

Reviews

- 5467 DOI: 10.1021/acs.energyfuels.5b01286
SO_x/NO_x Removal from Flue Gas Streams by Solid Adsorbents: A Review of Current Challenges and Future Directions
Fateme Rezaei,* Ali A. Rowanghi, Saman Monjezi, Ryan P. Lively, and Christopher W. Jones*

Articles

Fossil Fuels

- 5487 DOI: 10.1021/acs.energyfuels.5b00366
Effects of Native and Non-Native Resins on Asphaltene Deposition and the Change of Surface Topography at Different Pressures: An Experimental Investigation
Farhad Soorghali, Ali Zolghadr, and Shahab Ayatollahi*

- 5495 DOI: 10.1021/acs.energyfuels.5b00423
Viscosity Measurements of Aviation Turbine Fuels
Tara J. Fortin* and Arno Laesecke

- 5507 DOI: 10.1021/acs.energyfuels.5b01302
Mixed Interfaces of Asphaltenes and Model Demulsifiers, Part II: Study of Desorption Mechanisms at Liquid/Liquid Interfaces
Diego Pradilla,* Sébastien Simon, and Johan Sjöblom

- 5519 DOI: 10.1021/acs.energyfuels.5b00500
Effect of Five Different Additives on the Sintering Behavior of Coal Ash Rich in Sodium under an Oxy-fuel Combustion Atmosphere
Hao Zhou,* Jianyang Wang, and Bin Zhou

- 5534 DOI: 10.1021/acs.energyfuels.5b01381
Effects of Fracture and Matrix on Propagation Behavior and Water Shut-off Performance of a Polymer Gel
Yingrui Bai, Falin Wei, Chunming Xiong, Junjian Li,* Ruyi Jiang, Hanbing Xu, and Yong Shu

