New Technology of Unconventional Metallurgy

Jinhui Peng Libo Zhang Hongying Xia
Shaohua Ju Guo Chen Lei Xu

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Preface

Unconventional metallurgy is a new technology developed in recent years, mainly focusing on major pressing issues of comprehensive utilization of mineral resources, energy saving and emission reduction, and deep processing of value-added metallurgical products in metallurgical industry, using modern technology to improve traditional metallurgical process, developing an efficient and environment-friendly new metallurgical reactor, deepening metallurgical theory and process under the outside fields and extreme conditions, obtaining the original innovations and intellectual property in the fields of unconventional metallurgy, enhancing the scientific and technological innovation in metallurgical industry, and promoting the leading role of the metallurgical industry on the national economy and social development. At present main research interests include: (1) novel technology of microwave metallurgy; (2) application of microwave technology in materials science and chemical engineering; (3) novel technology of ultrasonic metallurgy and micro-fluidics metallurgy.

As a green heating mode, microwaves heat materials directly through internal energy dissipation of materials, with advantages of selective heating, fast heat rate and high efficiency, and furthermore can lower the reaction temperature, shorten the reaction time, resulting in the energy saving and consumption reducing, is one of the effective way to realize clean production in metallurgical industry. So, it is of great importance to develop new microwave metallurgical technology. In recent years, the authors and members of the research group have conducted in-depth research on microwave metallurgy technologies, built up the microwave heating network models; determined the dielectric properties and temperature rising characteristics of metallurgical materials in microwave field, in-

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vestigated changes of material properties by microwave drying, reduction, calcining, roasting and leaching; and carried out the application of microwave new technology in materials science and chemical engineering, promoted the comprehensive utilization of the strategic non - ferrous metals refractory resources in China.

The cavitation effects, mechanical effects and thermal effects of ultrasonic can make the ultrasonic wave produce fast and intensive mechanic motion when propagation in a liquid, forming bubbles or holes, when the bubbles shrink rapidly, they would result in local high temperature and high pressure accompanied by an intense shock wave, promoting phase boundary and interface updating and disturbing, accelerating the heat and mass transfer, which has been widely used in metallurgical, chemical, solution purification and other fields. The authors and members of the research group investigated the typical metallurgical units of ultrasonic metallurgy, studying the leaching kinetics of zinc residue under ultrasonic field, and compared with conventional leaching process, showing that the ultrasound technique can make up for the shortcomings of traditional hydrometallurgy technology, strengthening the leaching process and reducing the processing time, is a new and effective way.

Micro - fluid metallurgical technology refers to techniques of control, manipulation and detection of complex fluids under the microscopic size, realizing the micro - and nano - level mixing, mass transfer and reaction in a micro - channel. The authors and members of the research group investigated the typical metallurgical units of micro - fluidic metallurgy, studying the extraction, separation of In, Fe and Zn by micro - fluids, realizing the separation of In and Fe, Zn, shortening the reaction time, and enhancing the security of the process; for the separation extraction of nickel and cobalt ions, the micro fluidic single - stage extraction efficiency increased more than 10%, total extraction stages can be reduced by 4 levels. Combined with the advantages of fast mixing mass transfer rate, reacting homogenously, continuous stable of micro - fluidic technology, realizing the continuous rapid preparation process of nano – powders through micro – channel mixing. Micro – fluidic metallurgical technology has been developing rapidly, promoting industrial upgrading of the metallurgical industry by using its advantages of high efficiency, low consumption and safety, to transform unit processes of the traditional metallurgical industries with disadvantages of low efficiency and high consumption, such as the extraction, heat transfer and mixing.

The book is divided into four chapters. The Chapter Ⅰ discusses the application of microwave metallurgical technology in the drying, reduction, calcining, roasting, leaching, comprehensive utilization of the metallurgical material and process simulation of interaction between microwave field and materials; the Chapter Ⅱ introduces the application of microwave technique in material science and chemical engineering, such as novel materials preparation by microwave sintering, and the comprehensive utilization of waste/spent catalyst and the regeneration of activated carbon; the Chapter Ⅲ describes the effect of ultrasonic metallurgical technique on the process of zinc residue leaching and model of leaching kinetics; the Chapter Ⅳ introduces the application of micro – fluid metallurgical technique in the extraction separation and the synthesis of nano – powders. The book is informative, illustrated, reader – friendly and practical, not only has practical value, but also make it easier for the reader's understanding of new technologies and innovation.

