CONTENTS

ENERGY CARRIERS AND CONVERSION SYSTEMS WITH EMPHASIS ON HYDROGEN



Energy Carriers And Conversion Systems With Emphasis On Hydrogen - Volume 1 No. of Pages: 382 ISBN: 978-1-905839-29-2 (eBook) ISBN: 978-1-84826-929-3 (Print Volume)

Energy Carriers And Conversion Systems With Emphasis On Hydrogen - Volume 2 No. of Pages: 436 ISBN: 978-1-905839-30-8 (eBook) ISBN: 978-1-84826-930-9 (Print Volume)

For more information of e-book and Print Volume(s) order, please **click here**

Or contact : eolssunesco@gmail.com

CONTENTS

VOLUME I

Energy Carriers and Conversion Systems with Emphasis on Hydrogen
Tokio Ohta, Yokohama National University, Japan
Turhan Nejat Veziroglu, Clean Energy Research Institute, University of Miami, Coral USA

- 1. Energy Resources
 - 1.1. Energy, Energy Resources, and Energy Carriers
 - 1.2. Fossil Fuels
 - 1.2.1. Coal
 - 1.2.2. Coal and Hydrogen
 - 1.2.3. Oil
 - 1.2.4. Oil and Hydrogen
 - 1.2.5. Methane
 - 1.3. Nuclear Energy
 - 1.3.1. General Survey
 - 1.3.2. Difficulties of Nuclear Power Utilization
 - 1.3.3. Nuclear-Hydrogen Energy Systems
 - 1.4. Renewable Energy Systems
 - 1.4.1. General Survey
 - 1.4.1.1. Classification of Natural Energies
 - 1.4.1.2. Amount of Resources
 - 1.4.2. Feasibilities of Renewable Energy-Hydrogen Systems
 - 1.4.2.1. Preliminary Requirements for Hydrogen Energy Systems
 - 1.4.2.2. World Energy Network Systems
 - 1.4.2.3. Ocean Raft Systems for Hydrogen Energy
- 2. Proposed Systems and the Elementary Technologies
 - 2.1. Combined Energy Systems of Electric Power with Hydrogen
 - 2.1.1. Primary Energies
 - 2.1.2. Secondary Energies
 - 2.1.3. Tertiary Energy Systems (Utilization Systems)
 - 2.2. Hydrogen Production from Water
 - 2.2.1. Thermodynamics of Water-Splitting and Sources for Free Energies
 - 2.2.2. Diagram of Water-Splitting and Direct Thermal Decomposition
 - 2.2.3. Principle of Thermochemical Decomposition
 - 2.2.4. Electrolysis
 - 2.2.4.1. Principle of Electrolysis and Traditional Technology
 - 2.2.4.2. Solid Polymer Electrolyte (SPE)
 - 2.2.4.3. Solar Cell-Electrolysis Systems
 - 2.3. Photo Electrochemical Systems
 - 2.3.1. Photochemical Cycle Systems
 - 2.3.2. Mechano-Catalytic Water-Splitting
 - 2.4. Fuel Cells
 - 2.4.1. Principle
 - 2.4.2. Hydrogen–Oxygen (Air) Fuel Cells
 - 2.4.3. Proton Exchange Membrane (PEM) Fuel Cells
 - 2.4.4. Next and Third Generations of Fuel Cells
- 3. Metal Hydrides and Hydrogen
 - 3.1. Properties of Metal Hydrides
 - 3.1.1. Graphite Nanofibers
 - 3.2. Applications
 - 3.2.1. Hydrogen Storage and Heat Storage
 - 3.2.2. Heat Pumps
- 4. Safety

Preliminaries of Hydrogen Energy Systems

Tokio Ohta, Yokohama National University, Kamakura, Japan

- 1. Introduction: From Fossil Fuel to Hydrogen
 - Meaning of Water-splitting Technology
 - 2.1. Resource Leveling

2.

- 2.2. Key Technology of Natural Recycles
- 3. Four Innovative Hydrogen Production Technologies
 - 3.1. Solid Polymer Electrolysis
 - 3.2. Thermochemical Cycle Method
 - 3.3. Photoelectrochemical Method
 - 3.4. Mechano-catalytic Method
- 4. Four Noble Hydrogen Conversion Systems
 - 4.1. Ecological Combustion with High Power
 - 4.2. Catalytic Conversion with High Efficiency
 - 4.3. Reversible Conversion
 - 4.4. Cyclic Chemical Conversion
 - 4.4.1. Chemical Heat Pump
 - 4.4.2. Electric Generation by Low Grade Heat

