

**COAL CHARACTERIZATION AND ITS RELATION TO  
QUALITY AND OCCURRENCE OF RARE EARTH  
ELEMENTS**



**Thesis submitted in partial fulfillment for the**

**Award of Degree**

**Doctor of Philosophy**

**By**

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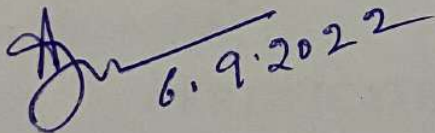
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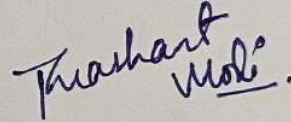
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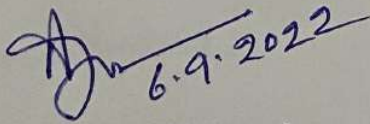
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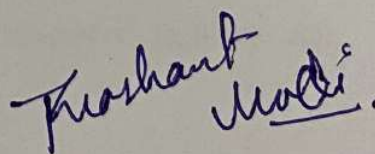
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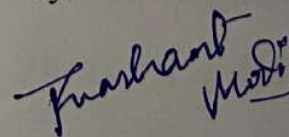
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## List of abbreviations/symbols

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ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
BT	Billion Tonnes
CCPs	Coal Combustion Products
CFA	Coal fly ash
CMPDI	Central Mine Planning and Design Institute
DI	De-Ionized
FC	Fixed Carbon
FTIR	Fourier Transform Infrared Spectroscopy
GCV	Gross Calorific Value
g	Gram
GOI	Government of India
GSI	Geological Survey of India
h	Hour
HREEs	Heavy rare earth elements
ICPMS	Inductively Coupled Plasma Mass Spectrometry
JCPDS	Joint Committee on Powder Diffraction Standards
Kcal	Kilo Calorie
Kg	Kilo gram
Km	Kilo metre
LREEs	Light rare earth elements
M	Metre
<i>M</i>	Molarity
ma	Million of years ago
min	Minutes
mm	Millimetre
MT	Million tonnes

MTPA	Million tonnes per annum
OCM	Opencast Mine
ORP	Oxidation Reduction Potential
PCC	Pearson Coefficient Correlation
ppb	Parts per billion
ppm	Parts per million
REEs	Rare Earth Elements
REOs	Rare Earth Oxides
REY	Rare Earth Elements and Yttrium
SEM	Scanning Electron Microscope
SN	Serial number
TGA	Thermogravimetric Analysis
TDS	Total Dissolved Solids
TREE	Total rare earth elements
TSS	Total Suspended Solids
USGS	United States Geological Survey
VM	Volatile Matter
XRD	X-ray Diffraction

## Preface

---

India is the world's second-largest coal-producing country, with massive coal reserves for future. Coal is the most essential and abundant fossil fuel in India. It accounts for 55% of the country's energy need. The country's industrial heritage was built upon indigenous coal. Most coal lies in the Gondwana basin in India of the Permian age. However, coal also accounts for the generation of coal waste (coal ash, toxic metals and gaseous emission of SO<sub>x</sub> and NO<sub>x</sub>) due to coal combustion, which is a significant environmental concern.

Rare earth elements (REE) are critical components of our technological society and essential for renewable energy technologies. Traditional thermochemical processes to extract REEs are costly and environmentally harmful, and thus more sustainable extraction methods require exploration.

Gondwana basin consists of many coalfields in it. Sohagpur is one of the coalfields, which is the study area for the current research work. Sohagpur Coalfield contains a total of ten opencast and underground mines. Characterizing and understanding its properties is paramount to understanding the behaviour of coal. In the present work, the main emphasis has been laid on the geochemical characterization, coal quality, qualitative-quantitative study of REEs in coal and its recovery.

The entire gamut of the thesis has been divided into ten chapters. The first chapter describes the introduction of coal, rare earth elements and the objective of the study. The overview of the study area has been presented in the second chapter. This chapter gives a detailed description of the study area, including the location, climatological conditions, geomorphology and geology. The third chapter discussed detailed literature review state

of the art understanding regarding the characterization of coal, rare earth elements in coal and coal by-products, along with research works done to recover these valuable elements. The fourth chapter deals with the materials and methods adopted for the various studies and experimental works. The results of the investigations are discussed in the chapters five to eight. The megascopic characterization and its origin in coal samples is discussed in the fifth chapter. The sixth chapter explains the geochemical analysis and surface morphology of coal samples with elemental concentration and coal characterization. This analysis reports on the characterization of coal samples. The seventh chapter details the rare earth elements occurrence, its distribution in coal and its by-products which are further compared with the world coal average. The chapter eight is based on the study by experimental methods with the help of leaching in coal samples by water, different chemical reagents and thermal treatments. This chapter explains to understand the occurrence of REEs and it's recovery by different chemicals reagents. The ninth chapter is related with results explanations, discussion and correlations of various parameters. The last chapter is conclusions and suggestions for future works. This research work is an attempt to contribute to the study of the coal, rare earth elements, and it's recovery from coal and coal by-products. It may be helpful in waste utilization and fulfilling the demand for rare earth elements for the benefit and growth of the society.