Authors refer to a number of books and literatures in the process of writing the book, the authors pay the deep respect and gratitude to whom concerned the book and gave suggestions and comments. Special thanks go to the National Science Foundation of China, Fund of Ministry of Science and Technology and Ministry of Education, Yunnan Provincial Natural Science Foundation and Supports of Corporate. With these supports, the authors can carry out the uninterrupted research on unconventional metallurgical technique, and included the results in the book. This book was completed under the guidance of me and members of

the research group, the achievements of research group in the book are always impregnated with successive sweat and wisdom of doctoral students, graduate and undergraduate students, here, I would like to take the occasion of completing the book to give my heartfelt thanks to them.

The authors are aware that the expertise is limited and that there may be some errors in the book. If so, please do not hesitate to point them out.

Jinhui Peng
January 2015

About the Author

Jinhui Peng was born in December 1964 and got the doctor's degree from Kunming University of Science and Technology in 1992, then got to Germany and England for postdoctoral research from 1994 to 1996 and from 1999 to 2000, respectively. Now he is a tutor of Ph. D students in the field of non – ferrous metallurgy and chairman of the Key Laboratory of Unconventional Metallurgy, Ministry of Education, at the same time, he is foreign academician of Academy of Natural Sciences, Russia, and Institute of International Mineral Resources, meantime, he also enjoys the special allowance of the State Department.

Prof. Jinhui Peng has devoted himself to establishing the new technology of unconventional metallurgy, accomplished more than 70 projects of 973 Program, 863 Program, National Natural Science Foundation of China, International S&T Cooperation Program of China, Science Foundation of Ministry of Education of China, Key Enterprise Entrusted Brainstorm Project, etc. He has won many prizes of state technological invention award, science and technology innovation prize of Ho Leung Ho Lee foundation, award nomination for the top ten national excellent science and technology workers, outstanding contribution award for national science & technology during the "11th Five – Year Plan", etc. In addition, **Prof. Jinhui Peng** is one of the sixth discipline appraisal group members of the state department, a subject matter expert for 863 Program during the "12th Five – Year Plan", and one of reviewing expertise group members of post – doctoral research station. **Prof. Jinhui Peng** has published 4 books, more than 500 papers, and 160 patents.

As a project engineer, the research results achieved by **Prof. Jinhui Peng** are in the international advanced level. The group independently developed a series of new type of microwave high temperature device, and established some large – scale, continuous, and automatic microwave high temperature pilot lines, which are successfully used for material modification, waste comprehensive utilization, and metallurgical products, etc., achieving the aim of high efficiency, energy saving and environment friendly.

Contents

Chapter Ⅰ New Technology of Microwave Metallurgy

Microwave Sensor for Measuring the Properties of a Liquid Drop ··· 3

A New Equation for the Description of Dielectric Losses under Microwave Irradiation ··· 12

Microwave Absorbing Properties of High Titanium Slag ··· 20

Microwave Cavity Perturbation Technique for Measuring the Moisture Content of Sulphide Minerals Concentrates ··· 29

Effect of Temperature on Dielectric Property and Microwave Heating Behavior of Low Grade Panzhihua Ilmenite Ore ··· 32

Dielectric Properties and Temperature Increase Characteristics of Zinc Oxide Dust from a Fuming Furnace ··· 44

Temperature and Moisture Dependence of the Dielectric Property of Silica Sand ··· 56

Dielectric Properties and Optimization of Parameters for Microwave Drying of Petroleum Coke Using Response Surface Methodology ··· 68

Dimension Optimization for Silica Sand Based on the Analysis of Dynamic Absorption Efficiency in Microwave Drying ··· 87

Optimization of Processing Parameters for Microwave Drying of Selenium - rich Slag Using Incremental Improved Back - propagation Neural Network and Response Surface Methodology ··· 95

Dielectric Properties and Microwave Heating Characteristics of Sodium Chloride at 2. 45GHz ··· 105

Preparation of Reduced Iron Powders from Mill Scale with Microwave Heating: Optimization Using Response Surface Methodology ··· 120