- 5544
Investigation of Rock Wettability Alteration by Carbonated Water through Contact Angle Measurements
Mojtaba Seyyedi,* Mehran Sohrabi, and Amir Farzaneh
DOI: 10.1021/acs.energyfuels.5b01069
- 5554
Investigating the Trace Polar Species Present in Diesel Using High-Resolution Mass Spectrometry and Selective Ionization Techniques
Elize Smit,* Christopher P. Rüger, Martin Sklorz, Stefan De Goede, Ralf Zimmermann, and Egmont R. Rohwer
DOI: 10.1021/acs.energyfuels.5b00831
- 5563
Self-Preservation Effect for Hydrate Dissociation in Water + Diesel Oil Dispersion Systems
Yi-Ning Lv, Meng-Lei Jia, Jun Chen, Chang-Yu Sun,* Jing Gong,* Guang-Jin Chen,* Bei Liu, Ning Ren, Shu-Di Guo, and Qing-Ping Li
DOI: 10.1021/acs.energyfuels.5b00837
- 5573
Determination of Ni and V in Crude Oil Samples Encapsulated in Zr Xerogels by Laser-Induced Breakdown Spectroscopy
Mauro Martínez, Ryszard Lobinski, Brice Bouyssiere, Vincent Piscitelli, José Chirinos, and Manuel Caetano*
DOI: 10.1021/acs.energyfuels.5b00960
- 5578
Pyrolytically Derived Polycyclic Aromatic Hydrocarbons in Marine Oils from the Tarim Basin, NW China
Haiping Huang,* Shulchang Zhang, and Jin Su
DOI: 10.1021/acs.energyfuels.5b01007
- 5587
Elemental Analysis of Crude Oils Using Microwave Plasma Atomic Emission Spectroscopy
Jenny Nelson, Greg Gilleland, Laura Poirier, David Leong, Paul Hajdu, and Francisco Lopez-Linares*
DOI: 10.1021/acs.energyfuels.5b01026
- 5595
Effect of Asphaltene Aggregation on Rheological Properties of Diluted Athabasca Bitumen
S. Mozaffari, P. Tchoukov, J. Atlas, J. Czamecki, and N. Nazemifard*
DOI: 10.1021/acs.energyfuels.5b00918
- 5600
Hydrogenation Behavior of Bicyclic Aromatic Hydrocarbons in the Presence of a Dispersed Catalyst
Wenan Deng,* Jing Lu, and Chuan Li
DOI: 10.1021/acs.energyfuels.5b01048
- 5609
Effect of Charge Distribution on the Viscosity and Viscoelastic Properties of Partially Hydrolyzed Polyacrylamide
Kristine Spildo* and Endre I. Ø. Sæ
DOI: 10.1021/acs.energyfuels.5b01066
- 5618
Synthesis and Evaluation of Terpolymers Consist of Methacrylates with Maleic Anhydride and Methacrylic Morpholine and Their Amine Compound as Pour Point Depressants in Diesel Fuels
Mingan Zhou, Yi He, Yanwei Chen, Yingpin Yang, Hualin Lin,* and Sheng Han*
DOI: 10.1021/acs.energyfuels.5b01072
- 5625
Analysis of Internal Common Rail Injector Deposits via Thermodesorption Photon Ionization Time of Flight Mass Spectrometry
Kornelia Lau, Rene Junk, Sophie Klingbeil, Ulrike Schümann, and Thorsten Streibel*
DOI: 10.1021/acs.energyfuels.5b01114
- 5633
Transformations and Roles of Sodium Species with Different Occurrence Modes in Direct Liquefaction of Zhundong Coal from Xinjiang, Northwestern China
Xiao Li, Zong-Qing Bai,* Jin Bai, Yan-Na Han, Ling-Xue Kong, and Wen Li
DOI: 10.1021/acs.energyfuels.5b01138
- 5640
Diesel Fuel Desulfurization via Adsorption with the Aid of Activated Carbon: Laboratory- and Pilot-Scale Studies
Penelope Baltzopoulou, Kyriakos X. Kallis, George Karagiannakis,* and Athanasios G. Konstandopoulos*
DOI: 10.1021/acs.energyfuels.5b01133
- 5649
Microemulsification-Based Method: Analysis of Monoethylene Glycol in Samples Related to Natural Gas Processing
Jaqueline G. da Cunha, Leandro Y. Shiroma, Gabriela F. Giordano, Bruno C. Couto, Rogério M. Carvalho, Angelo L. Gobbi, Lauro T. Kubota, and Renato S. Lima*
DOI: 10.1021/acs.energyfuels.5b01166
- 5655
Miscible CO₂ Simultaneous Water-and-Gas (CO₂-SWAG) Injection in the Bakken Formation
Yanbin Gong and Yongan Gu*
DOI: 10.1021/acs.energyfuels.5b01182
- 5666
A Geological Model for the Origin of Fluid Compositional Gradients in a Large Saudi Arabian Oilfield: An Investigation by Two-Dimensional Gas Chromatography (GC × GC) and Asphaltene Chemistry
Jeremiah C. Forsythe,* Andrew E. Pomerantz, Douglas J. Selfert, Kang Wang, Yi Chen, Julian Y. Zuo, Robert K. Nelson, Christopher M. Reddy, Arndt Schimmelmann, Peter Sauer, Kenneth E. Peters, and Oliver C. Mullins
DOI: 10.1021/acs.energyfuels.5b01192
- 5681
Guest Migration Revealed in CO₂ Clathrate Hydrates
A. N. Salamatin, A. Falenty, T. C. Hansen, and W. F. Kuhs*
DOI: 10.1021/acs.energyfuels.5b01217
- 5692
Probability Distributions of Natural Gas Hydrate Formation in Sodium Dodecyl Sulfate Aqueous Solutions
Barbara Sowa and Nobuo Maeda*
DOI: 10.1021/acs.energyfuels.5b01246

5701 **5** DOI: 10.1021/acs.energyfuels.5b01280
Studies on the Preliminary Cracking of Heavy Oils: The Effect of Matrix Acidity and a Proposal of a New Reaction Route
Bin Wang, Chaoyi Han, Qiang Zhang, Chunyi Li,* Chaohe Yang, and Honghong Shan

