

Clearwater Clean Energy Conference 2017

42nd International Technical Conference on Clean Energy

Clearwater, Florida, USA
11-15 June 2017

Editor:

Barbara A. Sakkestad

ISBN: 978-1-5108-4498-8

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2017) by Coal Technologies Associates
All rights reserved.

Printed by Curran Associates, Inc. (2017)

For permission requests, please contact Coal Technologies Associates
at the address below.

Coal Technologies Associates
Post Office Box 1130
Louisa, Virginia 23093
USA

Phone: 540-603-2022

BarbaraSak@aol.com

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2633
Email: curran@proceedings.com
Web: www.proceedings.com

Table of Contents

Chemical Looping I

Dr. Ronald Breault, National Energy Technology Laboratory, U.S. Department of Energy, and Dr. Andrew Tong, Ohio State University

48. Development of an Advanced Oxygen Carrier Attrition Characterization Methodology for Chemical Looping Combustion

Harry Feilen M.S./M.E., Dr. Michael Mann, Dr. Steve Benson, Dr. Dan Laudal, University of North Dakota – Institute for Energy Studies; Dr. Srivats Srinivasachar, and Teagan Nelson, Envergen LLC, USA.....1

83. Real-time High Temperature Analysis of Natural Hematite During Cyclic Redox Gas Exposures for Chemical Looping Applications

Anna Nakano, Jinichiro Nakano, (AECOM), and James Bennett, U.S. Department of Energy National Energy Technology Laboratory, USA.....13

58. Oxygen Carrier Development of Calcium Manganite-Based Materials with Perovskite Structure for Chemical Looping Combustion of Methane

Patrick Moldenhauer, Peter Hallberg, Max Biermann, Tobias Mattisson, and Anders Lyngfelt, Department of Energy and Environment, Chalmers University of Technology,, SWEDEN; Frans Snijkers, Flemish Institute for Technological Research, NV (VITO), BELGIUM; and Knuth Albertsen, Euro Support Advanced Materials B.V., THE NETHERLANDS.....21

57. Attrition Prediction in Chemical Looping Systems

Ronald Breault, Samuel Bayham, and Esmail Monazam (REM Engineering Services), National Energy Technology Laboratory, U.S. Department of Energy; and Nathan Galinsky, Oak Ridge Institute for Science and Education, USA.....33

145. The Biomass-to-Syngas Chemical Looping Process for Thermochemical Gasification of Biomass

Andrew Tong, Dikai Xu, Yitao Zhang, Tien-Lin Hsieh, Mengqing Guo, Lang Qin, and Liang-Shih Fan, Ohio State University, USA.....41

Chemical Looping II

Dr. Ronald Breault, National Energy Technology Laboratory, U.S. Department of Energy, and Frederic Vitse, GE Power Systems

24. Development of a Spouted Fluid Bed Reactor for Chemical Looping Combustion

Johannes George van der Watt, Dr. Michael Mann, Ryder Shallbetter, Harry Feilen, and Dr. Daniel Laudal, University of North Dakota – Institute for Energy Studies; Dr. Gautham Krishnamoorthy, University of North Dakota – Department of Chemical Engineering; and Teagan Nelson, and Dr. Srivats Srinivasachar, Envergen, USA.....42*

17. Update on the GE Power Limestone-based Chemical Looping Process

Frederic Vitse, Steve Unker, Timothy Braun, David Sloan and Glen Jukkola, GE Power Inc., USA.....54

- 34. GE's 100 kW_{th} Pilot Scale Limestone-Based Chemical Looping Testing Facility**
Steve Unker, Frederic Vitse, David Sloan and Timothy Braun, GE Power Inc., USA.....66
- 5. Oxygen Polishing of Chemical Looping Combustion Flue Gases**
Jakob Johansson, Klas Andersson, Rikard Edland and Frederik Normann, Chalmers University of Technology, Department of Energy and Environment, SWEDEN77*
- 112. Scale-Up Production of Iron-based Oxygen Carriers for Coal-Fueled Chemical Looping Combustion: A Case Study of Rotary Kiln-Produced Red Mud**
Kunlei Liu, Jinhua Bao, Liang Kong, Heather Nikolic, and Zhen Fan, Center for Applied Energy Research, University of Kentucky, USA.....89

Chemical Looping III

Dr. Ronald Breault, National Energy Technology Laboratory, U.S. Department of Energy, and Dr. Daniel Laudal, UND – Institute for Energy Studies and Energy & Environmental Research Center

- 49. Chemical Looping Combustion Reference Plant Design and Sensitivity Studies Using NETL's Oxygen Carrier**
Robert Stevens, U.S. Department of Energy, National Energy Technology Laboratory; Richard Newby, KeyLogic Systems, Inc.. – NETL; and Dale Keairns, Deloitte Consulting, LLP - NETL, USA.....90
- 6. Transient Cold Flow Simulation of Fast Fluidized Bed Fuel Reactors for Chemical Looping Combustion**
Mengqiao Yang, Subhodeep Banerjee and Ramesh Agarwal, Washington University in St. Louis, USA.....91
- 103. Efficiency Analysis of Combined-Cycle Power Plants Operating with Chemical-Looping Combustion of Natural Gas for CO₂ Capture**
Chen Chen and George M. Bollas, Department of Chemical & Biomolecular Engineering, University of Connecticut, USA.....103
- 94. Coal Direct Chemical Looping Process Development and Scale-Up**
Luis Vargas, Christopher Poling and Thomas Flynn, Babcock & Wilcox; and Andrew Tong, Cheng Chung & Liang-Shih Fan, Ohio State University, USA.....104