Physical and Chemical Properties of Hydrogen

Isao Abe, Office Tera, Chiba, Japan

- 1. Introduction
- 2. Physical and Chemical Properties
 - 2.1. Basic and Chemical Properties of Hydrogen
 - 2.2. Physical Properties of Hydrogen
- 3. Conclusion

Statistics on Hydrogen Production and Consumption

Isao Abe, Office Tera, Chiba, Japan

- 1. Introduction
- 2. Statistics
 - 2.1. Production
 - 2.2. Consumption
- 3. Conclusion

International Programs

Tokio Ohta, Yokohama National University, 4-8-5 Inamuragasaki, Kamakura 2480024, Japan Turhan Nejat Veziroglu, Clean Energy Research Institute, University of Miami, Coral Gables, FL 33124, USA

- 1. Hydrogen Production
 - 1.1. Hydrogen from Fossil Fuels
 - 1.2. Electrolysis
 - 1.3. Thermochemical Methods
 - 1.4. Other Methods
- 2. Hydrogen Storage and Transport
 - 2.1. Stationary Storage Systems
 - 2.2. Mobile Storage Systems
 - 2.3. Physico-Chemical Storage Systems
 - 2.4. Hydrogen Transport and Distribution
- 3. Hydrogen Utilization
 - 3.1. Combustion Systems

40

50

55

- 3.2. Fuel Cells
- 3.3. Hydride Applications
- 3.4. Other Applications
- 4. Transition to Hydrogen Economy
 - 4.1. Demonstration Projects
 - 4.2. Economics
 - 4.3. Safety
 - 4.4. Standards
- 5. International Centre for Hydrogen Energy Technologies
 - 5.1. Mission
 - 5.2. Linkage with Industry
 - 5.3. Partnerships
 - 5.4. Pilot Projects
 - 5.5. Demonstration Projects
 - 5.6. Research and Educational Activities
 - 5.7. Database Project

Cultural Development and the Key Technologies of Hydrogen Energy Systems- An Introductory review for the Beginners 90

Tokio Ohta, Frontier Information and Learning Organization(FILO), Inamuragasaki, Kamakura, Japan Nobuyuki Kamiya, Yokohama National University, Tokiwadai, Hodogayaku, Yokohama, Japan

- 1. Introduction
- 2. Formation of Hydrogen energy systems
- 3. Review of Elemental Technologies
- 4. Innovative WSS systems
- 5. Hydrogen storage
- 6. Fuel cells (FCs)
 - 6.1. Energy conversion by fuel cell systems
 - 6.2. Types of fuel cells
 - 6.3. PEFC
 - 6.3.1. Fuel reformer
 - 6.3.2. PEFC for Stationary Use
 - 6.3.3. Fuel Cell Vehicles
 - 6.3.4. Hydrogen for Vehicles
- 7. Annotations

Hydrogen Production from Fossil Fuels

Meyer Steinberg, Brookhaven National laboratory, USA

- 1. Introduction
- 2. Steam Reforming of Natural Gas (Methane)
- 3. Parted Oxidation (POX) of Hydrocarbons
- 4. Coal Gasification
- 5. Steam-Iron Process
- 6. Thermal Cracking of Natural Gas (Methane) and Hydrocarbons
- 7. Comparison of the Major Hydrogen Production Processes

Hydrogen Production from Water

Isao Abe, Syowa Denko, Co., Japan

- 1. Introduction
- 2. Direct Thermal Decomposition
- 3. Thermochemical Cycles
- 4. Electrolysis

117

- 5. Photolysis (Photoelectrochemical Method)
- 6. Mechano-catalytic Splitting
- 7. Conclusion

Thermodynamics of Water Splitting

Atsushi Tsutsumi, University of Tokyo, Japan

- 1. Introduction: Fundamentals
- 2. Electrolysis of Water
- 3. Thermochemical Water Splitting

Alkaline Water-Electrolysis

Isao Abe, Office Tera, Chiba, Japan

- 1. Introduction
- 2. Structure of Alkaline Water Electrolyzers
 - 2.1. Unipolar Electrolyzer
 - 2.2. Bipolar Water Electrolyzer
 - 2.3. High Pressure Water Electrolyzer
- 3. Advanced Water Electrolyzers
- 4. High Temperature, High Pressure Operation
- 5. Structural Materials
 - 5.1. Diaphragm Materials
 - 5.2. Electrode Materials
- 6. System Design
 - 6.1. Operating Temperature
 - 6.2. Operating Pressure
 - 6.3. Current Density
 - 6.4. Total System Flow
 - 6.5. GasLiquid Separator
- 7. Control System
 - 7.1. Pressure Control System
 - 7.1.1. The Combination of Pressure Control and Pressure Difference Control
 - 7.1.2. Bottom Connection of the GasLiquid Separators
 - 7.2. Other Controls
 - 7.2.1. Electrolyte Flow Control
 - 7.2.2. Temperature Control
 - 7.2.3. Other Safety Measures
- 8. Examples of Advanced Electrolyzers
 - 8.1. Sunshine Electrolyzer
 - 8.2. IME Technology Water Electrolyzer
 - 8.3. GHW Water Electrolyzer
 - 8.4. EI-250 Water Electrolyzer
- 9. Cost of Alkaline Water Electrolysis
 - 9.1. Plant Cost
 - 9.2. Cost of Electrolytic Hydrogen Production
- 10. Conclusion

