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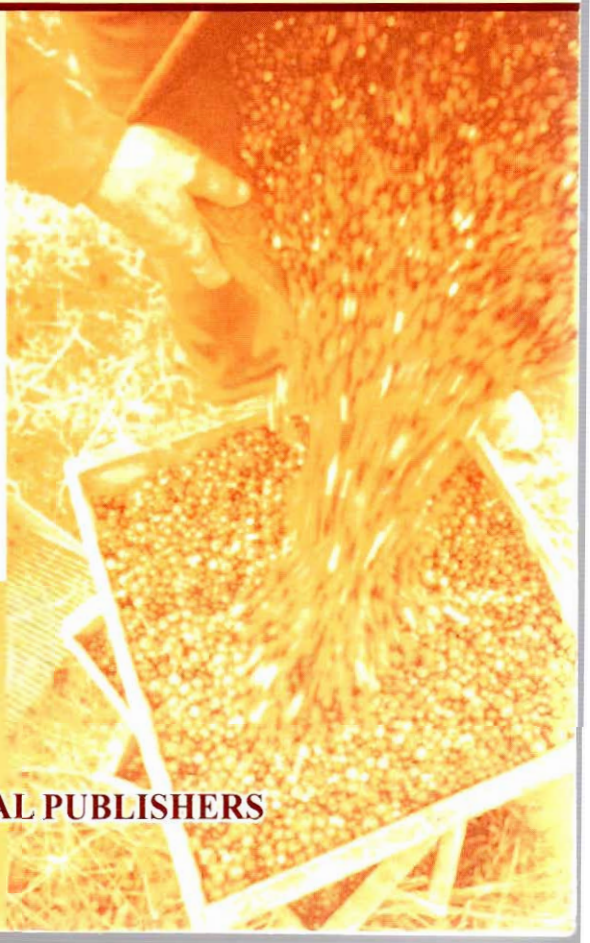
Principles of Extractive Metallurgy

H.S. Ray
A. Ghosh



NEW AGE INTERNATIONAL PUBLISHERS

PRINCIPLES OF EXTRACTIVE METALLURGY

[SECOND EDITION]

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TO PARENTS

(Late) Bejoy Panchanan Ghosh
Labanyamoyee Ghosh
and
Benoy Bhushan Ray
Mrinmayee Ray

FOREWORD

Towards achieving its objectives of promoting and advancing the art, science and technology of making, shaping and treating of metals and alloys, the Institute has been considering publishing text-books on various metallurgical engineering subjects. Lack of good text-books have made it difficult for the students appearing in the Associate Membership Examination of the Institute to keep themselves abreast of developments in the field of Extractive Metallurgy with special reference to Indian conditions. Besides, foreign books on various subjects are invariably costly and difficult to obtain. The Metal Sciences Division of the Institute which is concerned with research and development of metals and materials, took the initiative and suggested that the Institute could bring out a series of modules in the form of text-books for undergraduate students and particularly for AMIIM students. It was, at the meeting held on November 16, 1980 chaired by my predecessor Mr. C.V. Sundaram of Bhabha Atomic Research Centre, a final decision was taken to bring out two books—one on 'Principles of Physical Metallurgy' and another on 'Principles of Chemical Metallurgy', to start with. At that time, Prof. A. Ghosh who had authored a comprehensive note on 'Principles of Extractive Metallurgy', was approached by the undersigned with a request to author the book on 'Principles of Extractive Metallurgy'. After getting his consent, the matter was taken up with the Council of the Institute. The Council in its meeting on 8th February 1982 agreed in principle to publish this book under the banner of the Institute. Accordingly, the Metal Sciences Division has utilised the valuable Contributions made by Dr. A Ghosh and Dr. H.S. Ray to bring out the first book entitled 'Principles of Extractive Metallurgy' on a trial basis. This book is very well designed and planned to cover the requirements of the course on 'Principles of Extractive Metallurgy' at the undergraduate Degree course in Metallurgical Engineering in India and abroad. Some parts of the book will be useful even at the postgraduate level. Extractive Metallurgy is an important subject in Metallurgy which is generally less emphasised at the undergraduate level in most of the countries including India. There is also no single good book covering all aspects of 'Principles of Extractive Metallurgy'.

I have no doubt that the present book, the first of its kind published by the Institute, will be able to fill up this void and will gain great popularity amongst the students of Metallurgy and others interested in Extractive Metallurgy.

