

**Sohn  
International  
Symposium**

**ADVANCED PROCESSING OF  
METALS AND MATERIALS**

**New, Improved  
and Existing  
Technologies:**

- Iron and Steel**
- Recycling and  
Waste Treatment**

**Volume 5**

**Edited by  
Florian Kongoli  
Ramana G. Reddy**

**TMS**

**Sohn International Symposium**

**ADVANCED PROCESSING OF METALS AND MATERIALS**

Proceedings of the International Symposium

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VOLUME 5

**NEW, IMPROVED AND EXISTING TECHNOLOGIES:**

- IRON AND STEEL

- RECYCLING AND WASTE TREATMENT

Edited by

Florian KONGOLI

Ramana G. REDDY

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# FOREWORD

This international symposium is organized to honor the very distinguished work and lifetime achievements of Prof. H.Y. Sohn. Prof. Sohn is renowned for his impact in various fields such as non-ferrous, ferrous and nano-scale materials processing; in many processing routes including pyrometallurgy, hydrometallurgy, chemical vapor synthesis and processing and recycling; and in several investigation techniques such as experimental measurements and physical modeling and simulation. This symposium reflects this rich activity and covers the three equally important topical areas of **principles, technologies and industrial practice.**

The symposium was cosponsored by a record number of 104 Professional Organizations, Independent Publishers including 9 financial corporate cosponsors. It drew an overwhelming response from the international professional community. The 517 contributions received from all over the world made this symposium the biggest ever held in its class. Papers were sent by authors representing the following 52 countries: USA, Japan, China, Russia, Korea South, Australia, Canada, Turkey, Chile, India, Georgia, Mexico, Brazil, France, South Africa, Finland, Belgium, Germany, Argentina, Austria, Sweden, Great Britain, Norway, Albania, Egypt, Ukraine, Iran, Peru, Poland, Portugal, Czech Republic, England, Israel, Italy, Malaysia, Netherlands, Taiwan, Armenia, Bangladesh, Belarus, Bulgaria, Holland, Hungary, Indonesia, Nigeria, Serbia, Slovakia Republic, Slovenia, Spain, Switzerland, Venezuela, Zambia. (The order is according to the number of papers received). This record number of papers left us no option but to prepare 9 separate volumes totaling about 5,000 pages, classified according to the topical areas mentioned above although it should be noted that there is not a clear-cut classification. We believe that these volumes will be a useful contribution to the professional community worldwide.

We would like to express our appreciation to TMS successive Presidents Gregory Hildeman and Brajendra Mishra and successive TMS Executive Directors Alex Scott and Warren H. Hunt Jr. for their support and TMS staff for their help and dedication. In particular we would like to thank Christina Raabe, Michael Packard and Stephen J. Kendall for their continuous professional help as well as D. Steighner, B. Makowski, T. M. Osman, G. Miller, M. Boots, D. Prize, T. Dunlap, N. Commella, J. DeLuca, C. Wilson. We would also like to thank Professor Sohn's wife Mrs. Victoria (Bee Tuan Ngo) and their sons Berkeley Jihoon and Edward Jihyun for the cooperation.

Dr. Florian Kongoli would like to thank the Directors and staff of FLOGEN Technologies Inc. that not only sponsored financially the symposium but did the majority of the work. He wants to thank all the co-chairs of the symposium and especially Dr. Reddy for closer collaboration as well as all members of the international committees and authors. On a special note he wants to thank his wife Me. Migen Dibra for organizing a very interesting legal session and for graciously supporting him at a time when she was herself extremely busy working as a lawyer for a judge of the Quebec Court of Appeal. He also wants to thank his 6-year old son, Mr. Davis Kongoli, for forgiving the time that daddy was not staying with him as usual and his grand mother Madam Dibra for the help given during the extra hours of work dedicated to this symposium and proceedings.

Dr. Ramana G. Reddy wants to particularly thank the Chair of the symposium Dr. Florian Kongoli, whose leadership made this symposium in honor of Prof. Sohn such a big success. He also wants to thank both his wife, Mrs. Ramadevi Reddy, and his son, Mr. Bharat Reddy, for their continuous help and support.



**Dr. Florian Kongoli**

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**Dr. Ramana G. Reddy**

ACIPCO Professor and Associate Director  
Center for Green Manufacturing  
Dept. of Metallurgical and Materials Engineering  
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Tuscaloosa, Alabama, USA

## EDITORS' BIOGRAPHIES

### Dr. Florian Kongoli

Dr. Florian Kongoli, [BSc (Honors), MScA (Canada), PhD (Japan)/ MTMS, MCIM, MSME, MAIST, MSigmaXi, MIFAC, MACS] is **CEO of FLOGEN Technologies Inc.**, a new technology product company, independently incorporated in Canada and USA, specialized among others in the process and furnace control, optimization and automation as well as in developing low cost technologies for metallurgical, chemical and environmental industries through original physical modeling and simulation and experimental measurements.