SPE Water Electrolysis and Steam Electrolysis Isao Abe, *Office Tera, Chiba, Japan*

167

iv

1. SPE Water Electrolysis: Introduction

- 1.1 Principle of SPE Water Electrolysis
- 1.2 Membrane–Electrode Composite
 - 1.2.1 SPE Membrane
 - 1.2.2 Electrode Catalyst
 - 1.2.3 Preparation of the Membrane-Electrode Composite
 - 1.2.4 Chemical Plating Method
 - 1.2.5 Hot Press Method
- 1.3 Structural Materials
 - 1.3.1 Current Collectors and Bipolar Plates 1.3.2 Other Structural Materials
- 1.4 Advantages of SPE Water Electrolysis
- 1.5 Disadvantages of SPE Water Electrolysis
- 1.6 Status of Development 1.6.1 Experiments with Small-scale Electrolytic Cells 1.6.2 Scale-up Development
- 1.7 Conclusion and Future Development
- 2. High Temperature Steam Electrolysis (HTE)
 - 2.1. The Principle of THE
 - 2.2. The Advantages and Disadvantages of THE
 - 2.3. Status of Development and Conclusion

Photovoltaic Cell-Water Electrolysis System

Isao Abe, Office Tera, Chiba, Japan

- 1. Introduction
- 2. Total System
 - 2.1. Direct Coupling
 - 2.2. Coupling through a DC–DC Converter
 - 2.3. Stand-alone System
- 3. Requirements of Electrolyzer
- 4. Operation
- 5. Conclusion

Innovative Hydrogen Production from Water

Tokio Ohta, Yokohama National University, Japan

- 1. Definition of "Innovative Technology" 2.
 - Renewable Energy Resources
 - 2.1. Solar Energy
 - 2.2. Tide Energy and Geothermal Energy
- 3. Five Innovative Hydrogen Production Technologies
 - 3.1. Solid Polymer Electrolysis
 - 3.2. Ideal Water-splitting Process
 - 3.3. Thermochemical Cycle Method
 - 3.4. Photoelectrochemical Method
 - 3.5. Mechano-catalytic Method
- 4. Algae and Bacteria Hydrogen Systems
- 5. Hydrogen Production from Biomass

Thermochemical Cycles

Atsushi Tsutsumi, University of Tokyo, Japan

1. Thermochemical Cycles

180

Thermolysis

Atsushi Tsutsumi, University of Tokyo, Japan

1. Thermolysis and Direct Thermal Decomposition

Photochemical and Photoelectrochemical Water Splitting

Akira Fujishima, *University of Tokyo, Japan* Donald A. Tryk, *University of Tokyo, Japan*

- 1. Introduction
- 2. Photoelectrochemical Approaches
 - 2.1. Basics Aspects of Photoelectrochemistry
 - 2.2. Photoelectrochemical Water Splitting
 - 2.3. Hydrogen Production from HBr and HI
 - 2.4. Modular Approaches
- 3. Photochemical and Photocatalytic Processes
 - 3.1. Water Splitting
 - 3.2. Energy Storage Processes Other Than Water Splitting
 - 3.3. Relationship to Other Types of Photocatalytic Processes
- 4. Conclusions

Hydrogen from Biomass (1)

Jun Miyake, Tissue Engineering Research Center, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

- 1. Introduction
- 2. Photobiological Hydrogen Production by Photosynthetic Microorganisms (Bacteria)
 - 2.1. Photobiological Hydrogen Production from Organic Acids
 - 2.2. Photobiological Hydrogen Production from Carbohydrates
 - 2.3. Photobiological Hydrogen Production from Sulfuric Compounds
 - 2.4. Photobiological Hydrogen Production from Food Waste
 - 2.5. Photobiological Hydrogen Production from Organic Wastewater
 - 2.6. Photobiological Hydrogen Production Using Sunlight
- 3. Biological Hydrogen Production by Non-Photosynthetic Microorganisms
- 4. Photobiological Hydrogen Production by Mixed Culture with Non-Photosynthetic Bacteria