Chemical Looping IV

Dr. Ronald Breault, National Energy Technology Laboratory, U.S. Department of Energy

- 91. Syngas Production from Natural Gas Using Chemical Looping Partial Oxidation: from Reaction Mechanism to Process Scale-up**
Dikai Xu, Andrew Tong, Tien-Lin Hsieh, Zhuo Cheng, Lang Qin, Mengqing Guo, and Liang-Shih Fan, William G. Lowrie Department of Chemical and Biomolecular Engineering, The Ohio State University, USA.....119

93. Autothermal and Allothermal State of 10 MW Chemical Looping Combustion and Chemical Looping with Oxygen Uncoupling Using Powder River Basin Coal as Fuel	
<i>Matthew A. Hamilton, Steve Stafsholt, and JoAnn S. Lighty, Department of Chemical Engineering, University of Utah, USA.....</i>	120

Supercritical CO₂ Cycle I

*Dr. Ligang Zheng, CANMET, Canada; and
Dr. Timothy Held, Echogen Power Systems (DE), Inc.*

18. A Breakthrough SCO₂ Primary Cycle for Air-Combustible Fuels	
<i>David Stapp, Peregrine Turbine Technologies, LLC, USA.....</i>	127

72. Supercritical CO₂ Cycles for Power Production	
<i>Joshua J. Stanislawski, Energy Systems Development, Energy & Environmental Research Center University of North Dakota, USA.....</i>	139

50. Techno-Economic Evaluation of Utility-Scale Power Plants Based on the Indirect Supercritical CO₂ Brayton Cycle	
<i>Walter W. Shelton, Nathan T. Weiland, Travis R. Shultz, and Richard A. Dennis, National Energy Technology Laboratory, U.S. Department of Energy; and Charles W. White, KeyLogic, USA.....</i>	140

111. Experimental Study on S-CO₂ Compressor Off-design Performances Operating Near the Critical Point	
<i>Seungjoon Baik, Seong Kuk Cho, Jeong Ik Lee, Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, KOREA.....</i>	145

134. Overview of the Supercritical Transformational Electric Power (STEP) 10 MWe Test Facility Program	
<i>Ganesan Subbaraman and Michael McDowell, Gas Technology Institute, USA.....</i>	155

Supercritical CO₂ Cycle II

*Dr. Ligang Zheng, CANMET, Canada, and
David Stapp, Peregrine Turbine Technologies, LLC*

66. Printed Circuit Heat Exchanger Steady-State Off-Design and Transient Performance Modeling in a Supercritical CO₂ Power Cycle	
<i>Timothy J. Held and Vamshi Avadhanula, Echogen Power Systems, Inc., USA.....</i>	156

108. Study of Supercritical CO₂ Compressor Surge Prediction	
<i>Seong Kuk Cho, Seong Gu Kim, and Jeong Ik Lee, Dept. of Nuclear & Quantum Engineering, Korea Advanced Institute of Science and Technology, KOREA.....</i>	168

51. Corrosion of Materials in Intermediate Temperature Supercritical CO₂	
<i>A. J. Mackrory and J. M. Sarver, The Babcock & Wilcox Company, USA.....</i>	177

- 105. Numerical Modeling of S-CO₂ Integral Experiment Loop Transient Condition**
Bong Seong Oh, Seong Kuk Cho, and Jeong Ik Lee, Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST); and Yoon Han Ahn, and Jae Eun Cha, Korea Atomic Energy Research Institute, KOREA.....189
- 107. Development of KAIST-STA (System Transient Analysis) Code and Validation and Verification Results for Transient Analyses of Supercritical CO₂ Brayton Cycle**
Seong Jun Bae, Won Woong Lee, Bongseong Oh, and Jeong Ik Lee, Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, KOREA.....197

Supercritical CO₂ Cycle III

Dr. Ligang Zheng, CANMET, Canada, and Joshua Stanislawski, Energy & Environmental Research Center, University of North Dakota

- 23. Materials and Manufacturing Challenges for Compact Heat Exchangers of Supercritical CO₂ Power Cycles**
Ömer N. Doğan, Monica Kapoor, Richard P. Oleksak, Casey S. Carney, U.S. Department of Energy, National Energy Technology Laboratory; and Rajesh V. Saranam, Patrick S. McNeff and B.K. Paul, Mechanical, Industrial, and Manufacturing, Oregon State University, USA.....209
- 89. Thermal Integration of Closed, Indirect Supercritical CO₂ Brayton Power Cycles with Oxy-Fired Heaters**
Andrew Maxson and Scott Hume, Electric Power Research Institute, Inc.; Barteve Sakadjian and Ted Thome, The Babcock & Wilcox Company; Kiho Hong, Doosan America ATS; Jason Miller and David Buckmaster, Echogen Power Systems, LLC; Wei Zhang, GE Power, USA; Dougal Hogg, Howden Group Ltd., UNITED KINGDOM.....219
- 131. A Novel Method for Selection of Working Fluids in Power Cycles**
Nenad Sarunac, Alireza Javanshir, and Zahra Razzaghpanah, University of North Carolina, Charlotte, USA.....231