He has **about 18 years** of research and development and academic (lecturer) experience spread in many long time invited engagements in several continents, such as in **Australia, Europe, North America, South America and Asia**. He has a rich research background in both **pure and industry sponsored research** dealing with the control, optimization and automation of furnaces, processes and flowsheets; physical and thermochemical modeling; physicochemical properties of mattes, slags, metals, gases, oxysulfides etc. He has worked and successfully carried out many industrial projects for more than 47 well-known metallurgical and chemical companies such as **Mitsubishi Materials Corporation and Sumitomo Metal Mining (Japan), Falconbridge (Canada), Western Mining Corporation (Australia)**, to mention just a few. In his pure research work he has worked and cooperated with several well-known universities around the world such as **Tohoku University (Japan), Curtin University (Australia), University of Montreal (Canada)**, etc. His work is oriented among others in developing new low cost technologies for process and furnace control through physical and physicochemical modeling, simulation and laboratory experimental studies applicable in various metallurgical, chemical and environmental processes in both non-ferrous (Ni, Cu, Zn, Pb, Fe-Ni, Fe-Cr, PGMs, etc.) extraction and processing as well as in iron and steel making and processing

Dr. Kongoli has published **4 books** and about **50 scientific articles** in the last 5 years in peer review journals and other publications dealing with furnace control, optimization and automation, novel technological applications, modeling of various properties of industrial mattes, slags, metals, liquidus temperature, phase diagrams, effect of minor components, fluxing strategies, etc. He has delivered in 19 countries around the world about **130 plenary, keynote and invited presentations as well as articles, technical reports and research presentations**. The results of his work and some of his databases have been used by several companies around the world. He has also taught several continuing education/short courses including **"Sulfide Smelting: Principles, Technologies and Environmental Considerations"** held in San Diego, CA, 2003

He has served in many **leadership positions** in national and international organizations. He has been and actually is Chair/Vice-Chair/member of about **20 professional society committees** and has been a chair of about **15 technical sessions**. He is **Editorial Board member** of European Journal of Mineral Processing and Environmental Protection and the Minerals and Metallurgical Processing Journal and a peer reviewer of articles in various professional journals. He has organized several major successful International Symposiums during the last years and has been member of Organizing Committees or Scientific Committees of about a **dozen** of Professional International conferences.

He has excellent business management and organizations skills which have been instrumental in steering his company toward new ground breaking technologies.

## **Dr. Ramana G. Reddy**

Dr. R. G. Reddy is an **ACIPCO Professor** of Department of Metallurgical and Materials Engineering and **Associate Director** of Center for Green Manufacturing at The University of Alabama, Tuscaloosa, Alabama. His academic and research work experiences include: **Professor and Chairman** of the Department of Chemical and Metallurgical Engineering at University of Nevada, Reno; **Visiting Researcher** at Lawrence Berkeley Laboratory, Berkeley; Indian Institute of Technology, Bombay; and Argonne National Laboratory, Chicago.

Professor Reddy has over **25 years of teaching and research experience** in the field of chemical and materials engineering. He obtained his Ph.D. degree from the University of Utah. He has conducted projects involving **thermodynamics and kinetics** of metallurgical reactions; plasma processing of materials, molten salts and ionic liquids electrolysis, and fuel cells.

He has **published over 286 research papers** in more than 40 journals and **10 books** including one undergraduate student **textbook in thermodynamics**. He has also delivered more than **168 invited lectures** and research presentations (43 invited, 12 distinguished /plenary and 4 keynote) in **20 nations** (United States, Austria, Australia, Belgium, Canada, Chile, Finland, France, Germany, Greece, India, Italy, Japan, Kuwait, Mexico, Netherlands, South Africa, Sweden, Turkey, and the United Kingdom). He is the recipient of **3 USA patents**.

As an Endowed Chair Professor in the college of engineering and administrator of many research projects (funding from including NSF, DOE, DOD, Industries), Dr. Reddy **advised and worked with over 75 research scholars, students and visiting scientists**. For his outstanding contribution to the field, **his alma mater** the University of Utah **recognized** him as a John Lewis **Distinguished Lecturer of the year**.

