath edge.
$n_{es\infty}$	Electron density assuming local saha equilibrium
N	Number of the seed droplets
N(E)	Auger electron as a function of kinetic energy
P	Pressure
P_0	power output per unit volume
$P_{,s}$	Partial pressures of various species

q	Density of the convective flux falling on the drop and its average
Q_L	Volumetric flow rate of seed solution
Q_A	Volumetric flow rate of atomising oxygen
r	Radius of the seed droplet
r_0	Mean radii
r_S	Radii of the saturated solution
r_M	Radii of the melted drop (at 1164K)
r_E	Radii of the evaporating drop
R	load
s	Saturated solution
S_i	Sensitivity of the i,th species for Auger emission
S_1 to S_5	Equilibrium constants
S_6	Constant
t	Time
Δt_i	total time taken by a droplet for evaporation ($\equiv \Delta t$)
t_1 to t_7	Time take by seed droplet during successive seven stages

T	Temperature
T_0	Ambient temperature (303K)
T_S	Boiling point of saturated solution
T_M	Melting point of solid K_2Co_3
T_E	Evaporation Temperature of liquid K_2Co_3
T_∞	Main plasma temperature
T_a	Anode temperature
T_C	Cathode temperature
U	Velocity of the seeded combustion products
V_i	Ion thermal velocity
V	Relative velocity of the atomising oxygen gas w.r.t. aqueous seed flow rate
V_1	Velocity of oxygen in atomising tube
V_2	Velocity of oxygen at the nozzle of atomising tube
V_a	Anode potential drop
V_C	Cathode potential drop
V_{app}	Applied voltage
W_i	Mole fraction of ith species
X_L	Axial distance from the Burner

Greek Letter Symbols

ρ_0	Density of 15% K_2CO_3 Solution
ρ_1	Density of solid K_2CO_3
ρ_2	Density of liquid K_2CO_3 at 1795 K
ρ_s	Density of saturated seed solution
ρ_E	Density of liquid K_2CO_3 at 1945 K
ν_t	Total collision frequency
ν_{en}	Collision frequency of electron and neutral particles
σ	Electrical conductivity of seeded combustion plasma
σ_T	Surface tension of the seed solution
φ	Work function
ϵ	Weight per cent of Potassium
δ	Solid shell thickness of K_2CO_3
δ_c	Cathode electrostatic sheath thickness
δ_T	Thermal sheath thickness
$\alpha, \beta, \& \gamma$	Constants

CONTENTS