Carbothermal Reduction of Low - grade Pyrolusite by Microwave Heating ··· 133

Pilot - scale Production of Titanium - rich Material Using Ilmenite Concentrates as Raw Materials by Microwave Reduction ··· 144

Optimization of Preparation for Co_3O_4 by Calcination from Cobalt Oxalate Using Response

Surface Methodology 153
Prediction Model of Ammonium Uranyl Carbonate Calcination by Microwave Heating Using Incremental Improved Back - Propagation Neural Network 164
Investigation on Phase Transformation of Titania Slag Using Microwave Irradiation 174
Leaching of Palladium and Rhodium from Spent Automobile Catalysts by Microwave Roasting 182
Leaching Zinc from Spent Catalyst: Process Optimization Using Response Surface Methodology 190
Green Evaluation of Microwave - assisted Leaching Process of High Titanium Slag on Life Cycle Assessment 201
Removing Chlorine of CuCl Residue from Zinc Hydrometallurgy by Microwave Roasting 212
Dechlorination of Zinc Dross by Microwave Roasting 222
Removal of Fluorides and Chlorides from Zinc Oxide Fumes by Microwave Sulfating Roasting 231
An External Cloak with Arbitrary Cross Section Based on Complementary Medium and Coordinate Transformation 241
An Efficient 2 - D FDTD Method for Analysis of Parallel - Plate Dielectric Resonators 252
Efficient Analys is of Ridged Cavity by Modal FDTD Method 258
Parallel Algorithm for the Effective Electromagnetic Properties of Heterogeneous Materials on 3D RC Network Model 267

Chapter II New Technology of Microwave Applications in Material and Chemical Engineering

Microwave Plasma Sintering of Nanocrystalline Alumina 277
Influences of Temperatures on Tungsten Copper Alloy Prepared by Microwave Sintering 281
Application of Response Surface Methodology (RSM) for Optimization of the Sintering Process of Preparation Calcia Partially Stabilized Zirconia (CaO - PSZ) Using Natural Baddeleyite 289
Microwave Initiated Self - Propagating High - Temperature Synthesis of SiC 301
Microwave Ignited Combustion Synthesis of Aluminium Nitride 310
Microwave Initiated Self - Propagating High Temperature Synthesis of Materials: A Review 315

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Synthesis and Microwave Absorbing Properties of Corundum – mullite Refractories 334
Improvement of Electrochemical Properties of $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ by Coating with $La_{0.4}Ca_{0.6}CoO_3$ 341
Influence of Carbon Coating Prepared by Microwave Pyrolysis on Properties of $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ 351
Preparation of High Surface Area Activated Carbon from Coconut Shells Using Microwave Heating 360
Comparison of Activated Carbon Prepared from Jatropha Hull by Conventional Heating and Microwave Heating 373
Comparison between Microwave and Conventional Thermal Reactivations of Spent Activated Carbon Generated from Vinyl Acetate Synthesis 385
Utilization of Crofton Weed for Preparation of Activated Carbon by Microwave Induced CO_2 Activation 396
Regeneration of Microwave Assisted Spent Activated Carbon: Process Optimization, Adsorption Isotherms and Kinetics 411
Pilot – scale Extraction of Zinc from the Spent Catalyst of Vinyl Acetate Synthesis by Microwave Irradiation 431

Chapter Ⅲ New Technology of Ultrasonic Metallurgy

A Comparison of the Conventional and Ultrasound – Augmented Leaching of Zinc Residue Using Sulfuric Acid 445
Leaching Kinetics of Zinc Residues Augmented with Ultrasound 460

Chapter Ⅳ New Technology of Microfluidic

Microfluidic Solvent Extraction and Separation of Cobalt and Nickel 475
Synthesis of Copper Nanoparticles by a T – shaped Microfluidic Device 485
Solvent Extraction of In^{3+} with Microreactor from Leachant Containing Fe^{2+} and Zn^{2+} 494

About the Laboratory 502

Chapter Ⅰ

New Technology of Microwave Metallurgy

Microwave Sensor for Measuring the Properties of a Liquid Drop[●]

Ming Huang, Jingjing Yang, Jiaqiang Wang, Jinhui Peng

Abstract: A novel microwave sensor for measuring the properties of a liquid drop has been invented, its analytical theory established and a working prototype has been constructed and tested. It was also found that the theory based on the microwave sensor is in good agreement with the experimental results. Excellent linearity is achieved by optimizing the design, with an accuracy of distilled water drop volume measurement of approximately 0.5μL, and this microwave sensor has been used to measure surface tension, species concentration and the microwave absorption properties of a liquid drop simultaneously, which are the key parameters in the fields of physical chemistry and microwave chemistry.

