

Article

Reaction Engineering of Direct Coal Liquefaction

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Abstract: Direct coal liquefaction has been studied and practiced since the 1930s. It was used in Germany during World War II to produce synthetic fuels when there was no oil allowed into the country. Since then, it has been studied in the United States and many different technologies have been investigated. Since the US is rich in coal resources, this is one way to be energy independent. Most of the development activity occurred in the 1980s and numerous technologies were studied, the most notable of these being H-Coal, Exxon Donor Solvent, Solvent Refined Coal, and Two Stage Liquefaction. The key elements of these technologies, particularly the reaction/reactor scheme, are discussed in this review.

Keywords: coal; liquefaction; reactors; kinetics; catalysis; deactivation; reaction engineering

1. Introduction

1.1. A Brief History of Coal Liquefaction

Interest in coal liquefaction has seen several high and low periods over the last 60 years. Direct coal liquefaction starts just prior to World War II by Germany, continues through the 1950s and 1960s with the research by the U.S. Bureau of Mines, and then hit an extensive pace following the Arab oil embargo of 1973. Since the early 1980s, interest has waned due to the decrease in crude oil prices, but the invasion of Kuwait by Iraq in 1990 caused the world to reevaluate their position and think about a national energy policy which will provide incentives to develop U.S. natural resources. The largest source of liquid hydrocarbons is crude oil and the United States has found and used up the cheap domestic crude that it once had. When demand exceeds supply, or a political or military action in one of the oil producing countries happens, the price of crude oil will increase. This stimulates alternative

Reaction Engineering In Direct Coal Liquefaction

Yatish T. Shah

A decorative graphic consisting of a red circular shape with a white center, partially obscured by a white horizontal bar that extends from the left edge of the slide.

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Reaction Engineering in Direct Coal Liquefaction Yatish T. Shah, 1981 **Fossil Energy Update**, 1981 Chemistry of Coal Conversion Richard H. Schlosberg, 2013-11-21 The impetus for this book is twofold First in response to the well documented oil shocks of the 1970s there arose a resurgence of research activity in the synthetic fuels area This book attempts to capture some of the leading edge advances which have been made over the past decade in the area of the chemistry of coal conversion The second driving force behind this book is to jog people's memories about the fundamental truths of the energy industry i.e. there IS a finite amount of liquid hydrocarbons on and under the earth's surface most of the easy to find produce and use liquid hydrocarbons have been exploited and the real need continues to be for liquid hydrocarbons for use as transportation fuels The uncertainty is not if synthetic liquids will be needed but rather when they will be needed The inability to answer that question accurately caused many of the financial and research disruptions following the double shocks of the 1970s Since future projections can only be based upon the historical record they cannot anticipate major disruptions such as e.g. discovery of huge easily producible oil fields or on the other side global or regional economic disruptions such as warfare With this level of uncertainty then the second impetus is to point out how much research remains to be done at a time when fiscal support for fossil fuels research in the United States is rapidly spiraling downward *Global Chemical Kinetics of Fossil Fuels* Alan K. Burnham, 2017-02-11 This book covers the origin and chemical structure of sedimentary organic matter how that structure relates to appropriate chemical reaction models how to obtain reaction data uncontaminated by heat and mass transfer and how to convert that data into global kinetic models that extrapolate over wide temperature ranges It also shows applications for in situ and above ground processing of oil shale coal and other heavy fossil fuels It is essential reading for anyone who wants to develop and apply reliable chemical kinetic models for natural petroleum formation and fossil fuel processing and is designed for course use in petroleum systems modelling Problem sets examples and case studies are included to aid in teaching and learning It presents original work and contains an extensive reanalysis of data from the literature **Energy**, 1982 **Handbook of Industrial Chemistry and Biotechnology** James A. Kent, Tilak V. Bommaraju, Scott D. Barnicki, 2017-08-01 This widely respected and frequently consulted reference work provides a wealth of information and guidance on industrial chemistry and biotechnology Industries covered span the spectrum from salt and soda ash to advanced dyes chemistry the nuclear industry the rapidly evolving biotechnology industry and most recently electrochemical energy storage devices and fuel cell science and technology Other topics of surpassing interest to the world at large are covered in chapters on fertilizers and food production pesticide manufacture and use and the principles of sustainable chemical practice referred to as green chemistry Finally considerable space and attention in the Handbook are devoted to the subjects of safety and emergency preparedness It is worth noting that virtually all of the chapters are written by individuals who are embedded in the industries whereof they