5714 DOI: 10.1021/acs.energyfuels.5b01327
Structural Characterization of Large Polycyclic Aromatic Hydrocarbons. Part 1: The Case of Coal Tar Pitch and Naphthalene-Derived Pitch
Valentina Gargiulo,* Barbara Apicella, Michela Alfè, Carmela Russo, Fernando Stanzione, Antonio Tregrossi, Angela Amoresano, Marcos Millan, and Anna Ciajolo

5723 DOI: 10.1021/acs.energyfuels.5b01376
Density and Refractive Index of Petroleum, Cuts, and Mixtures
H. W. Yarranton,* J. C. Okafor, D. P. Ortiz, and F. G. A. van den Berg

5737 **5** DOI: 10.1021/acs.energyfuels.5b01491
Asphaltene Aggregation Behavior in Bromobenzene Determined By Small-angle X-ray Scattering
Masato Morimoto,* Hiroshi Imamura, Satoshi Shibuta, Takeshi Morita, Keiko Nishikawa, Hideki Yamamoto, Ryuzo Tanaka, and Toshimasa Takanohashi

5744 DOI: 10.1021/acs.energyfuels.5b01575
Utilization of Carbonaceous Materials To Restore the Coking Properties of Weathered Coals
Miguel Castro-Díaz,* María Fernanda Vega, Carmen Barriocanal, and Colin E. Snape

5750 **5** DOI: 10.1021/acs.energyfuels.5b01568
CO₂-Soluble Ionic Surfactants and CO₂ Foams for High-Temperature and High-Salinity Sandstone Reservoirs
Zheng Xue, Krishna Panthi, Yunping Fei, Keith P. Johnston, and Kishore K. Mohanty*

Biofuels and Biomass

5761 DOI: 10.1021/acs.energyfuels.5b00835
Thermochemical Characterization of Bio- and Petro-diesel Fuels Using a Novel Laser-Heating Technique
Cary Presser,* Ashot Nazarian, Thomas J. Bruno, Jacolin A. Murray, and John L. Molloy

5773 DOI: 10.1021/acs.energyfuels.5b00983
Cleavage of Covalent Bonds in the Pyrolysis of Lignin, Cellulose, and Hemicellulose
Muxin Liu, Jianli Yang, Zhenyu Liu,* Wenjing He, Qingya Liu, Yunmei Li, and Yong Yang

5781 **5** DOI: 10.1021/acs.energyfuels.5b01032
A Novel Group Contribution Method for the Prediction of the Derived Cetane Number of Oxygenated Hydrocarbons
Manuel Dahmen and Wolfgang Marquardt*

5802 **5** DOI: 10.1021/acs.energyfuels.5b01045
Effect of Water Vapor on High-Temperature Corrosion under Conditions Mimicking Biomass Firing
Sunday Chukwudi Okoro,* Melanie Montgomery, Flemming Jappe Frandsen, and Karen Pantleon

5816 DOI: 10.1021/acs.energyfuels.5b01078
Improvement of Biohydrogen Production through Combined Reuses of Palm Oil Mill Effluent Together with Pulp and Paper Mill Effluent in Photofermentation
Pretty Mori Budiman, Ta Yeong Wu,* Ramakrishnan Nagasundara Ramanan, and Jamaliah Md. Jahim

5825 **5** DOI: 10.1021/acs.energyfuels.5b01101
Influence of Torrefaction Pretreatment on Reactivity and Permanent Gas Formation during Devolatilization of Spruce
Georgios-Archimidis Tsalidis,* Konstantinos Voulgaris, Konstantinos Anastasakis, Wiebren De Jong, and Jaap H. A. Kiel

5835 DOI: 10.1021/acs.energyfuels.5b01127
Ethanol-Enhanced Liquefaction of Lignin with Formic Acid as an *in Situ* Hydrogen Donor
Xinping Ouyang, Xiangzhen Huang, Yuan Zhu, and Xueqing Qiu*

5841 DOI: 10.1021/acs.energyfuels.5b01170
Pretreatment of Corn Stover for Methane Production with the Combination of Potassium Hydroxide and Calcium Hydroxide
Lin Li, Chang Chen,* Ruihong Zhang, Yanfeng He, Wen Wang, and Guangqing Liu*