Dr. A.K. Seal
Ex-Chairman,
Metal Sciences Division,
and
Ex-President
The Indian Institute of Metals

PREFACE TO THE SECOND EDITION

The first edition of the book was well-received. Moreover there is no book yet in the market which has the approach used in this text. It covers a variety of principles in a nutshell so as to provide an integrated view of Extractive Metallurgy as a discipline in Engineering. The objective all through has been elucidation of basic concepts in an introductory fashion and in a manner which would suit students, researchers and practising metallurgists.

Therefore it was decided to bring out a second edition. Since the Indian Institute of Metals, which brought out the first edition, is not geared for large scale publication and marketing of the same, it was undertaken by the present publisher. The authors wish to thank the Indian Institute of Metals for giving up their copyright claim in the larger interest of the profession.

In the second edition, some minor changes in contents have been made. The text has been extensively edited. Emphasis has also been given in clarification of points where scope existed. Answers to problems have been added and some more recent references have been incorporated.

Ahindra Ghosh
Hem Shanker Ray

PREFACE TO THE FIRST EDITION

The authors have been engaged in the teaching of various aspects of Extractive and Chemical Metallurgy for nearly two decades. During the course of teaching they have consistently felt the need for a book on the principles of the subject for metallurgy students in the country. Several years ago the first author had cyclostyled some of his lecture notes on the Principles of Extractive Metallurgy which were well received by students as well as many professional colleagues. The present book owes its origin to those preliminary notes. The scope, content and coverage, of this book, however, are much more extensive.

There are a good number of books on the subject in the market now. These can be put into three distinct categories. Books in the first category deal with unit processes in a descriptive manner. Another category of books deal with physical chemistry aspects of metallurgical reactions and processes emphasising primarily thermodynamics. This approach had gained considerable popularity at one time, specially in the area of ferrous metallurgy. In the third category, there are only limited number of books where Extractive Metallurgy is dealt as an engineering discipline akin to chemical engineering. We accept this as the best approach and this book has been written accordingly. However, some useful features of the other approaches have also been included.

The present book contains brief descriptive summary of some important metallurgical unit processes. Subsequently it discusses not only the physical chemistry of metallurgical reactions and processes but also rate phenomena including heat and mass transfer, fluid flow, mass and energy balance, elements of reactor engineering. A variety of scientific and engineering aspects of unit processes have been discussed with stress on the basic principles throughout. There is an attempt to introduce, as much as possible, quantitative treatments and engineering estimates. The latter may often be approximate from the point of view of theory but yield results that are very valuable to both practising metallurgists as well as others.

While the book is meant primarily for the undergraduate students, it assumes that the reader has been previously exposed to Metallurgical Thermodynamics and elementary transport-phenomena. The book can serve as a text book for a single course if the students are already familiar with the first principles of the various topics covered. Alternatively, the various Chapters can be used in the teaching of different courses. All undergraduate Metallurgy Departments in the country offer separate courses in Metallurgical Thermodynamics and several of them also offer courses on heat, mass and momentum transfer, kinetics and electro- and hydrometallurgy. It is hoped that this book will be useful in all these courses. The authors hope that the book will prove useful also to graduate students, researchers and professional colleagues and serve as a ready reference for basic concepts in the areas relevant to Extractive Metallurgy.

The book starts with an overview of some definitions and descriptions of some important extraction and refining processes so that principles to be discussed later are better understood with respect to actual processes. The first two chapters thus form the Introductory Part A. Part B, consisting of seven chapters from 3 to 9 deals largely with Principles of Pyrometallurgy although some concepts

discussed are equally applicable elsewhere. The reason for this emphasis on Pyrometallurgy should be self evident. After all, bulk of common metals is still produced by high temperature operations. Part C consisting of Chapters 10 and 11 summarizes the principles of Electro- and Hydrometallurgy.

Dispersed throughout the text are many solved examples to elucidate the theory. At the end of each chapter is a list of general reading and references and also some questions and/or problems. Numerical figures and calculations are in SI units. There are a list of contents, a list of symbols and a subject index for ready reference. There is also some useful information in the Appendix. The figures generally follow their first mention in the text. To reduce the bulk, some separate figures have been printed in single pages. In such cases, the figures follow the first mention in the text of the last figure. The reader is, therefore, requested to flip through some more pages in case the required figure does not follow immediately.