Keywords: liquid drop; microwave sensor; surface tension; absorption properties

1 Introduction

The formation of drops is a phenomenon ubiquitous in daily life, science and technology[1]. It is found that a great deal of information on liquid properties is contained in the process of drop formation. This makes it possible to measure several physical parameters of a liquid by using dropanalysis. The development of a fibre drop multianalyser has been reported over the last 15 years[2]. It has proved to be a powerful analytical tool for determining the physical and chemical characteristics of liquids. More recently, capacitive tensiography has been reported[3,4]. It has been demonstrated that the capacitive transducer gives a direct measurement of the volume in the pendant liquid drop, with a resolution of 1μL.

It is well known that microwave and infrared form a continuous electromagnetic spectrum that extends from RF frequency to optical wave. It has been shown that the RF capacitive sensor and fibre sensor can measure the parameters of a liquid drop[2,3]. Therefore, it is possible to measure the parameters of a liquid drop by a microwave sensor. The objective of this paper is to apply the microwave sensor for the measurement of the parameters of a liquid drop. Preliminary experiments have been carried out and these show that the microwave sensor is capable of measuring drop volumes with an accuracy of down to 0.5μL. It can also measure microwave absorption properties, species concentration and surface tension simultaneously.

2 Theory

Microwave sensors based on cavity perturbation techniques have been studied by many research-

● This article was reviewed in "Nature CHINA" on 6 June 2007.

ers[5,6]. Measurements of a liquid drop are performed by inserting a small, appropriately shaped liquid drop into a cavity and determining the properties of the liquid drop from the resultant change in the resonant frequency and loaded quality factor which is given by[7]

$$f_0 - f_s = \frac{1}{2}(\varepsilon'_r - 1) f_s W_0^{-1} \int_{v_s} E \cdot E_0^* \, dv \tag{1}$$

$$Q_s^{-1} - Q_0^{-1} = \frac{1}{2} W_0^{-1} \varepsilon''_r \int_{v_s} E \cdot E_0^* \, dv \tag{2}$$

here $\varepsilon_r = \varepsilon'_r - j\varepsilon''_r$ is the complex permittivity of the liquid drop; ε'_r and ε''_r are the real part and the imaginary part; E_0 is the field in the unperturbed cavity and E is the field in the interior of the liquid drop; v_s is the volume of the liquid drop; Q_0 and f_0 are the quality factor and resonance frequency of the cavity in the unperturbed condition respectively and Q_s, f_s the corresponding parameters of the cavity loaded with the liquid drop; W_0 is the total energy stored in the cavity.

Under the quasi - static approximation, the electric field within a liquid drop sphere placed in a uniform external electric field E_0 is given by[8]

$$E = \frac{3E_0}{\varepsilon'_r + 2} \tag{3}$$

Substitution of this expression into (1) yields the usual expression for the perturbation of the frequency by a small liquid drop sphere,

$$\Delta f = f_0 - f_s = \frac{3E_0^2(\varepsilon'_r - 1) f_s}{2W_0(\varepsilon'_r + 2)} V_s(t) \tag{4}$$

where $V_s(t)$ is the volume of the liquid drop which grows in the process of drop formation. Eq. (4) indicates that the resonant frequency change Δf of the cavity is directly proportional to $V_s(t)$.

The microwave cavity is a two - port network. The insertion loss and half power width of this network can be written as[9]

$$T = \frac{2\sqrt{\beta_1 \beta_2}}{1 + \beta_1 + \beta_2} \tag{5}$$

$$Q_s = \frac{f_s}{B} \tag{6}$$

where T is the insertion loss of the network, and $T = (P_{in} - P_{out})/P_{in}$; P_{in} and P_{out} are the microwave input power and the microwave output power of the cavity respectively; β_1 and β_2 are the input coupling coefficient and the output coupling coefficient of the network respectively, and $\beta_1 = Y_{01}/n_1^2 G$, $\beta_2 = Y_{02}/n_2^2 G$; Y_{01} is the equivalent input admittance of the network; Y_{02} is the equivalent output admittance of the network; n_1 and n_2 are the turns ratio of the input ideal transformer and the turns ratio of the output ideal transformer, respectively; G is the equivalent conductance of the networks; B is the half power width of the network.