Hydrogen from Biomass (2)

Yukihiko Matsumura, University of Tokyo, Japan

- 1. Overall Scope
 - 1.1. Characteristics of Biomass Energy
 - 1.2. Importance of Hydrogen Production from Biomass
 - 1.3. Technologies for Hydrogen Production from Biomass
- 2. Thermochemical Biomass Gasification
- 3. Biomethanation
- 4. Hydrothermal Gasification

Hydrogen Separation and Handling

Itsuki Uehara, National Institute of Advanced Industrial Science and Technology, Japan

- 1. Introduction
- 2. Separation and Purification of Hydrogen
 - 2.1. Partial Condensation
 - 2.2. Absorption Methods

vi

204

200

228

241

- 2.3. Adsorption Methods
- 2.4. Membrane Separation
- 2.5. Separation by Metal Hydrides
- 3. Hydrogen and Natural Gas Mixture
 - 3.1. Burner Combustion of Natural Gas Mixed with Hydrogen
 - 3.2. Hydrogen-Natural Gas Mixtures for Internal Combustion Engines
- 4. Handling and Safety of Hydrogen
- 4.1. Safety Aspects of Gaseous Hydrogen
 - 4.1.1. Fire Hazards, Related Damage, and Their Minimization4.1.2. Explosion Hazards, Related Damage, and Preventive Measures
 - 4.2. Safety Aspects of Liquid Hydrogen
 - 4.3. Safety Aspects of Metal Hydrides
 - 4.4. Materials for Safe Handling
 - 4.5. Detection of Hydrogen and Its Fires
 - 4.6. Basic Measures for Safe Handling

Separation and Purification of Hydrogen

Itsuki Uehara, National Institute of Advanced Industrial Science and Technology, Japan

- 1. Introduction
- 2. Partial Condensation
- 3. Absorption Methods
 - 3.1. Physical Absorption Processes
 - 3.2. Chemical Absorption Processes
- 4. Adsorption Methods
 - 4.1. Adsorption Processes
 - 4.2. Pressure Swing Adsorption Processes
- 5. Membrane Separation
 - 5.1. Polymer Membrane Processes
 - 5.2. Palladium Membrane Processes
- 6. Separation by Metal Hydrides

Hydrogen and Natural Gas Mixture

Itsuki Uehara, National Institute of Advanced Industrial Science and Technology, Japan

- 1. Introduction
- 2. Burner Combustion of Natural Gas Mixed with Hydrogen
- 3. Hydrogen-Natural Gas Mixtures for Internal Combustion Engines

Handling and Safety of Hydrogen

Itsuki Uehara, National Institute of Advanced Industrial Science and Technology, Japan

- 1. Introduction
- 2. Safety Aspects of Gaseous Hydrogen
 - 2.1. Fire Hazards and Related Damage
 - 2.1.1. Leaked States
 - 2.1.2. Flammability Limits
 - 2.1.3. Ignition Sources
 - 2.1.4. Burning and Quenching Characteristics
 - 2.1.5. Fire Damage
 - 2.2. Explosion Hazards and Related Damage
 - 2.2.1. Deflagration
 - 2.2.2. Detonation
 - 2.2.3. Explosive Damage
- 3. Safety Aspects of Liquid Hydrogen

268

283

- 3.1. Low Temperature Hazards
- 3.2. Fire and Explosive Hazards
- 4. Safety Aspects of Metal Hydrides
- 5. Materials for Safe Handling
 - 5.1. Hydrogen Embrittlement
 - 5.2. Materials for Gaseous Hydrogen
 - 5.3. Materials for Liquid Hydrogen
- 6. Detection of Hydrogen and its Fires
 - 6.1. Techniques for Detection of Hydrogen Leakage
 - 6.2. Techniques for Detection of Hydrogen Fires
- 7. Basic Measures for Safe Handling

Index

309

About EOLSS

317

1

VOLUME II

Hydrogen as a Transport Fuel: Past and Present Usage

William D. Van Vorst, Department of Chemical Engineering, University of California, Los Angeles (UCLA), USA