5847 **5** DOI: 10.1021/acs.energyfuels.5b01204
Mass Spectrometry and Nuclear Magnetic Resonance Spectroscopy Study of Carbohydrate Decomposition by Hydrothermal Liquefaction Treatment: A Modeling Approach on Bio-oil Production from Organic Wastes
Annamaria Croce, Ezio Battistel, Stefano Chiaberge, Silvia Spera, Samantha Reale,* and Francesco De Angelis

5857 **5** DOI: 10.1021/acs.energyfuels.5b01214
Exploring the Products from Pinewood Pyrolysis in Three Different Reactor Systems
Alexander M. Zmiewski, Nicole L. Hammer, Rene A. Garrido, Trevor G. Misera, Charles G. Coe, and Justinus A. Satrio*

5865 DOI: 10.1021/acs.energyfuels.5b01263
Effect of Torrefaction on Biomass Physicochemical Characteristics and the Resulting Pyrolysis Behavior
Bin Ru, Shurong Wang,* Gongxin Dai, and Li Zhang

5875 DOI: 10.1021/acs.energyfuels.5b01314
Compression Ignition and Exhaust Gas Emissions of Fuel Molecules Which Can Be Produced from Lignocellulosic Biomass: Levulinates, Valeric Esters, and Ketones
Elina Koivisto,* Nicos Ladommatos, and Martin Gold

5885 DOI: 10.1021/acs.energyfuels.5b01329
Technoeconomic Assessment of a Fast Pyrolysis Bio-oil Production Process Integrated to a Fluidized Bed Boiler
Kristin Onarheim,* Jani Lehto, and Yrjö Solantausta

5894 DOI: 10.1021/acs.energyfuels.5b01342
Pilot-Scale Fluidized-Bed Co-gasification of Palm Kernel Shell with Sub-bituminous Coal
Carlos F. Valdés, Gloria Marrugo, Farid Chejne,* Jorge I. Montoya, and Carlos A. Gómez

5902 DOI: 10.1021/acs.energyfuels.5b01418
Cassava Stem Powder as an Additive in Biomass Fuel Pellet Production
Sylvia Larsson,* Oscar Lockneus, Shaojun Xiong, and Robert Samuelsson

Environmental and Carbon Dioxide Issues

5909 DOI: 10.1021/acs.energyfuels.5b00841
Effect of Syngas Constituents on CdO- and MgO-Based Sorbents for Pre-combustion CO₂ Capture
Christian Vogt, Gregory P. Knowles, and Alan L. Chaffee*

5919 DOI: 10.1021/acs.energyfuels.5b00850
In Situ Nuclear Magnetic Resonance Mechanistic Studies of Carbon Dioxide Reactions with Liquid Amines in Aqueous Systems: New Insights on Carbon Capture Reaction Pathways
Pavel V. Kortunov,* Michael Siskin, Lisa Saunders Baugh, and David C. Calabro

5940 DOI: 10.1021/acs.energyfuels.5b00985
In Situ Nuclear Magnetic Resonance Mechanistic Studies of Carbon Dioxide Reactions with Liquid Amines in Non-aqueous Systems: Evidence for the Formation of Carbamic Acids and Zwitterionic Species
Pavel V. Kortunov,* Michael Siskin, Lisa Saunders Baugh, and David C. Calabro

5967 DOI: 10.1021/acs.energyfuels.5b00988
In Situ Nuclear Magnetic Resonance Mechanistic Studies of Carbon Dioxide Reactions with Liquid Amines in Mixed Base Systems: The Interplay of Lewis and Brønsted Basicities
Pavel V. Kortunov,* Lisa Saunders Baugh, Michael Siskin, and David C. Calabro

5990 DOI: 10.1021/acs.energyfuels.5b00876
Pathways of the Chemical Reaction of Carbon Dioxide with Ionic Liquids and Amines in Ionic Liquid Solution
Pavel V. Kortunov,* Lisa Saunders Baugh, and Michael Siskin

6008 DOI: 10.1021/acs.energyfuels.5b01063
Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Light-Duty Vehicles
Fan Tong,* Paulina Jaramillo, and Inês M. L. Azevedo

