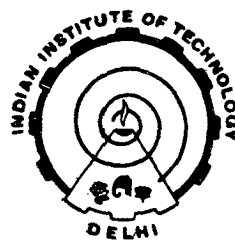


**ENVIRONMENTAL ASPECTS AND ANALYSIS
OF COAL COMBUSTION PRODUCTS FOR
INDIAN MHD POWER PLANT**

by

**UMESH KUMAR SINGH
Centre for Energy Studies**

***SUBMITTED
IN FULFILMENT OF THE REQUIREMENTS OF
THE DEGREE OF
DOCTOR OF PHILOSOPHY***



**to the
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA**

April, 1992

CERTIFICATE

This is to certify that the thesis entitled "ENVIRONMENTAL ASPECTS AND ANALYSIS OF COAL COMBUSTION PRODUCTS FOR INDIAN MHD POWER PLANT" being submitted by Umesh Kumar Singh, for the award of the degree of Doctor of Philosophy to the Indian Institute of Technology, Delhi, is a record of bonafide research work he has carried out under my supervision. The results in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

A. Chandra
(Dr. A. Chandra)

Centre for Energy Studies,
Indian Institute of Technology,
New Delhi - 110016, India.

ACKNOWLEDGMENTS

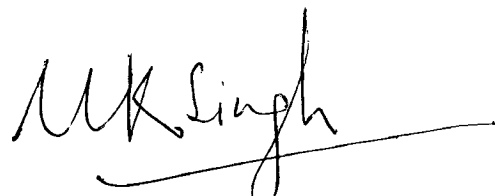
The research work presented in this thesis has been carried out under the valuable and expert guidance of Dr. A. Chandra. I have been greatly benefited from his deep insight into the subject and constant moral support during numerous discussions. I wish to express my sincere thanks to him with a deep sense of affection and gratitude .

My thanks are due to Prof. H. P. Garg, Head, Centre for Energy Studies, to provide facilities for pursuing the work. I must also acknowledge here the fruitful discussions that I had time and again with Dr. V.R. Malghan (Deputy General Manager, MHD Research Centre, BHEL, Tiruchirapalli), Prof. D. P. Kothari, Dr. G. N. Tiwari and Dr. S.S Verma . Special thanks to Dr. S. C. Sharma for encouragement and providing financial support during my thesis writing.

I am grateful to Mr. B.S. Bhaduria, Mr. Varun Bhatt, Mr. B. P. Kala and Mr. L. D. Kala for their sincere cooperation extended to me in tabulating the data.

The timely assistance given to me by my brothers Prof. Vindyachal Singh, Mr. K. P. Singh, Prof. S. K. Singh and my brother in laws Dr. J. P. Singh and Mr. B. K. Ray in compiling the thesis is also worth appreciation.

Finally, the patient understanding and co-operation extended throughout the work by my wife Mrs. Rita Singh and my daughter Chitragada is greatly appreciated.

A handwritten signature in black ink, appearing to read 'MK Singh', with a long horizontal flourish extending to the right.

(UMESH KUMAR SINGH)

April, 1992

New Delhi.

PREFACE

The design and performance of MHD/retrofitted thermal power plants depend upon the plasma properties (electrical, thermodynamic and transport properties like, electrical conductivity, hall parameter, molecular weight, density, specific heat, isentropic coefficient, sonic velocity, thermal conductivity, viscosity etc.) of the fuel/oxidants system to be used as a working fuel.

In this thesis, investigations have been made for four major varieties of Indian coals namely, Singraulli, Talchar, Korba and Wardha Coal in order to evaluate the feasibility of using them as fuels for coal-fired MHD generators. Analytical calculations have been made to evaluate the composition, combustion temperature, electrical, thermodynamic and transport properties of the seeded (with alkali salts) combustion products of the above varieties of coal with air/enriched air at different pressures based on the software developed on the basis of NASA-SP 273. Investigations have been made of their

relative performance to obtain the best suitable variety of Indian coals on the basis of electrical, thermodynamic and transport properties at different combustion conditions for being used as working fuel for MHD power system. The effect of pre-heating on the combustion temperature and electrical conductivity of the combustion products of these coal has also been investigated. Investigations have been made of their relative performance to obtain the best suitable variety of Indian coals on the basis of electrical, thermodynamic and transport properties under similar conditions of combustion.

The performance of power plant is greatly affected due to presence of ash. Indian coals are high ash content coals unlike USA and Australia coals. The composition, combustion temperature, electrical, thermodynamic and transport properties of seeded (with K) combustion products of Singraulli coal have been analytically evaluated at a various slag removal rates for different temperatures and combustion pressures. The effect of pre-heating on the combustion temperature and electrical conductivity of the combustion products of the Singraulli coal at various slag removal rates has been studied.

Techno-economic review of the seeding systems introduced to Singraulli coal for coal-fired MHD power system has been done. Different combination of Potassium and Cesium salts introduced to Singraulli coal have been analytically studied in order to have the cost optimization of seeding system for better performance of the coal-fired MHD/retrofitted thermal power plants.