Advanced Beneficiation I

Dr. Dave Osborne, Somerset International Australia Pty Ltd., Australia

- 16. Recovery of Ultrafine Coal from Plant Waste Streams Using the MRC HHS Process**
P. J. Bethell, Marshall Miller and Associates; S. Suboleski, N. Gupta, and J. Reyher, Minerals Refining Company; and N. Gupta, R.-H. Yoon and G.H. Luttrell, Virginia Tech, USA.....232
- 79. Optimizing Power Plant Performance Through Coal Beneficiation**
Mark Ness, P.E., and Sandra Broekema, Great River Energy; Nenad Sarunac, University of North Carolina at Charlotte; Una Nowling, Black & Veatch Corporation, USA.....240
- 92. Coal Treatment Helps Lakeland McIntosh Reduce Fuel Costs**
Ken Riddle, Lakeland Electric, USA.....242

102. Creating Value in the Coal Delivery Chain to a Captive Power Plant
Dr. Dave Osborne, Somerset International Australia Pty Ltd.; and Dan Eyre, Uniper Technologies Ltd., AUSTRALIA251

106. Effective Capture of Ultra-Fine Coal with State of the Art SUB325™ Centrifuge
T. Anthony Toney and Jeff Hayden, Somerset Coal International, USA.....252

Advanced Beneficiation II

Dr. Dave Osborne, Somerset International Australia Pty Ltd., Australia

142. Centribaric: A New Technology for Ultrafine Coal Recovery
G.H. Luttrell and R.-H. Yoon, Virginia Tech; T. Estes and W. Schultz, Decanter Machine Inc.; and J. Franklin, Jim Walter Resources, USA.....253

137. Nimble, Net-Negative CO₂ Power from Biomass
Louis Wibberley and Daniel G. Roberts, CSIRO Energy Technology, AUSTRALIA.....261

152. EDF Torrefied Biomass Test Burn
Mathieu Insa, Électricité du France (EDF), FRANCE.....262

Advanced Beneficiation III

Dr. Dave Osborne, Somerset International Australia Pty Ltd., Australia

139. Yield Enhancement via Fines Recovery
Alistair Harriman, Peabody Energy Australia; and James Graham and Kelly Walton Somerset International Australia Pty Ltd., AUSTRALIA.....263

141. Plant Trail for the Optimisation and Control of Dense Medium Cyclone Circuits
M. O'Brien, and S. Hu, CSIRO Energy Flagship; Andrew Taylor and P. Holtham, JKMR; and B. Firth, Consultant, AUSTRALIA.....265

129. Rapid Beneficiation of Coal Tailings Using Two-Stage Reflux Flotation
J.E. Dickinson, Centre for Advanced Particle Processing and Transport, and and K.P. Galvin, Newcastle Institute for Energy and Resources, The University of Newcastle, AUSTRALIA.....271

Solutions for Power Generation and Wastewater Treatment

Prasanna Seshadri, The Babcock & Wilcox Company, and Zel Jones, Tampa Electric Co.

30. First Evaluation of an Absorption Based Technology for Combined SO_x and NO_x Control using Chlorine Dioxide

Anette Heijnesson Hultén, Pär Nilsson, and Marie Samuelsson, Akzo Nobel Pulp and Performance Chemicals; Sima Ajdari, Fredrik Normann, and Klas Andersson, Department of Energy and Environment, Chalmers University of Technology, SWEDEN.....273

90. Long Term Environmental & Economic Sustainability of Existing Coal-Fired Power Generation
Byron Burrows, P.E., Lyndsey Figler, P.E. and Robert Velasco, P.E., Tampa Electric Co., USA.....282

144. Operating Challenges of Existing Air Quality Control Systems
Suzette Puski, Business Development, Babcock Power Inc., USA.....283

73. Dewatering a Beneficial Use of High Salinity Brines Extracted During CO₂ Storage
Jinesh Jain, Jason Arena, Alexandra Hakala, Christina Lopano, and Nicholas Siefert, National Energy Technology Laboratory, U.S. Department of Energy, USA.....295

99. Emerging Water Management Challenges at Coal-Fired Power Stations to Address New US EPA Regulations
Catherine Magliocco and Zel Jones, Tampa Electric Company, Big Bend Power Station; and Michael Condran and Matthew Munz, GHD, USA.....296

Advanced Energy Conversion

Massood Ramezan, KeyLogic

13. An Industrial Scale Test Rig for the Investigation of Heat Transfer to Supercritical Water in Advanced Power Engineering Applications
Gerrit A. Schatte, Andreas Kohlhepp and Hartmut Spliethoff (Bavarian Center for Applied Energy Research (ZAE Bayern), Institute for Energy Systems, Technische Universität München, GERMANY307*

19. OTM Combined Reformer for IGCC and CTL
Juan Li, Jamie Wilson, Shrikar Chakravarti, Sean Kelly, and Maxwell Christie, Praxair, Inc.; and Gokhan Alptekin, Ambal Jayaraman, and Byron Wall, TDA Research, Inc., USA.....319

39. Combined Heat and Power (CHP) Plants Offering Reliable and Environmental Friendly Solutions for Industrial and Commercial Applications
Dalia El Tawy, Siemens Energy, Inc., USA.....331

150. Energy Boost in Gas Power Station
J. Lichota, Wroclaw University of Technology, POLAND.....332

Carbon Dioxide Utilization

Ramesh Agarwal, Washington University in St. Louis

41. Advanced Catalysts for Chemicals Synthesis from Carbon Dioxide
Naomi Klinghoffer and Shiguang Li, Gas Technology Institute; and Xinhua Liang and Zeyu Shang, Missouri University of Science and Technology, USA.....334