6019 DOI: 10.1021/acs.energyfuels.5b01062
Absorption Performance and Mechanism of CO₂ in Aqueous Solutions of Amine-Based Ionic Liquids
Pengcheng Hu, Rui Zhang, Zhichang Liu, Haiyan Liu, Chunming Xu, Xianghai Meng,* Meng Liang, and Shuangshuang Liang

6025 DOI: 10.1021/acs.energyfuels.5b01253
Mercury Interaction with the Fine Fraction of Coal-Combustion Fly Ash in a Simulated Coal Power Plant Flue Gas Stream
Adam D. Jew,* Erik C. Rupp, Dawn L. Geatches, Ji-Eun Jung, Gabriela Farfan, Louisa Bahet, James C. Hower, Gordon E. Brown Jr., and Jennifer Wilcox

6039 DOI: 10.1021/acs.energyfuels.5b01274
Highly Selective Capture of CO₂ by Ether-Functionalized Pyridinium Ionic Liquids with Low Viscosity
Shaojuan Zeng, Jian Wang, Lu Bai, Binqi Wang, Hongshuai Gao, Dawei Shang, Xiangping Zhang,* and Suojang Zhang*

6049 DOI: 10.1021/acs.energyfuels.5b01294
CO₂ and H₂S Adsorption on γ -Al₂O₃-Supported Lanthanum Oxide
Benjamin J. Feist and Josephine M. Hill*

Catalysis and Kinetics

6057 DOI: 10.1021/acs.energyfuels.5b00669
Reactive Adsorption Desulfurization of Hydrotreated Diesel over a Ni/ZnO-Al₂O₃-SiO₂ Adsorbent
Feng Ju, Changjun Liu, Chun Meng, Shuai Gao, and Hao Ling*

6068 DOI: 10.1021/acs.energyfuels.5b01083
Catalytic Thermal Cracking of Postconsumer Waste Plastics to Fuels. 1. Kinetics and Optimization
Sriiram R. Chandrasekaran,* Bidhya Kunwar, Bryan R. Moser, Nandakishore Rajagopalan, and Brajendra K. Sharma*

6078 DOI: 10.1021/acs.energyfuels.5b01175
Synthetic Middle-Distillate-Range Hydrocarbons via Catalytic Dimerization of Branched C₆-C₈ Olefins Derived from Renewable Dimethyl Ether
Mayank Behl, Joshua A. Schaidle, Earl Christensen, and Jesse E. Hensley*

6088 DOI: 10.1021/acs.energyfuels.5b01180
Flow Pattern Effects on the Oxidation Deposition Rate of Aviation Kerosene
Xinyan Pei, Lingyun Hou,* and Zhuyin Ren

6095 DOI: 10.1021/acs.energyfuels.5b01212
Fluidizable NiO/Ce- γ -Al₂O₃ Oxygen Carrier for Chemical Looping Combustion
Shamseldin A. Mohamed, Mohammad R. Qudus, Shaikh A. Razzak, Mohammad M. Hossain,* and Hugo I. de Lasa

Formation Kinetics of Cyclopentane + Methane Hydrates in Brine Water Systems and Raman Spectroscopic Analysis
 Qiunan Lv, Lu Li, Xiaosen Li,* and Zhaoyang Chen

Combustion

Reaction Dynamics of Rocket Propellant with Magnesium Oxide Nanoparticles
 Michael N. Bello, Michelle L. Pantoya,* Keerti Kappagantula, William S. Wang, Siva A. Vanapalli, David J. Irvin, and Leslie M. Wood

Experimental Study of Tetrahydrofuran Oxidation and Ignition in Low-Temperature Conditions
 Guillaume Vanhove,* Yi Yu, Mohamed A. Boumehdi, Ophélie Frottier, Olivier Herbinet, Pierre-Alexandre Glaude, and Frédérique Battin-Leclerc

Comprehensive Comparison of Chemical Kinetics Mechanisms for Syngas/Biogas Mixtures
 H. C. Lee, A. A. Mohamad,* and L. Y. Jiang