Frano Barbir, Proton Energy Systems, USA

- 1. Introduction
- 2. Historical Review of Efforts Leading to the Hydrogen-Fueled Engine
 - 2.1. Prior to 1875
 - 2.2. From 1875 to 1950
 - 2.3. From 1950 to 2000
 - 2.4. Development of Fuel Cells
 - 2.5. Nonautomotive Applications of Hydrogen As a Fuel
- 3. Hydrogen As a Fuel
 - 3.1. Some Properties of Hydrogen and Their Significance
 - 3.2. Some Advantages of Hydrogen
 - 3.3. Ancillary Concerns with the Use of Hydrogen As a Fuel
 - 3.3.1. Overall Cost and Production3.3.2. Safety Considerations
 - 3.3.3. Onboard Storage of Hydrogen
- 4. Some Further Observations on Hydrogen Power in Various Modes of Transport
 - 4.1. Air Transportation
 - 4.2. Rail Transportation
 - 4.3. Marine Vessels
 - 4.4. Surface Vehicles
 - 4.4.1. A Note on Engine Operation
 - 4.4.2. Dual-Fuel Engine Operation
 - 4.5. The Use of Hydrogen As a Complement of Natural Gas
- 5. Conclusions

Vehicles with Hydrogen-Air Fuel Cells

Frano Barbir, Proton Energy Systems, Wallingford, CT, USA

- 1. Introduction
- 2. Proton Exchange Membrane Fuel Cell
- 3. Fuel Cell System
- 4. Propulsion Configurations

- 5. Systems with Onboard Reforming
- 6. Fuel Cell and Fuel Cell System Efficiency
- 7. Automotive Fuel Cell Technical Specifications: Status and Targets
- 8. Prototype Fuel Cell Vehicles
- 9. Conclusion

Some Information On The Hydrogen Combustion Process And Rocket Propulsion Systems 46

Tokio Ohta, Yokohama National University, 79-1 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan

Ikuo Komatsu, Iwatani International Corporation, 3-21-8, Nishi Shinbashi, Minato-ku, Tokyo, 105-8458, Japan

- 1. Hydrogen Combustion Data
- 2. Space Rocket and the Hydrogen Fuel
- 3. Design of Supersonic (Hypersonic) Aircraft
- 4. An Experiment of Hydrogen/Oxygen Turbine for Power Plant

Hydrogen Storage

Kunihiro Takahashi, Tokyo Gas Co., Ltd., Japan

- 1. Introduction
- 2. Gas Storage in a Gaseous State
 - 2.1. Storage under Atmospheric Pressure 2.1.1. Water-sealed Gas Holder
 - 2.1.2. Dry Type Gas Holder
 - 2.2. Storage under Pressure
 - 2.2.1. Cylinders 2.2.2. Tank
 - 2.3. Underground Storage
- 3. Storage as Liquid Hydrogen
 - 3.1. Liquefaction of Hydrogen
 - 3.1.1. Raw Hydrogen Refining
 - 3.1.2. OrthoPara Conversion
 - 3.1.3. Liquefaction Process of Hydrogen
 - 3.1.4. Storage by Slush Hydrogen
 - 3.1.5. Liquid Hydrogen Tank
- 4. Hydrogen Storage by Chemical Hydrides
 - 4.1. Storage by Metal Hydrides
 - 4.1.1. Hydrogen Storage Vessels
 - 4.2. Hydrogen Storage by Organic Compound 4.2.1. Potassium Formate
 - 4.2.2. Ammonia, Methanol, and Methylcyclohexane System
 - 4.3. Glass Microspheres and Others
 - 4.3.1. Carbon Materials4.3.2. Glass Balloon and Zeolite

Pressurized Hydrogen Storage

Jo Suzuki, Chief Executive Engineer, Development Dept., Suzuki Shokan Co., Ltd., Kawagoe City, Japan Kunihiro Takahashi, Director, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Pressurized Hydrogen Storage
- 2. Safety Points
- 3. Technical Development of Storage Vessels for Pressurized Hydrogen and Actual Examples of Pressurized Hydrogen Storage

4. Web Sites for Reference

Hydrogen Storage By Chemical Hydrides

Kunihiro Takahashi, Director, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Metalhydrides, Energy Storage, and Other Applications
 - 1.1. Heat Storage
 - 1.2. Electricity Storage
 - 1.3. Heating/Cooling
 - 1.4. Electricity Generation
 - 1.5. Pumping or Pressurizing
 - 1.6. Hydrogen Purification
 - 1.7. Deuterium Separation
- 2. Hydrogen Storage by Using Organic Compounds, etc.