119. Low Temperature Process for Ethylene Production from Shale and Coal Derived Flue Gases
Jadid E. Samad and Amit Goyal, Sustainable Chemistry and Catalysis, Southern Research, USA.....336

126. **Assessment of Leading Approaches for Carbon Capture and Utilization**
Dr. Lars-Erik Gaertner and Dr. Krish Krishnamurthy, The Linde Group, USA.....337

113. **University Coalition for Fossil Energy Research**
Joel L. Morrison, Bruce G. Miller, and Chunshan Song, The Pennsylvania State University, EMS Energy Institute, USA.....338

Combustion Fundamentals

*Dr. Edmundo Vasquez, Consultant,
Boiler Combustion and Emission Controls*

22. **Combustion Investigations with Colombian Coal: Summary of Experiments and Numerical Interpretation**
Martin Schiemann, Philipp Graeser, Sebastian Heuer, Nikita Vorobiev, and Viktor Scherer, Ruhr-University Bochum, Department of Energy Plant Technology, GERMANY.....349

27. **Influence of Devolatilization Conditions on Char Reactivity**
Nikita Vorobiev, Martin Schiemann, Ruhr-University Bochum, Department of Energy Plant Technology, GERMANY, and Osvalda Senneca, IRC-CNR, ITALY361*

61. **Rheological Properties and Ignition and Combustion Characteristics of Biochar-Algae-Water (BAW) Slurry Fuels**
Mingming Zhu, Zhezi Zhang, Pengfei Liu and Dongke Zhang, Centre for Energy (M473), The University of Western Australia, AUSTRALIA.....372

63. **Volatile Release During Pulverised Coal Injection as a Factor in Determining Combustability**
Prof. Terry Wall and Dr. Liza Elliott, Chemical Engineering, University of Newcastle, AUSTRALIA.....381

33. **Chemiluminescence Measurements in a Pulverized Fuel Furnace of Pure Torrefied Biomasses in Comparison to Solid Fossil Fuels**
G. Möller, A. Maßmeyer, J. Hees, D. Zabrodiec, M. Habermehl, and R. Kneer, Institute of Heat and Mass Transfer, RWTH Aachen University, GERMANY.....387

Gasification Technologies

Massood Ramezan, KeyLogic

81. **Application of Liquid and Gaseous CO₂ in Enhancing Coal and Biomass Gasification and Energy Recovery; Use in Distributed Power Systems**
John P. Doohar, Adelphi University/Doohar Institute of Physics and Energy; Marco J. Castaldi, Chemical Engineering Department, the City College of New York, City University of New York; and Dean Modroukas, Innoveering, USA.....399

117. **Eulerian-Eulerian Modeling of Fluidized Bed Gasification: Intrinsic and Surface-based Submodels**
P. Roessger, and A. Richter, Institute for Chemical Engineering, Technische Universität Bergakademie Freiberg, Freiberg, GERMANY; and P. Nikrityuk, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, CANADA.....411

- 125. Experiences from Biomass Gasification for Advanced Biofuel Production in Industrial Scale**
Henrik Thunman, Teresa Berdugo Vilches, Jelena Maric and Martin Seemann, Division of Energy Technology, Chalmers University of Technology, SWEDEN412
- 127. Kinetic Study of Coke Gasification Behaviour with Carbon Dioxide: Thermogravimetric Analysis**
Sania Tasnim Basher, Deepak Pudasainee, Rajender Gupta Department of Chemical and Materials Engineering, University of Alberta, CANADA.....424
- 96. Modular Energy Systems**
Dave Lyons, U.S. DOE, National Energy Technology Laboratory; and Chuck Pruss, and Massood Ramezan, KeyLogic Systems, Inc., USA.....426

Small Scale Power Production

Dr. James, Fisher, NETL, U.S. Department of Energy

- 38. Coal Electrolysis for the Removal of Mercury and Hydrogen Production**
Alamgir Mojibul, Xiang Lyu and Gerardine G. Botte, Center for Electrochemical Engineering Research Department of Chemical and Biomolecular Engineering Russ College of Engineering and Technology, USA.....427
- 110. Enabling Technologies for Industrial-Scale Production of High Purity Hydrogen**
Michael Dolan, Daniel Roberts, and David Harris, CSIRO Energy, AUSTRALIA.....428
- 123. Development of a Modular Coal/Biomass to Liquids Process Pilot Research Facility**
Andrew Placido, Rodney Andrews, Don Challman and Kunlei Liu, University of Kentucky, Center for Applied Energy Research, USA.....429
- 124. Microwave-assisted Coal conversion to Value-added Chemicals**
Dushyant, Shekhawat, Mark Smith, Victor Abdelsayed (AECOM), Christina Wildfire and Mike Spencer (Oak Ridge Institute of Science and Education), National Energy Technology Laboratory, U.S. Department of Energy, USA.....441

Modeling

*Dr. Edmundo Vasquez, Consultant,
 Boiler Combustion and Emission Controls*

- 68. System-level Dynamic Simulation and Optimization of a Subcritical Power Plant under Time-Varying Power Load and Carbon Footprint Constraints**
Chen Chen, George M. Bollas, Department of Chemical & Biomolecular Engineering, University of Connecticut, USA.....442
- 100. A Comparison of Combined Measured Spectral Water Vapor and Broadband Particle Emissions with Modeled Spectral Emissions**
John Tobiasson and Dale R. Tree, Brigham Young University, USA.....444