Intracavity Laser Absorption Spectroscopy Study of HCO Radicals during Methane to Hydrogen Conversion in Very Rich Flames
 Alexey Fomin, Tatyana Zavlev, Vladimir A. Alekseev, Alexander A. Konnov, Igor Rahinov, and Sergey Cheskis*

Process Engineering

Development of a Coupling Oil Shale Retorting Process of Gas and Solid Heat Carrier Technologies
 Qingchun Yang, Yu Qian, Huairong Zhou, and Siyu Yang*

SO_x/NO_x Removal from Flue Gas Streams by Solid Adsorbents: A Review of Current Challenges and Future Directions

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ABSTRACT: One of the main challenges in the power and chemical industries is to remove generated toxic or environmentally harmful gases before atmospheric emission. To comply with stringent environmental and pollutant emissions control regulations, coal-fired power plants must be equipped with new technologies that are efficient and less energy-intensive than status quo technologies for flue gas cleanup. While conventional sulfur oxide (SO_x) and nitrogen oxide (NO_x) removal technologies benefit from their large-scale implementation and maturity, they are quite energy-intensive. In view of this, the development of lower-cost, less energy-intensive technologies could offer an advantage. Significant energy and cost savings can potentially be realized by using advanced adsorbent materials. One of the major barriers to the development of such technologies remains the development of materials that are efficient and productive in removing flue gas contaminants. In this review, adsorption-based removal of SO_x/NO_x impurities from flue gas is discussed, with a focus on important attributes of the solid adsorbent materials as well as implementation of the materials in conventional and emerging acid gas removal technologies. The requirements for effective adsorbents are noted with respect to their performance, key limitations, and suggested future research directions. The final section includes some key areas for future research and provides a possible roadmap for the development of technologies for the removal of flue gas impurities that are more efficient and cost-effective than status quo approaches.

1. INTRODUCTION AND MOTIVATION

The reliance of the energy sector on fossil fuels for electricity generation is still growing to address rising electricity demands. According to the U.S. Energy Information Administration (EIA),¹ coal-fired power generation is expected to increase by an average of 0.2% per year from 2011 through 2040, and coal remains the largest source of electricity despite the growing interest in natural gas as a fuel, as can be seen from Figure 1. This is primarily the case because natural gas prices are projected to increase more rapidly than coal prices over the

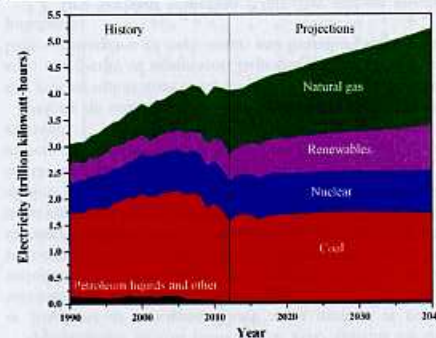


Figure 1. Electricity generation by fuel for the time period of 1990–2040 (10¹² kWh). Reprinted from ref 1.

next 30 years, which will keep coal as a significant fuel for power generation for decades to come.

SO_x and NO_x impurities are emitted into the atmosphere from both stationary and mobile combustion sources, including fossil fuel combustion in heating and thermal power plants, petroleum refineries, and on-road transportation vehicles. Flue gas streams from fossil-fuel-fired power plants alone are responsible for 87% of SO_x and 67% of NO_x emissions.^{1,2} Among various sulfur and nitrogen oxide species, SO₂, NO, and NO₂ are considered the most toxic and harmful gases emitted into the atmosphere. These acidic gases are primary sources for atmospheric pollution and are believed to be causing increasingly serious environmental problems, mainly through the formation of acid rain and photochemical smog as well as ozone layer destruction. Furthermore, high concentrations of these undesirable contaminants in air pose serious health threats to human beings by contributing to a broad range of health issues, including respiratory diseases such as asthma, bronchitis, emphysema, and throat inflammation, among others. In particular, these acid gases highly contribute to the formation of secondary organic aerosols (SOAs), which have an impact on the climate as well.^{3,4} These emissions stem from various sources, including the combustion of fossil fuels in power plants and petroleum refineries as well as in transportation vehicles.

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