Dr. Reddy has served in many **leadership positions** within the College of Engineering, University and other national and international organizations. **Chair/member of 24 professional societies committees, 43 technical sessions, and 25 public and universities committees; consultant to 25 industries, federal institutions and Universities; taught 12 continuing education/short courses; Associate Editor of Journal of Phase Equilibria and Diffusion and Editor-in-chief of an International Journal for Manufacturing Science & Production**. He is serving on several committees at the materials societies including TMS, SME and ASM international. He has successfully **organized 18 national and international symposia** including most recently the National Science Foundation **2003 NSF Design, Service, and Manufacturing Grantees and Research Conference**. He was **appointed as the University of Alabama Coordinator for the National Space Science and Technology Center (NSSTC) and NASA**, and served as **Council Member for the Alabama State Committee for Department of Defense-EPSCoR programs**.

**Honors and awards** include: Who's Who in Technology Today, National Dean's list, Phi Kappa Phi, Tau Beta Pi Society. Several of his students received outstanding student /research awards. Dr. Reddy is a **Fellow of ASM International**. He has received the **Service Award** and the **Best Research Paper Award** from Light Metals Division, TMS. Dr. Reddy also received the **Research Award** from J. Manufacturing Society. He is the recipient of the **Eminent Engineer** of the Tau Beta Pi Society and also the **TMS Extraction & Processing 2002 Distinguished Lecture Award**, and the **2005 Milton E. Wordsworth Award for Extractive Metallurgy** of SME, a member society of AIME.

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**Symposium: Thermo and Physicochemical Principles**

Non-Ferrous High Temperature Processing: Kinetics: *F. Patisson, S. Seetharaman*  
Non-Ferrous High Temperature Processing: Thermodynamics I: *O. Yücel, M.E. Schlesinger*  
Non-Ferrous High Temperature Processing: Thermodynamics II: *Y. Waseda, K. Itagaki*  
Non-Ferrous High Temperature Processing: Recycling and Recovery: *F. Jorgensen, Juergen Antrekowitsch*  
Non-Ferrous High Temperature Processing: Waste Treatment: *J. Shibata, A. Fuwa*  
Ferro Alloys and Titanium Extraction: *A. Jha, R.H. Eric*  
Alloys and Refining Processes: *Bill Corcoran, M.I. Zinigrad*  
Experimental Measurements and Techniques: *K. Itagaki, R.W. Hyers*

Iron Making: Alternative Routes, Blast Furnace, Coke and Coal: *Y. Matsui, P. Chaubal*  
Steel Making: Thermodynamics and Kinetics: *T. Tanaka*  
Steel Making: Liquid Steel Processing and Reactors: *J. Zhang, Sridhar Seetharaman*  
Steel Making: Inclusions and Steel Cleanliness: *H. Todoroki, P. Gardin*  
Steel Making: Casting: *V. Seshadri, L. E. K. Holappa*  
Steel Making: Modeling and Processing: *H. Jalkanen, P.J. Koros*

Nano and Composite Materials I: *Y.-B. Hahn, R.Y. Lin,*  
Nano and Composite Materials II: *M. Kawakami, D. Chandra*  
Ceramics, Refractories and Polymers: *J.S.J. van Deventer, D. Forrest,*  
Aqueous Processing: Leaching and Flotation: *D. Fray, M. Cross*  
Aqueous and Electrochemical Processing I: *R. K. Mishra, V.G. Papangelakis*  
Aqueous and Electrochemical Processing II: *O. A. Bascur, D. Dreisinger*  
Electrochemistry and Molten Salts: *A.C. Powell, R. O. Suzuki*

**Symposium: New, Improved and Existing Technologies**

Non-Ferrous High Temperature Processing I: *Michael Potesser T. H. Okabe*  
Non-Ferrous High Temperature Processing II:- *Dinesh Agrawal, Christian Wieckert*  
Non-Ferrous High Temperature Processing III: *E. Vidal, U. Pal*  
Non-Ferrous High Temperature Processing IV: *A.V. Tarasov, L.Sh. Tzemekhman*

Materials Processing I: *Balashandran P. Kamath, Kalathur S. Narasimhan*  
Materials Processing II: Nano, Ceramic and Composite Materials: *O. Yamamoto, K. Koyama*  
Iron Making: *A. Ullah, J. J. Poveromo*  
Steel: *S. Asai, J.-Y. Hwang*

Recycling I: Batteries, Electronic Scrap, and Light Metals: *F. Tedjar, T. Takasu*  
General Recycling and Waste Treatment I: *Kang-in Rhee, A.E. Bohé*  
General Recycling and Waste Treatment II: *M. Pasetto, P.-D. Oudenne*  
Waste Treatment and Remediation: *P. Taylor, Robert W. Bartlett*