- 40. Computational Modelling of High Temperature-entrained Flow Reactor for Coal Pyrolysis**
M.A. Kibria, Pavan Pramod Sripada, and Sankar Bhattacharya, Dept. of Chemical Engineering, Monash University, AUSTRALIA (This paper was withdrawn as we went to "press" and couldn't be deleted).....N/A

Solutions to Fouling and Slagging Deposition

Dr. James Bennett, NETL, U.S. Department of Energy

- 85. Investigations of Fouling and Slagging in High Temperature Gasification and Use of that Information to Minimize Those Tendencies**

James Bennett, Jinichiro Nakano and Anna Nakano (AECOM), National Energy Technology Laboratory, U.S. Department of Energy, USA.....459

- 87. Sulfate Removal by Kaolin Addition to Address Fouling in the Full-scale Furnace Burning High-alkaline Zhundong Coal**

Xuebin Wang, Renhui Ruan, Adewale Adeosun, Richard L. Axelbaum, Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis, USA; Bo Wei and Houzhang Tan, MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, CHINA.....471

- 76. The Influence of Temperature on the Spectral Emittance of Ash Deposits taken from a 1.5 MW, Pulverized Coal Test Facility**

Teri Draper, Lauren Kolczynski, Andrew Fry, Terry Ring, and Eric Eddings, Department of Chemical Engineering and Institute for Clean and Secure Energy, University of Utah, USA; and Jeanette Gorewoda, and Viktor Scherer, Department of Mechanical Engineering and Energy Plant Technology, Ruhr University Bochum, GERMANY.....481

- 20. Effects of Flexible Operation Modes on Deposits from Hard Coal Combustion**

Matthias Dohrn, and Michael Müller, Institute of Energy and Climate Research, Microstructure and Properties of Materials (IEK-2), GERMANY.....482*

- 21. Investigations of Fireside Corrosion for Biomass Co-Firing Condition in Boiler Tube**

Seuk Cheun Choi, Youngjae Lee and Seokkyun Park, Thermochemical Energy System R&BD Group, Korea Institute of Industrial Technology, SOUTH KOREA.....493

- 132. Experimental and Numerical Study of BP-1150 Boiler Operation for Evaluation of the Fouling and Corrosion Risks**

Robert Lewtak, and Sławomir Kakietek, Department of Thermal Processes, Institute of Power Engineering, POLAND.....500

Biomass

Les Marshall, Ontario Power Generation, Canada, and Mathieu Insa, Électricité du France (EDF), France

- 2. Synergistic Effects in Steam Gasification of Combined Biomass and Plastic Waste Mixtures**

K. G. Burra, and A. K. Gupta, Combustion Lab, Department of Mechanical Engineering, University of Maryland, USA.....501*

- 59. Contrasting the Pyrolysis Behaviour of Selected Biomass and the Effect of Lignin**
Zhezi Zhang, Mingming Zhu, and Dongke Zhang, Centre for Energy (M473), The University of Western Australia; Philip Hobson and William Doherty, Sugar Research and Innovation, Centre for Tropical Crops and Biocommodities, Queensland University of Technology, AUSTRALIA.....507
- 4. Chemical Interactions Between NO, KCl and SO₂ in C₃H₈ Flames**
Thomas Ekvall, and Klas Andersson Department of Energy and Environment, Division of Energy Technology, Chalmers University of Technology, SWEDEN.....516*
- 78. Milling of Utah, Sufco Coal with 15% Prepared Manti – La Sal Woody Biomass in a Raymond Bowl Mill**
Andrew Fry, and Seyedhassan Fakourian, Department of Chemical Engineering, Brigham Young University; Eric Eddings, and Zsolt Dobó, Department of Chemical Engineering and Institute for Clean and Secure Energy, University of Utah; and Ken Clark, PacifiCorp, USA....528
- 44. Entrained Flow Gasification Characteristics of Pine Bark**
Pavan Pramod Sripada, Mahmud Arman Kibria, and Sankar Bhattacharya, Department of Chemical Engineering, Monash University-Clayton, AUSTRALIA.....529*
- 60. Effect of Biochar Addition and Temperature on Hydrogen Production in the First Phase of Two-Phase Anaerobic Digestion of Carbohydrates Food Waste**
Nimas M. S. Sunyoto, Mingming Zhu, Zhezi Zhang, and Dongke Zhang, Centre for Energy (M473), The University of Western Australia, AUSTRALIA.....541
- Oxy-Combustion I**
*Dr. Klas Anderson, Chalmers University, Sweden, and
 Dr. Andrew Fry, Brigham Young University*
- 47. Experimental Study of SO_x and NO_x Removal from Oxy-combustion Flue Gas under High Pressure**
Yujia Min, Piyush Verma, Young-Shin Jun, Prof. Benjamin Kumfer, and Prof. Richard Axelbaum Department of Energy, Environmental and Chemical Engineering; Washington University in St. Louis; and Prof. Gregory Yablonsky, Parks College, Department of Chemistry, Saint Louis University, USA.....548
- 25. Development Status of a Pilot Scale Coal Powered Oxy-fired Pressurized Fluidized Bed Combustor with CO₂ Capture**
Mark A. Fitzsimmons, William W. Follett IV, and Megan T. Huang, GTI; Stevan Jovanovic, and Makini Byron, Linde LLC, USA; David McCalden, and Scott Champagne, Natural Resources Canada; and Marc-Andre Seguin, and Poupak Mehrani, University of Ottawa, CANADA..... 552
- 3. NO Formation and Reduction in Flames with High Feed Gas Oxygen Concentrations**
Thomas Ekval, and Klas Andersson, Department of Energy and Environment, Division of Energy Technology, Chalmers University of Technology, SWEDEN.....564
- 130. Technology Development for a Pressurized Dry Feed Oxy-Coal Reactor – Program Overview**
Bradley Adams, Andrew Fry, and Dale Tree, Brigham Young University, USA.....576