write so knowledgeably **Applied Coal Petrology** Isabel Suarez-Ruiz, John C. Crelling, 2008-10-09 This book is an integrated approach towards the applications of coal organic petrology and discusses the role of this science in the field of coal and coal related topics Coal petrology needs to be seen as a continuum of organic macerals and inorganic minerals and trace elements contributions to the total coal structure with the overprint of coal rank All this influences the behavior of coal in utilization the coal by products the properties of coal as a reservoir for methane or a sequestration site for carbon dioxide and the relationships of coal utilization with health and environmental issues The interaction of coal properties and coal utilization begins at the mine face The breakage of the coal in mining influences its subsequent beneficiation Beneficiation is fundamental to the proper combustion of coal and is vital to the preparation of the feedstock for the production of metallurgical coke An understanding of basic coal properties is important for achieving reductions in trace element emissions and improving the efficiency of combustion and combined cycle gasification The production of methane from coal beds is related to the properties of the in situ coal Similarly coal bed sequestration of carbon dioxide produced from combustion is dependent on the reservoir properties Environmental problems accompany coal on its way from the mine to the point of utilization and beyond Health aspects related with coal mining and coal utilization are also included because in planning for coal use it is impossible to separate environmental and health issues from the discussion of coal utilization The book is aimed at a wide audience ranging from researchers lecturers and students to professionals in industry and discusses issues such as the environmental and health that are of concern to the general public as a whole This book focuses on the applications of coal organic petrology to our modern society It is an integrated approach to help the reader appreciate the importance of coal quality and coal utilization Coal composition macerals mineral trace elements and the overprint of coal rank are treated together The book synthesises all the possibilities of the organic petrology as a tool for coal utilization in conventional applications mining and beneficiation coal combustion gasification liquefaction carbonization as a precursor of carbon materials and as a petroleum source and reservoir rock The role of applied petrology in the characterization of solid by products from coal utilization is also discussed In addition this book describes the present status of environmental and health problems linked to coal utilization and the ways in which such problems might be overcome in the future Energy

Research Abstracts ,1988 **Chemical Energy from Natural and Synthetic Gas** Yatish T. Shah, 2017-03-16 Commercial development of energy from renewables and nuclear is critical to long term industry and environmental goals However it will take time for them to economically compete with existing fossil fuel energy resources and their infrastructures Gas fuels play an important role during and beyond this transition away from fossil fuel dominance to a balanced approach to fossil nuclear and renewable energies Chemical Energy from Natural and Synthetic Gas illustrates this point by examining the many roles of natural and synthetic gas in the energy and fuel industry addressing it as both a transition and end game fuel The book describes various types of gaseous fuels and how they are recovered purified and converted to liquid fuels and electricity

generation and used for other static and mobile applications It emphasizes methane syngas and hydrogen as fuels although other volatile hydrocarbons are considered It also covers storage and transportation infrastructure for natural gas and hydrogen and methods and processes for cleaning and reforming synthetic gas The book also deals applications such as the use of natural gas in power production in power plants engines turbines and vehicle needs Presents a unified and collective look at gas in the energy and fuel industry addressing it as both a transition and end game fuel Emphasizes methane syngas and hydrogen as fuels Covers gas storage and transport infrastructure Discusses thermal gasification gas reforming processing purification and upgrading Describes biogas and bio hydrogen production Deals with the use of natural gas in power production in power plants engines turbines and vehicle needs Energy and Fuel Systems Integration Yatish T. Shah, 2015-10-15 Energy and Fuel Systems Integration explains how growing energy and fuel demands paired with the need for environmental preservation require different sources of energy and fuel to cooperate and integrate with each other rather than simply compete Providing numerous examples of energy and fuel systems integration success stories this book Discusses the use of different mixtures of fuels for combustion gasification liquefaction pyrolysis and anaerobic digestion processes Describes the use of hybrid nuclear and renewable energy systems for power and heat cogenerations with nonelectrical applications Details the holistic integration of renewable nuclear and fossil energy systems by gas heat and smart electrical grids Energy and Fuel Systems Integration emphasizes the many advantages of these integrated systems including sustainability flexibility for optimization and scale up and more efficient use of storage transportation and delivery infrastructures **Handbook of Heat and Mass Transfer** Nicholas P. Cheremisinoff, 1986 **Carbon Materials for Advanced Technologies** T.D. Burchell, 1999-07-22 The inspiration for this book came from an American Carbon Society Workshop entitled Carbon Materials for Advanced Technologies which was hosted by the Oak Ridge National Laboratory in 1994 Chapter 1 contains a review of carbon materials and emphasizes the structure and chemical bonding in the various forms of carbon including the four allotropes diamond graphite carbynes and the fullerenes In addition amorphous carbon and diamond films carbon nanoparticles and engineered carbons are discussed The most recently discovered allotrope of carbon i e the fullerenes along with carbon nanotubes are more fully discussed in Chapter 2 where their structure property relations are reviewed in the context of advanced technologies for carbon based materials The synthesis structure and properties of the fullerenes and nanotubes and modification of the structure and properties through doping are also reviewed Potential applications of this new family of carbon materials are considered The manufacture and applications of adsorbent carbon fibers are discussed in Chapter 3 The manufacture structure and properties of high performance fibers are reviewed in Chapter 4 and the manufacture and properties of vapor grown fibers and their composites are reported in Chapter 5 The properties and applications of novel low density composites developed at Oak Ridge National Laboratory are reported in Chapter 6 Coal is an important source of energy and an abundant source of carbon The production of engineering carbons