Hydrogen Storage By Glass Microspheres and Others

Kunihiro Takahashi, Director, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Introduction
- 2. Activated Carbon
- 3. Graphite Nanofibers and Carbon Nanotubes
- 4. Glass Microspheres
- 5. Zeolite

Hydrogen Liquefaction

Takuji Hanada, Air Liquide Japan Co., Ltd., Tokyo, Japan Kunihiro Takahashi, Center for Supply Control and Disaster Management, Tokyo, Japan

- 1. Introduction
- 2. Process of Refining Source Hydrogen
 - 2.1 Pressure Swing Adsorption (PSA) Method
 - 2.2 Cryogenic Adsorption Purification Method
- 3. Ortho-Para Conversion Method
- 4. Liquefaction Process
 - 4.1 Hydrogen Liquefaction Process for Continuous Ortho-para Conversion
 - 4.2 Helium- Brayton Hydrogen Liquefaction Process

Liquid-Hydrogen Storage

Takuji Hanada, Air Liquide Japan Co., Ltd., Tokyo, Japan Kunihiro Takahashi, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Introduction
- 2. Insulation of Liquid Hydrogen Tank
- Selection of Liquid Hydrogen Storage Tanks by Purpose 3.
- 4. Type and Shape of Liquid Hydrogen Storage Facilities
- 5. Carriers for Liquid Hydrogen Transportation

Hydrogen Transportation

Kunihiro Takahashi, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

125

114

104

96

- 1. Introduction
- 2. Hydrogen Transportation by Pipeline
 - 2.1. Pipeline Transportation of Gaseous Hydrogen
 - 2.2. Transportation Efficiency in Pipeline Transportation of Gaseous Hydrogen
 - 2.3. Auxiliary Equipment for Gaseous Hydrogen Transportation Pipelines
 - 2.4. Gaseous Hydrogen Pipeline Transportation Cost
- 2.5. Transportation of liquid hydrogen by Pipeline
 Batch Transportation of Hydrogen
 - 3.1. Batch transportation of Pressurized Hydrogen gas
 - 3.2. Batch Transportation of Liquid Hydrogen
 - 3.3. Transportation of hydrogen in forms of compounds or combined with other materials 3.3.1. Metal Hydrides
 - 3.3.2. Transportation of Hydrogen using Organic Compounds and Carbon Materials, etc.
- 4. Ocean Transportation of Hydrogen
- 5. Appendix
 - 5.1 Compressibility Factor
 - 5.2 Transportation Coefficient

Transportation of Hydrogen by Pipeline

Kunihiro Takahashi, Director, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Introduction
- 2. Distinctive Features of Pipeline Transportation System
- 3. Equipment Constituting Pipeline Transportation System
 - 3.1. Main Body of Pipeline
 - 3.1.1. Selection of Pipeline Route and Construction to Lay Pipeline
 - 3.1.2. Material Quality for Pipes, etc.
 - 3.1.3. Selection of Pipeline Design Pressure and Pipe Diameter
 - 3.2. Pressure-regulating Equipment
 - 3.2.1. Boosters
 - 3.2.2. Pressure-reducing Equipment
 - 3.2.3. Demand/Supply Adjustment Equipment
- 4. Operation of Pipeline

Batch-Systems of Hydrogen Transportation

Kunihiro Takahashi, Director, Center for Supply Control and Disaster Management, Tokyo Gas Co., Ltd., Tokyo, Japan

- 1. Introduction
- 2. Pressurized Hydrogen Gas Batch Transportation System
 - 2.1. Refining Processes
 - 2.2. Compression Process
 - 2.3. Pressurized Hydrogen Transport Vessels
- 3. Liquid Hydrogen Transportation System
 - 3.1. Liquid Hydrogen Transport Vessels
 - 3.2. Liquefaction Process
 - 3.3. Boil-off Gas during Transportation
- 4. Metal Hydride Transportation System
 - 4.1. Metal Hydride Transportation System

Ocean Transportation of Hydrogen

Hiroshi Sano, Director, Laboratory Office of Global Energy System, Osaka, Japan

1. Introduction

148

- 2. Liquid Hydrogen Property for Cargo
- 3. Problems of Liquid Hydrogen Tankers
- 4. Performance of Energy Transportation
- 5. Conclusion

Ammonia Energy System Hiroshi Sano, Director, Laboratory Office of Global Energy System, Osaka, Japan

- 1. Features of Ammonia Energy
- 2. Tanker Transportation
- 3. Ammonia Energy System
- 4. Ammonia Direct Use
- 5. Conclusion

Alcohol Energy Systems

T. Honjou, Senior Researcher, National Institute of Advanced Industrial Science and Technology, Japan Hiroshi Sano, Director, Laboratory Office of Global Energy System, Osaka, Japan

- 1. Introduction
- 2. Feature of methanol Energy system
- 3. Methanol Energy Systems
 - 3.1. CO_2 Supply
 - 3.2. Methanol Synthesis
 - 3.3. Tanker Transportation
 - 3.4. Recovery of Hydrogen from Methanol
 - 3.5. Energy Use
- 4. Methanol Direct Use
- 5. Conclusion