148. An Investigation into the NO_x and SO_x Interaction in Oxy-combustion Flue Gas
Nujhat Choudhury, Ph. D. Candidate, and Dr. Bihter Padak Department of Chemical Engineering, University of South Carolina, USA.....596

86. The Synergetic Promotion of SO₃ and NO₂ Formation in the Post-flame Region of Pressurized Oxy-combustion

Xuebin Wang (MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University), Adewale Adeosun, Zhiwei Yang, Yuanzi Sun, and Richard L. Axelbaum- Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis; Grigory Yablonsky, Parks College of Engineering, Aviation & Technology, Saint Louis University, USA; and Houzhang Tan, MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, CHINA.....585

Oxy-Combustion II

Dr. Klas Anderson, Chalmers University, Sweden, and

Dr. Andrew Fry, Brigham Young University

55. Design and Commissioning of the Staged, Pressurized Oxy-Combustion Experiment

Zhiwei Yang, Adewale Adeosun, Dishant Khatri, Tianxiang Li, Benjamin M. Kumfer, and Richard. L. Axelbaum, Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis, USA.....603

77. Thermal Performance of a Maximum O₂ Concentration Oxy-Coal Flame in a 1.5 MW Pulverized Coal Combustor

Andrew Fry, Department of Chemical Engineering, Brigham Young University; Kevin Whitty, Zsolt Dobó, Department of Chemical Engineering and Institute for Clean and Secure Energy, University of Utah; Andrew Chiodo, and Kevin Davis, Reaction Engineering International, USA.....610

67. Oxy-fuel Co-Combustion of Coal and Biomass in Spouted Bed Reactor

Chunxiang Zhu and George M. Bollas, Department of Chemical & Biomolecular Engineering, University of Connecticut; and Benjamin Baird, Precision Combustion Inc., USA.....611

54. Predicting Ash Deposition from Non-Isothermal, Turbulent Parallel Flows: Application to Staged, Pressurized Oxy-Combustion

Zhiwei Yang, Akshay Gopan and Richard. L. Axelbaum, Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis, USA.....613

133. Model-Based Characterization of High Temperature Oxy-Coal Combustion Systems

Andrew Chiodo, Kevin Davis, Zhonghua Zhan, Dave Wang, Martin Denison, James Valentine, and Hong-Shig Shim, Reaction Engineering International; Kevin Whitty, Jost Wendt, and Yueming Wang, Department of Chemical Engineering and Institute for Clean and Secure Energy, University of Utah; Andrew Fry, Department of Chemical Engineering, Brigham Young University; and Mark Schoenfeld, Jupiter Oxygen, USA.....619

Oxy-Combustion III

*Dr. Klas Anderson, Chalmers University, Sweden, and
Dr. Andrew Fry, Brigham Young University*

62. Burner and Boiler Design Concepts for a Low Recycle, Staged, Pressurized Oxy-Combustion Power Plant

Akshay Gopan, Zhiwei Yang, Adewale Adeosun, Benjamin M. Kumfer, and Richard L. Axelbaum, Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis, USA.....629*

64. CO₂ Quality Control at the Callide Oxyfuel Project During Compression with Emphasis on NO_x, SO_x and Mercury Gases Which Impact Plant Operation

Prof. Terry Wall and Dr. Rohan Stanger, Chemical Engineering, University of Newcastle, AUSTRALIA.....635

151. SO₃ Formation and Implications for Low-Recycle and Pressurized Oxy-Combustion Systems

Klas Andersson and Fredrik Normann, Department of Energy and Environment, Chalmers University of Technology, SWEDEN; Eric Eddings, Department of Chemical Engineering, University of Utah; and Andrew Fry, Department of Chemical Engineering, Brigham Young University, USA.....639

82. Oxy-fuel Investigations with a Cement Kiln Prototype Burner

Francisco Carrasco-Maldonado, Simon Grathwohl, and Jörg Maier, Institute of Combustion and Power Plant Technology (IFK), University of Stuttgart, GERMANY.....650

Combustion Technologies & Issues

*Alan Paschedag, Covanta, and
J.J. Letcavits, American Electric Power*

10. Measurements and Modeling of the Soot Volume Fraction in Propane Flames Using Laser Techniques and Radiative Heat Transfer Models

Adrian Gunnarsson, Daniel Bäckström, and Klas Andersson, Energy and Environment, Chalmers University of Technology; and Johan Simonsson, Manu Mannazhi, and Per-Erik Bengtsson, Combustion Physics, Lund University, SWEDEN.....657*

65. Mitigation of Refractory Damage in a Slagging Coal Boiler Retrofit for Low NO_x Firing

James Valentine and Kevin Davis, Reaction Engineering International; Mark Simpson, Edward McGovern, and Annette Hope, Ohio Valley Electric Corporation, Kyger Creek Station; and J.J. Letcavits, American Electric Power, USA.....669

121. The Impact of Different Lignite Mass Share in the Hard and Lignite Coal Blend on Co-firing Behaviour and Parameters of PC Boiler