and graphite from coal via a solvent extraction route is described in Chapter 7 Applications of activated carbons are discussed in Chapters 8 10 including their use in the automotive arena as evaporative loss emission traps Chapter 8 and in vehicle natural gas storage tanks Chapter 9 The application of activated carbons in adsorption heat pumps and refrigerators is discussed in Chapter 10 Chapter 11 reports the use of carbon materials in the fast growing consumer electronics application of lithium ion batteries The role of carbon materials in nuclear systems is discussed in Chapters 12 and 13 where fusion device and fission reactor applications respectively are reviewed In Chapter 12 the major technological issues for the utilization of carbon as a plasma facing material are discussed in the context of current and future fusion tokamak devices The essential design features of graphite moderated reactors including gas water and molten salt cooled systems are reviewed in Chapter 13 and reactor environmental effects such as radiation damage and radiolytic corrosion are discussed The fracture behaviour of graphite is discussed in qualitative and quantitative terms in Chapter 14 The applications of Linear Elastic Fracture Mechanics and Elastic Plastic Fracture Mechanics to graphite are reviewed and a study of the role of small flaws in nuclear graphites is reported

Principles of Catalyst Development James T. Richardson, 2013-12-21 Successful industrial heterogeneous catalysts fulfill several key requirements in addition to high catalytic activity for the desired reaction with high selectivity where appropriate they also have an acceptable commercial life and are rugged enough for transportation and charging into plant reactors Additional requirements include the need to come online smoothly in a short time and reproducible manufacturing procedures that involve convenient processes at acceptable cost The development of heterogeneous catalysts that meet these often mutually exclusive demands is far from straightforward and in addition much of the actual manufacturing technology is kept secret for commercial reasons thus there is no modern text that deals with the whole of this important subject *Principles of Catalyst Development* which deals comprehensively with the design development and manufacture of practical heterogeneous catalysts is therefore especially valuable in meeting the long standing needs of both industrialists and academics As one who has worked extensively on a variety of catalyst development problems in both industry and academia James T Richardson is well placed to write an authoritative book covering both the theory and the practice of catalyst development Much of the material contained in this book had its origin in a series of widely acclaimed lectures attended mainly by industrial researchers given over many years in the United States and Europe All those in industry who work with catalysts both beginners and those of considerable experience should find this volume an essential guide

Energy Research Abstracts, 1993 Includes all works deriving from DOE other related government sponsored information and foreign nonnuclear information

[Coal Abstracts](#), 1993

Proceedings of the 2nd International Conference on Innovative Solutions in Hydropower Engineering and Civil Engineering Shuren Wang, Jingan Li, Kui Hu, Xingxian Bao, 2023-05-20 This open access book is compilation of selected papers from 2nd International Conference on Innovative Solutions in Hydropower Engineering and Civil Engineering HECE 2022 The work focuses on novel techniques for

topics in hydropower and sustainable development maximizing and communicating the multiple benefits of hydro the food water energy nexus approach synergy among the renewables making hydro more competitive managing and mitigating risk regional development through power trading hydropower technology civil engineering materials for dams and appurtenant works advances in design and construction techniques recent developments in dam construction monitoring and engineering for safe structures and sites Hydropower offers significant potential for carbon emissions reductions The installed capacity of hydropower by the end of 2008 contributed 16% of worldwide electricity supply and hydropower remains the largest source of renewable energy in the electricity sector The contents make valuable contributions to academic researchers engineers in the industry and regulators of hydropower and civil engineering authorities *Water for Energy and Fuel Production* Yatish T. Shah, 2014-05-16 This text describes water's use in the production of raw fuels as an energy carrier e.g. hot water and steam and as a reactant reaction medium and catalyst for the conversion of raw fuels to synthetic fuels It explains how supercritical water is used to convert fossil and bio based feedstock to synthetic fuels in the presence and absence of a catalyst It also explores water as a direct source of energy and fuel such as hydrogen from water dissociation methane from water based clathrate molecules and more **Thermal Energy** Yatish T. Shah, 2018-01-12 The book details sources of thermal energy methods of capture and applications It describes the basics of thermal energy including measuring thermal energy laws of thermodynamics that govern its use and transformation modes of thermal energy conventional processes devices and materials and the methods by which it is transferred It covers 8 sources of thermal energy combustion fusion solar fission nuclear geothermal microwave plasma waste heat and thermal energy storage In each case the methods of production and capture and its uses are described in detail It also discusses novel processes and devices used to improve transfer and transformation processes *Subject Catalog* Library of Congress, **Chemical Engineering Progress**, 1982

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