Metal Hydrides

Toshiki Kabutomori, *The Japan Steel Works, Ltd. 1-1, Nikko-Machi, Fuchuu, 183-8503, Japan.* Keizou Ohnishi, *The Japan Steel Works, Ltd. 1-1, Nikko-Machi, Fuchuu, 183-8503, Japan.*

- 1. Hydrogen Storage Metal
- 2. Properties of Hydrogen Storage Alloys
 - 2.1. Function and Features of Hydrogen Storage Alloys
 - 2.2. Thermodynamics of Metal Hydride
 - 2.3. Reaction and Equilibrium in Metal-Hydrogen System 2.3.1. Pressure-Composition-Isotherms (P-C-T)
 - 2.3.2. Pressure-Temperature (P-T) Diagrams
 - 2.4. Representative Hydrogen Storage Alloys
 - 2.5. Crystal Structure of Metal Hydride and Hydrogen Site
 - 2.6. Energy Conversion in Hydrogen Storage Alloys
- 3. Use of Hydrogen Storage Alloys
 - 3.1. Various Usages
 - 3.2. Hydrogen Storage
 - 3.3. Heat Pump
 - 3.4. Batteries
 - 3.4.1. Construction and Features of Ni-MH
 - 3.4.2. Hydrogen Storage Alloys for Ni-MH Batteries
 - 3.5. Purification and Recovery
 - 3.6. Actuator
- 4. Properties Required for Hydrogen Storage Alloys for the Practical Use

179

186

Physics of Metal Hydrides Etsuo Akiba, *National Institute of Materials and Chemical Research, Japan*

- 1. The Stability of Hydrides
- 2. Crystal Structures of Metal hydrides
- 3. Examples of Crystal Structure of Ternary Hydrides
- 4. The Relation between Crystal Structure and Thermodynamic Properties
- 5. Electronic Properties of Ternary Hydrides
- 6. Electronic Structures of LaNi5 and its hydride

Kinds and Characteristics of Hydrogen Storage Alloy

Toshiki Kabutomori, *Manager, The Japan Steel Works, Ltd., Japan* Keizou Ohnishi, *Adviser, The Japan Steel Works, Ltd., Japan*

- 1. Classification of Hydrogen Storage Alloys
- 2. Characteristics of A2B Alloys
 - 2.1. Hydriding Properties of Mg₂Ni alloy
- 3. Characteristics of AB Alloys
 - 3.1. Hydriding Properties of TiFe Alloy
- 4. Properties of AB2 Alloys
 - 4.1. Hydriding Properties of TiCr₂ Alloy
 - 4.2. Hydriding Properties TiMn_{1.5} Alloy
 - 4.3. Other AB₂ Alloys
- 5. Properties of AB5 Alloys
 - 5.1. Hydriding Properties of CaNi₅ Alloy
 - 5.2. Hydriding Properties of LaNi₅ Alloy
 - 5.3. Hydriding Properties of MmNi₅ Alloy
- 6. Novel Materials

Metal Hydride Air-Conditioning

Harunobu Takeda, *The Japan Steel Works Ltd., Japan* Toshiki Kabutomori, *The Japan Steel Works, Ltd., Japan* Keizou Ohnishi, *The Japan Steel Works Ltd., Japan*

- 1. Alloys Used for Metal Hydride Air-Conditioning (heat pump, heat storage)
 - 1.1 Metal Hydride Air Pump
 - 1.1.1 Heat Driven Type MH Heat Pump
 - 1.1.1.1 Single-Stage Type Heat Pump
 - 1.1.1.2 Dual-Effect Type MH Pump
 - 1.1.1.3 Multi-Stage Type MH Heat Pump
 - 1.1.2 Compression Type MH Heat Pump
 - 1.1.3 General Principle System
 - 1.1.3.1 Enforced Type MH Heat Pump
- 2. Theme of R&D for MH Heat Pump System
- 3. Practical Applications
 - 3.1 Heat Driven MH Heat Pump
 - 3.2 Compression-Type MH Heat Pump
 - 3.3 Refrigerating System
 - 3.4 Heat Transport System

Metal Hydride Batteries

Tetsuo Sakai, Head of Battery Section, Osaka National Research Institute, Japan

- 1. General Background
- 2. Battery Structure and Performances

264

xiii

249

232

2.1. Battery Materials

3. EV Application

Other Applications (Actuator, Hydrogen Purification and Isotope Separation) Hideaki Itoh, *The Japan Steel Works Ltd., Japan* Toshiki Kautomori, *The Japan Steel Works Ltd., Japan* Harunobu Takeda, *The Japan Steel Works Ltd., Japan* Keizou Ohnishi, *Advisor, The Japan Steel Works, Ltd., Japan*