Aqueous Processing I: Leaching and Biotechnology: *S.K. Kawatra, R. Padilla*  
Aqueous Processing II: *M.C. Ruiz, W. Dunaway*  
Aqueous Processing III: Preparation and Synthesis: *T. Carvalho, Dirk Verhulst*  
Aqueous Processing IV: *G. Deschênes, N.E. Izatt*  
Electrochemistry: *M. Stelter, M. L. Free*  
Geothermal in Mineral Recovery and General Minerals Processing: *J.M. Canty, R.G. Bloomquist*

### **Symposium: Industrial practice**

Non-Ferrous High Temperature Processing: *A. Moyano*.  
Iron Making: *M. Naito, T. Usui*  
Steel: *Eugene Pretorius, A. K. Singh*  
Metals and Materials Processing: *R.D. Peterson, P.F Mendez*  
Aqueous and Electrochemical Processing: *C.G. Anderson, M. Brueggeman*

### **Sulfide Smelting**

Smelter Projects: *Y. Yasuda, F. Kongoli*  
Technologies and Recent Developments I: *M. Van Camp, U. Kerney*  
Technologies and Recent Developments II: *A. Lossin, C. Acuna??*  
Sulfur and Gas Handling: *T. Okura, K. Yamaguchi*,  
Analysis and Optimizations I: *T. Edens*  
Analysis and Optimizations II: *A. Vahed*

### **Symposium: Legal, Management and Environmental Issues**

Legal Perspectives: *M. Dibra, F. Kongoli*,  
Business Management: *B. Yalamanchili, Pedro Morales*  
Management of Environmental, Recycling and Waste Treatment I: *M. Palacios*  
Management of Environmental, Recycling and Waste Treatment II: *M. Sánchez*

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21. Cobalt Development Institute
22. Colegio de Ingenieros de Chile
23. CSIRO, Australia
24. Czech Society for New Materials and Technologies
25. Danish Ceramic Society
26. Danish Chemical Society
27. Danish Metallurgical Society
28. Electrochemical Society
29. Electrochemical Society of Japan
30. Engineering Conferences International
31. Eurometaux

32. European Ceramic Society (includes 23 societies)
33. Federation of European Materials Societies (includes 21 societies)
34. Georgian Ceramic Society
35. German Society for Mining, Metallurgy, Resource and Environmental Technology
36. Gintsvetmet Institute
37. Gipronickel Institute, JS
38. Hellenic Ceramic Society
39. Indian Institute of Metals
40. Institute for Nonferrous and Rare Metals
41. Institute of Materials Engineering Australasia
42. Institute of Materials, Minerals and Mining
43. Institute of Metals and Technology
44. Institute of Non-Ferrous Metals
45. Instituto Argentino de Siderurgia
46. Integrated Chemists of the Philippines
47. International Aluminium Institute
48. International Energy Foundation
49. International Lead Zinc Research Organization, Inc.
50. Iron and Steel Institute of Japan
51. Israel Chemical Society
52. Japan Institute of Metals
53. Jordanian Chemical Society
54. Korean Academy of Science and Technology
55. Korean Chemical Society
56. Korean Institute of Chemical Engineers
57. Korean Institute of Metals and Materials
58. Malaysian Institute of Chemistry
59. Materials Research Society
60. Materials Society of Portugal
61. Metallurgical Society of CIM
62. Minerals Engineering International
63. Mining and Materials Processing Institute of Japan
64. Nonferrous Metals Society of China
65. North American Thermal Analysis Society
66. Polish Association of Metallurgical Engineers and Technicians
67. Portuguese Chemical Society
68. Slovak Metallurgical Society
69. Slovenian Ceramics Society
70. Slovenian Society of Materials
71. Société Française de Chimie
72. Société Française de Métallurgie et de Matériaux
73. Societe Royale de Chimie
74. Society for Mining, Metallurgy, and Exploration
75. Society of Chemical Engineering Japan
76. South African Institute of Mining and Metallurgy
77. Swedish Society for Materials Technology
78. Swedish Steel Producers Association
79. Technologisch Instituut VZW
80. The American Ceramic Society
81. The Chemical Society of Thailand
82. The Finnish Association of Mining and Metallurgical Engineers

## **Independent Journals and Publishers**

1. Canadian Mining Journal
2. Ferrous Metals Journal
3. Industrial Minerals
4. Journal of Technical Electronic Materials
5. Magnesium Monthly Review
6. Materials Engineering News
7. Mineral and Metallurgical Processing
8. Mineral Processing Journal
9. Mining Journal
10. Nonferrous Metals Journal
11. Ore and Metals Publishing House
12. The European Journal of Mineral Processing and Environmental Protection

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