In coal-fired power plant main pollutants produced are oxides of Nitrogen (NO_x), Sulfur (SO_x), Carbon (CO_x), particulate matters etc. Analytical evaluations have been made to determine the combustion conditions like flame temperature, combustion pressure, stoichiometric ratio, oxygen enrichment ratio and seeding ratio to control the emission of NO_x , SO_x , CO_x and particulate matters resulting from the combustion of Indian coals namely Singraulli, Talchar, Korba and Wardha coal including ash and at various slag removal rates.

CONTENTS

	Page No.
ACKNOWLEDGEMENTS	i
PREFACE	iii
NOMENCLATURE	vi
CHAPTER - ONE :- INTRODUCTION	
1.1 Introduction	1.1
1.2 MHD Power Generation	1.3
1.3 Seeding and Conductivity	1.4
1.4 Coal-fired MHD power plant	1.6
1.4.1 Retrofit	1.13
1.5 Present Work: Summary	1.14
CHAPTER - TWO :- MATHEMATICAL MODELLING	
2.1 Introduction	2.1
2.2 Equation Discription of Chemical Equilibrium	2.3
2.2.1 Equation of state	2.3
2.2.2 Minimization of Gibbs free energy	2.4
2.2.3 Gibbs iteration equations	2.9
2.2.4 Reduced Gibbs iteration equations	2.11
2.3 Thermodynamic derivative from Matrix solution	2.13
2.3.1 Derivatives with respect to temperature	2.14

2.3.2	Derivatives with respect to Pressure	2.16
2.4	Other thermodynamic derivatives	2.18
2.5	Input calculations	2.19
2.4.1	Transport properties of the fuel/oxidants system	2.24
2.4.2	Electrical properties of the fuel/oxidants system	2.26
2.4.3	Adiabatic flame temperature	2.28
CHAPTER - THREE :- ANALYSIS OF INDIAN COALS INCLUDING ASH		
3.1	Introduction	3.1
3.2	Selection and Data Source	3.4
3.3	Results and Discussions	3.5
3.3.1	Combustion Temperature	3.6
3.3.2	Electrical properties	3.9
3.3.2.1	Electrical conductivity	
3.3.2.2	Hall parameter	
3.3.3	Thermodynamic Properties	3.12
3.3.3.1	Specific heat	3.13
3.3.3.2	Sonic velocity	3.15
3.3.3.3	Density	3.17
3.3.3.4	Molecular weight	3.19
3.3.3.5	Isentropic coefficient	3.20
3.3.4	Transport Properties	3.22

3.3.4.1	Thermal Conductivity	3.23
3.3.4.2	Viscosity	3.25
3.4	Conclusions	3.26
CHAPTER - FOUR :- ANALYSIS OF THE INDIAN COAL (SINGRAULLI COAL) AT DIFFERENT SLAG REMOVAL RATES		
4.1	Introduction	4.1
4.2	Results and Discussions	4.4
4.2.1	Combustion Temperature	4.5
4.2.2	Electrical properties	4.6
4.2.2.1	Electrical conductivity	
4.2.2.2	Hall parameter	
4.2.3	Thermodynamic Properties	4.8
4.2.3.1	Specific heat	4.8
4.2.3.2	Sonic velocity	4.9
4.2.3.3	Density	4.10
4.2.3.4	Molecular weight	4.11
4.2.3.5	Isentropic coefficient	4.12
4.2.4	Transport Properties	4.13
4.2.4.1	Thermal Conductivity	4.13
4.2.4.2	Viscosity	4.15
4.2.5	Conclusions	4.16
CHAPTER - FIVE :- TECHNO-ECONOMIC ANALYSIS OF THE SEEDING SYSTEM		

5.1	Introduction	5.1
5.2	Results and Discussions	5.3
5.3	Conclusions	5.8
CHAPTER - SIX :- ENVIRONMENTAL ASPECTS OF COAL BASED INDIAN MHD POWER PLANTS		
6.1	Introduction	6.1
6.2	Results and Discussions	6.2
6.2.1	Oxides of Nitrogen	6.4
6.2.1.1	Nitric oxide (NO)	6.5
6.2.1.2	Nitrogen oxide (NO ₂)	6.7
6.2.2	Oxides of Carbon	6.10
6.2.2.1	Carbon monoxide (CO)	6.10
6.2.2.2	Carbon dioxide (CO ₂)	6.13
6.2.3	Oxides of Sulfur	6.16
6.2.3.1	Sulfur monoxide (SO)	6.17
6.2.3.2	Sulfur dioxide (SO ₂)	6.19
6.2.3.3	Sulfur trioxide (SO ₃)	6.22
6.2.4	Particulates matter	6.24
6.2.4.1	Oxides of Aluminium	6.24
6.2.4.2	Oxides of Silicon	6.26
6.2.4.3	Oxides of Iron	6.29
6.3	Conclusions	6.31

APPENDIX I	AI.1
APPENDIX II	AII.1
APPENDIX III	AIII.1
REFERENCES	R.1
RESUME	
APPENDIX <u>IV</u>	AIV.1