The authors will consider their labour rewarded if the book proves useful to students and colleagues interested in Extractive Metallurgy.

Ahindra Ghosh
November 1982 Hem Shanker Ray

ACKNOWLEDGEMENT

While the authors were looking for publisher for the first edition, the Indian Institute of Metals (IIM) came forward and readily took up the publication work. The authors received wholehearted cooperation from the Council and the office bearers of the IIM in this endeavour. As a result, the first edition of the book could be published by the Indian Institute of Metals in 1984. The authors are grateful to all of them especially to Professor A.K. Seal, the then Chairman, Metal Sciences Division of the Indian Institute of Metals for encouragement and for writing a Foreword to the first edition.

During preparation of the manuscript for the first edition the authors received help, advice and suggestions from several colleagues and students both at the Indian Institute of Technology, Kanpur and Indian Institute of Technology, Kharagpur. We are grateful to all of them.

Finally the authors wish to thank their wives, Dr. (Mrs.) Radha Ghosh and Mrs. Chitra Ray for their cooperation and patience during the period of writing.

Ahindra Ghosh
Hem Shanker Ray

LIST OF SYMBOLS

a = activity, constant, acceleration
a_i = activity of species i
A = frequency factor, surface area, ampere
Bi = Biot's number
cp = centipoise
C = concentration, specific heat, velocity of light
C_p = specific heat at constant pressure
C_v = specific heat at constant volume
d = diameter, draft in furnace
D = particle diameter, diffusion coefficient
e = roughness of pipe wall, electron
e_i^j = interaction coefficient describing influence of j on activity coefficient of i in weight percent scale
E = electrode potential, activation energy, internal energy, extraction coefficient
E = eddy conductivity, activation energy for conduction
f = Henrian activity coefficient
F = fraction of reaction completed, force, Faraday constant
F_B = view factor
Fo = Fourier's number
g = gram, acceleration due to gravity
G = free energy
ΔG = a finite change in free energy
G° = standard free energy
$\overline{G}_i$ = partial molar free energy of species i
Gr = Grasshoff's number
h = heat transfer coefficient, Planck's constant, Henrian activity, hour
H = enthalpy, heat content
i = constituent of a solution, current density
I = current
j = constituent of a solution
J = Joule
k = rate constant of a reaction
k_m = mass transfer coefficient
K_B = Boltzmann's constant
K_e = equilibrium constant
l = length
L = length, characteristic length
m = mass
M = mass, molecular mass, symbol for metal
n = number of mols
$\dot{n}$ = rate in mols per unit time
N = Avogadro's number
Nu = Nusselt's number
p_i = partial pressure of species i
P = total pressure
Pr = Prandtl's number
Q = volumetric flow rate
r = radius

R = Universal gas constant, electrical resistance
R_{th} = thermal resistance
Re = Reynold's number
S = cross sectional area for flow, surface renewal factor, entropy, space velocity, surface
Sc = Schmidt's number
Sh = Sherwood's number
t = time
t_R = residence time
T = temperature
u = velocity
U = overall heat transfer coefficient
V = volume, voltage, 'Vee' ratio
X = mole fraction
Z = valency

Greek Letters

α = Stoichiometric factor, thermal diffusivity, fraction of radiation absorbed
β = coefficient of volumetric thermal expansion
γ = activity coefficient
∂ = thickness, partial derivative
δ = thickness, partial derivative
$\delta_{c,\,eff}$ = effective concentration boundary layer thickness
$\delta_{T,\,eff}$ = effective thermal boundary layer thickness
Δ = finite difference
ε = interaction parameter in terms of mole fraction, emissivity, porosity, a characteristic energy term in heat transfer
η = viscosity
η' = dimensionless position
η_a, η_c = overpotential at anode and cathode
χ = electrical conductivity
λ = thermal conductivity, wavelength of light, equivalent conductivity
μ = chemical potential
ρ = density
σ = surface tension, Stefan-Boltzman constant, number of molecules hitting unit area on wall
θ = dimensionless temperature, angle, fraction of surface covered by adsorbed gas
τ = fraction of radiation transmitted, tortuosity factor, shear stress, space time
ω = fraction of radiation reflected
[A] = A in metallic solution
(A) = A in oxide solution
[=] = has the dimensions of

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