Halina Pawlak -Kruczek, Michał Ostrycharczyk, Marcin Baranowski, Marcin Dębowski, Michał Czerep, Jacek Zgóra, Krystian Krochmalny, and Mateusz Kowal, Wrocław University of Science and Technology; and Zbigniew Plutecki, Opole University, POLAND.....675

45. Validation and Prediction of Ultra-Low NO_x Burner Performance for Boiler Applications

Sandeep Alavandi, and David Cygan, Gas Technology Institute; and Anchal Jatale and Muhammad Sami, Ansys Inc., USA.....696

- 8. Impact of Biomass Co-Firing on Unreactive Coals in Pulverised Fuel Combustion**
C. Bridge, and Prof. C. Snape, University of Nottingham, Faculty of Engineering; and G. Kelsall, GE Power, Willans Works, Newbold Road, UNITED KINGDOM.....689

Energy Efficiency Technologies

Dr. Ashwani Gupta, University of Maryland

- 31. First Evaluation of Iron-Ore Pelletization with Heat Utilization**
Fredrik Normann, Adrian Gunnarsson, and Klas Andersson, Division of Energy Technology, Department of Energy and Environment Chalmers University of Technology; and Samuel Nordgren and Johan Sandberg, LKAB, SWEDEN.....707
- 14. A New Type of Catalyst Fixed-Bed Reactors: Proof of Concept**
Yi Ran Lu, and P. Nikrityuk, Department of Chemical and Materials Engineering, University of Alberta, CANADA717*
- 114. Deployment of Sustainable Energy Technologies in Pennsylvania: A Unique Funding Model in the United States**
Joel L. Morrison, The Pennsylvania State University, EMS Energy Institute, University Park, USA.....723
- 128. High Efficiency and Low Emission (HELE) Technology for Coal to Electricity: Integrating Catalytic Gasification of Coal with Fuel Cell**
Rajender Gupta, and Jose Lourenco (Expansion Power, Inc.), University of Alberta, CANADA.....733
- 136. Nitrogen and Phosphorus Removal from Wastewater by the *Microalgae* Biofilm**
Fanghua Li, Srikanth Chakravarthula Srivatsa, and Warren Batchelor, Department of Chemical Engineering, Monash University, AUSTRALIA.....735

Energy From Waste

Alan Paschedag, Covanta

- 147. World-Class Technology for the Newest Waste-to-Energy Plant in the United States – Palm Beach Renewable Energy Facility No. 2**
L.A. Hiner, M.D. Fick, and K.L. Clark, The Babcock & Wilcox Company; W.J. Arvan, Palm Beach Resource Recovery Corporation; and R.H. Schauer, Solid Waste Authority of Palm Beach County, USA.....746
- 11. Selective Oxidation Processes for Ultra-Efficient Fuel and Waste Conversion, Materials Recycling, Gas Synthesis and Processing**
Fredrik Lind, Klas Andersson, Henrik Thunman, and Filip Johnsson, Chalmers University of Technology, Energy and Environment, SWEDEN.....764
- 109. R&D Addressing Technical Barriers to Gasification-based Waste to Energy**
Daniel Roberts, San Shwe Hla, and David Harris, CSIRO, AUSTRALIA.....776

122. Slow Pyrolysis of Waste Biomass and Sewage Sludge

Halina Pawlak -Kruczek, Jacek Zgóra, Krystian Krochmalny, and Mateusz Kowal, Wroclaw University of Science and Technology, POLAND.....777

35. Low Temperature Pyrolysis of the Automotive Shredder Residues (ASR) for Energy Recovery and Metal Recycling

Panagiotis Evangelopoulos, Nanta Sophonrat, and Weihong Yang, Royal Institute of Technology (KTH), Department of Material Science and Engineering; and Henrik Jilvero, Stena Recycling International AB, SWEDEN.....779*

Rare Earths, Carbon Sorbents and other Coal-Derived Products

Dr. Eric Eddings, University of Utah

36. Recovery of Rare Earth Elements from North Dakota Lignite Coal and Related Feedstocks

Dr. Daniel Laudal, and Dr. Steve Benson, UND Institute for Energy Studies and Energy & Environmental Research Center, USA.....790

15. Recovery of Rare Earth Minerals from Coal Byproducts Using the HHS Process

P. J. Bethell, Marshall Miller and Associates; S. Suboleski, N. Gupta, and J. Reyher, Minerals Refining Company; R.-H. Yoon, G.H. Luttrell, B. Li and S. Park, Center for Advanced Separation Technologies, Virginia Tech; and R.Q. Honaker, Mining Engineering Department, University of Kentucky, USA.....802

115. Recovery of Rare Earth Elements (REEs) from Powder River Basin (PRB) Coal Fly Ashes with Green and Inexpensive Technologies

Zaixing Huang, Kai Li, Kaiying Wang, Hanjing Tian, Yan Luo, Hertanto Adidharma, Maciej Radosz, Eric Williams, J. Fred McLaughlin, Wendong Wang, Jingke Tang, Maohong Fan, University of Wyoming; and Gabrielle Gaustad, Rochester Institute of Technology, USA.....803

71. Developments in the Production of High-value Products from Coal

Ding Wang, Swomitra Mohanty, and Eric Eddings, Department of Chemical Engineering and Institute for Clean and Secure Energy, University of Utah, USA.....805

143. Hydrometallurgical Extraction of Rare Earth Elements from Coal

Rick Honaker, Xinbo Yang, Alind Chandra and Wencai Zhang, Department of Mining Engineering, University of Kentucky Rick Honaker, University of Kentucky, USA.....808