1. Actuator

- 1.1. Principle of Energy Conversion
- 1.2. Characteristics of Metal Hydride Actuator
- 1.3. Demonstrating Equipment
- 1.4. Compliance of Metal Hydride Actuator
- 1.5. Applications of Metal Hydride Actuator
- 1.6. Prospects for the Future
- 2. Hydrogen Purification
 - 2.1. General Principle
 - 2.2. Application System
 - 2.2.1. Hydrogen Separation from Ammonia Feed Gas
 - 2.2.2. Purification of Hydrogen in the Generator
- 3. Isotope Separation
 - 3.1. Isotope effect of Metal Hydride
 - 3.2. Separation and Concentration of Hydrogen Isotope
 - 3.2.1. Uranium Hydride
 - 3.2.2. Vanadium Hydride
 - 3.2.3. Tritium Recovery

Fuel Cell Systems

Akifusa Hagiwara, Energy and Environment R&D Center, The Tokyo Electric Power Co., Yokohama, Japan

- 1. Introduction
- 2. Fuel Cell Structure and Principle of Operation
- 3. History
- 4. The Allure of Fuel Cells
- 5. Fuel Cell Types
 - 5.1. Alkaline Fuel Cells (AFCs)
 - 5.2. Polymer Electrolyte Fuel Cells (PEFCs)/or Proton Exchange Membrane Fuel Cells (PEMFCs)
 - 5.3. Phosphoric Acid Fuel Cells (PAFCs)
 - 5.4. Molten Carbonate Fuel Cells (MCFCs)
 - 5.5. Solid Oxide Fuel Cells (SOFCs)
- 6. Fuel Cell Power Generation Systems
- 7. Lifetime
- 8. Application Areas for Fuel Cells

Electrochemistry of Fuel Cell

Kouichi Takizawa, Tokyo Electric Power Company, Japan

- 1. Introduction
- 2. Principle of Electricity Generation by Fuel Cells
- 3. Electricity Generation Characteristics of Fuel Cells
- 4. Fuel Cell Efficiency

304

287

Reforming Systems for Fuel Cells

Akifusa Hagiwara, Tokyo Electric Power Co. Ltd., Japan

- 1. Introduction
- 2. Steam Reforming of Hydrocarbon Fuels
- 3. Fuel Processing System

Alkaline Fuel Cells

Hiroko Sotouchi, Tokyo Electric Power Company, Japan

- 1. Introduction
- 2. Background
- 3. Cell Structure
- 4. Features of Alkaline Fuel Cells

Proton Exchange Membrane Fuel Cells

Akira Watanabe, Tokyo Electric Power Company, Japan

- 1. Introduction
- 2. Principle of Operation
- 3. Construction
- 4. Features
- 5. System Configuration
- 6. Fuel Cell Electric Vehicles
- 7. Direct Methanol Fuel Cells

Phosphoric Acid Fuel Cells

Hiroko Sotouchi, Tokyo Electric Power Company, Japan Akifusa Hagiwara, Tokyo Electric Power Co. Ltd., Japan

- 1. Introduction
- 2. Cell Structure
- 3. Features of Phosphoric Acid Fuel Cells
- 4. Cell Lifetime
- 5. Plant Experiences

Molten Carbonate Fuel Cells

Kouichi Takizawa, Tokyo Electric Power Company, Japan

- 1. Introduction
- 2. Principle of Operation and Construction of MCFCs
- 3. Electric Power Generation System
- 4. Power Generation Characteristics
- 5. Gradation Phenomena
 - 5.1. Electrolyte Loss
 - 5.2. Pore Coarsening of Electrodes and the Electrolyte Matrix
 - 5.3. Short-circuits Due to Nickel Precipitation
- 6. Problems in MCFC Development

Solid Oxide Fuel Cells

Atsushi Kimura, Tokyo Electric Power Company, Japan

1. Introduction

XV

349

320

325

333

- 2. Cell Component Materials
- 3. Cell Structure
- 4. Applications

Potential Applications of Fuel Cells

Akifusa Hagiwara, Tokyo Electric Power Co. Ltd., Japan Hiroko Sotouchi, Tokyo Electric Power Company, Japan

- 1. Introduction
- 2. Commercial Applications
- 3. Distributed Regional Installations
- 4. Electric Utility Applications
- 5. Industrial Applications
- 6. Application in Mobile Power Sources
- 7. Home-use Power Sources
- 8. Emergency-use Power Supplies
- 9. Integrated Hydrogen Energy System Combined with Renewable Energy Sources

Index

363

356

About EOLSS