Suppose that n_1, n_2, Y_{01}, Y_{02} are constant, and $R = 1/G = k\varepsilon''_r V_s(t)$, where R is directly proportional to $V_s(t)$ with a coefficient k, $\beta_1 \ll 1$, $\beta_2 \ll 1$, then from Eq. (5), the following can be obtained

$$P_{out} = 1 - \frac{2\sqrt{\beta_1 \beta_2}}{1 + \beta_1 + \beta_2} \cdot P_{in} \approx 1 - 2\sqrt{\beta_1 \beta_2} \cdot P_{in}$$

$$= 1 - \frac{2P_{in}\varepsilon''_r k\sqrt{Y_{01}Y_{02}}}{n_1 n_2} \cdot V_s(t) = 1 - \frac{2P_{in}k'\varepsilon''_r}{n_1 n_2} \cdot V_s(t) \tag{7}$$

where $k' = k\sqrt{Y_{01}Y_{02}}$. Eq. (7) indicates that the larger the volume $V_s(t)$ of the liquid drop, the smaller the output power P_{out} of the cavity. Therefore, the smaller the P_{out}, the smaller the output voltage of the cavity, and the output voltage of the cavity is inversely proportional to $V_s(t)$.

Substituting Eq. (3) into Eq. (2) would yield

$$Q_s^{-1} = Q_0^{-1} + \frac{3\varepsilon''_r E_0^3}{2W_0(\varepsilon'_r + 2)} \cdot V_s(t) \tag{8}$$

Eq. (8) indicates that the larger $V_s(t)$ is, the smaller Q_s will be, and Q_s of the cavity is inversely proportional to $V_s(t)$.

3 Measuring equipment

The microwave sensor consists of a cavity, a microwave generator, an interface circuit, a detecting circuit and a computer. The cavity is a circular cylindrical E_{010} mode resonator, of which the resonance frequency is 2.45GHz, aperture diameter is 8 mm, the outside diameter of the liquid delivery tube is 3.5mm and the inside diameter of the liquid delivery tube is 1mm. The microwave generator is scan frequency with a resolution of 1MHz. The detecting circuit is composed of a linear detector, a low-pass filter and a 12-bit high speed A/D converter. The output voltage accuracy of the microwave sensor is 1.22mV. The sensor system was controlled by the computer. Its software ran in a windowsXP environment. The control software was programmed by visual basic. A structure diagram of the microwave sensor system is schematically presented in Fig. 1. The computer controlled the microwave generator through the interface circuit. The microwave signals were transmitted into the cavity. The output signals of the cavity were picked up by the detecting circuit. The data processing of the microwave sensor system was based on the computer.

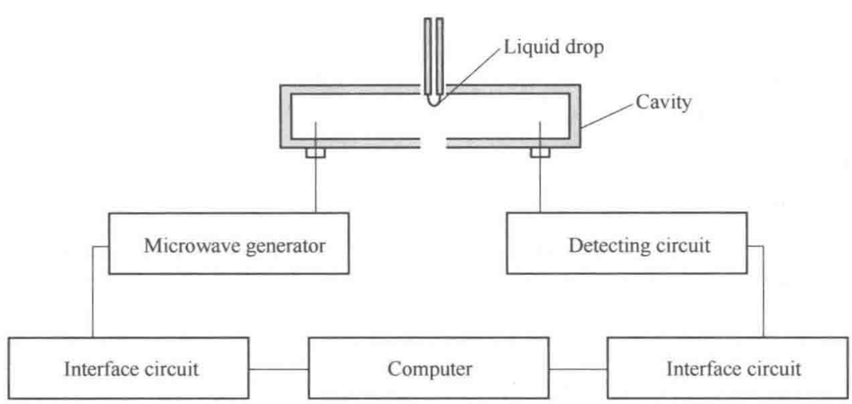

Fig. 1 Sketch of the microwave sensor for measuring the properties of a liquid drop

4 Results and discussion

Fig. 2 shows a 3D graph for constant-pressure delivery obtained from distilled water. Fig. 3 is ob-

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