Carbon Capture I

Dr. Ashwani Gupta, University of Maryland

53. Design, Development and Operation of an Integrated Fluidized Carbon Capture Unit Using Polyethylenimine (PEI) Sorbents

Ronald W. Breault and Lawrence J. Shadle, National Energy Technology Laboratory, U.S. Department of Energy, USA.....809

- 97. The U.S. Department of Energy CCS Major Demonstration Program**
Andrew Hlasko, U.S. Department of Energy, Office of Fossil Energy, Program Manager Large Carbon Management Projects, USA.....822
- 7. Real-time Aerosol Measurements in Pilot Scale Coal Fired Post-Combustion CO₂ Capture**
Dr. Chiranjib Saha, Southern Research, and Justin H. Anthony, Southern Company Services, Inc., National Carbon Capture Center, USA.....826
- 1. 2017 Update on Technology Testing at the National Carbon Capture Center**
Barry Shirley, and Ruth Ann Yongue, Southern Company, National Carbon Capture Center, USA.....838
- 149. Concept of the Novel Low Temperature Heat Accumulator Based on PCM and Zeolite**
J. Lichota, D. Smykowski, J.W. Kaczmar, K. Naplocha, O. Trzaska and A. Koniuszewska, Wroclaw University of Technology, POLAND.....854

Carbon Capture II

Prof. Sankhar Bhattacharaya, Monash University, Australia

- 26. Energy Efficient GO-PEEK Hybrid Membrane Process for Post-Combustion Carbon Dioxide Capture**
Shiguang Li, Naomi B. Klinghoffer, Travis J. Pyrzyński, Howard S. Meyer, Gas Technology Institute; Yong Ding, Air Liquide Advanced Separations; and Huynh Ngoc Tien, Fanglei Zhou, Jarvis Chen, and Miao Yu, University of South Carolina, USA.....862
- 12. Synthesis of High Surface Area Zeolite from Fly Ash for CO₂ Capture**
Abdallah Dindi, Dang Viet Quang, and Mohammad R.M. Abu Zahra, Department of Chemical and Environmental Engineering, Masdar Institute of Science and Technology, UNITED ARAB EMIRATES.....863
- 9. UKy-CAER CO₂ Capture System Secondary Stripping: Effectiveness for Reducing the Solvent Regeneration Energy and Capital Cost Reduction**
Heather Nikolic, Reynolds Frimpong, Jesse Thompson, and Kunlei Liu, University of Kentucky Center for Applied Energy Research, USA.....874
- 101. A Long-term Investigation of Post-combustion Carbon Capture Pilot Plant Directly Connected to an Operating Coal-fired Power Plant**
Wonyoung Choi, Jun Arakawa, Kenji Takano, Yasuro Yamanaka, and Toshiya Matsuyama, Energy & Plant Operations, IHI Corporation, JAPAN; Paul Feron, Aaron Cottrell, Ashleigh Cousins, and Sanger Huang, CSIRO Energy; and Paul Sertori, AGL Loy Yang, AUSTRALIA.....885
- 104. Screening of Amine Based Deep Eutectic Solvents for Post Combustion Carbon Capture**
Idowu Adeyemi, Mohammad R. M. Abu-Zahra, and Inas Alnashef, The Institute Center for Energy (Energy), Masdar Institute of Science and Technology, UNITED ARAB EMIRATES.....891

- 98. Post-Combustion CO₂ Capture by Hybrid Sorption (CACHYS™)**
Dr. Srivats Srinivasachar, and Teagan Nelson, Envergenx LLC; Dr. Steve Benson, Dr. Daniel Laudal, Harry Feilen, and Dr. Kirtipal Barse, University of North Dakota – Institute for Energy Studies, USA.....904

Fluidized Bed Fundamentals

Dr. Ronald Breault, NETL, U.S. Department of Energy

- 88. A Unique Optical System for Evaluation of Spouted Bed Fluid Hydrodynamics**
Phil Beylison. Department of Physics, Adelphi University, USA.....906*
- 80. Development of a Mobile Demonstration Unit**
Ye Yao and Mark Ness, P.E., Great River Energy, USA.....918
- 116. Estimation of Minimum Spouting Velocity in a Rectangular Spouted Bed**
Steven Rowan, Michael Bobek, and Jingsi Yang, Oak Ridge Institute for Science and Education, National Energy Technology Laboratory, U.S. Department of Energy; and Dr. Ronald W. Breault, National Energy Technology Laboratory, U.S. Department of Energy, USA.....919
- 120. Experimental Analysis of a Vortexing CFB for Process Intensification via High-G Flows**
Michael Bobek, and Jingsi Yang, National Energy Technology Laboratory, Oak Ridge Institute for Science and Education; and Justin Weber, Frank Shaffer, and Ronald W. Breault, National Energy Technology Laboratory, USA.....926
- 52. Eulerian-Eulerian Modeling of Fluidized Beds: Validation and Parameter Studies**
Hongbo Shi, A. E. Komrakova, Department of Mechanical Engineering; P. Nikrityuk, Department of Chemical and Materials Engineering, University of Alberta, CANADA.....934*
- 135. Characteristics of Bio-oil Produced Via Fixed Bed Catalytic Pyrolysis of Marine Microalgae *Tetraselmis Suecica***
Fanghua Li, Srikanth Chakravarthula Srivatsa, and Sankar Bhattacharya, Department of Chemical Engineering, Monash University, AUSTRALIA.....946