

Article

High-Efficiency Power Cycles for Particle-Based Concentrating Solar Power Plants: Thermodynamic Optimization and Critical Comparison

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Abstract: This paper investigates and compares several highly efficient thermodynamic cycles that are suitable for coupling with particle-in-tube fluidized-bed solar receiver technology. In such a receiver, high-temperature particles are used as both a heat transfer fluid and a storage medium. A dense particle suspension (DPS) is created through an upward bubbling fluidized-bed (UBFB) flow inside the receiver tubes, which constitutes the “particle-in-tube” solar receiver concept. Reaching higher temperatures is seen as a key factor for future cost reductions in the solar plant, as this leads to both higher power conversion efficiency and increased energy storage density. Three advanced thermodynamic cycles are analyzed in this work: the supercritical steam Rankine cycle (s-steam), supercritical carbon dioxide cycle (s-CO₂) and integrated solar combined cycle (ISCC). For each one, 100% solar contribution, which is considered the total thermal input to the power cycle, can be satisfied by the solar particle receiver. The main findings show that the s-CO₂ cycle is the most suitable thermodynamic cycle for the DPS solar plant, exhibiting a net cycle efficiency above 50% for a moderate temperature range (680–730 °C). For the other advanced power cycles, 45.35% net efficiency can be achieved for the s-steam case, while the efficiency of the ISCC configuration is limited to 45.23% for the solar-only operation mode.

Keywords: power cycles; particle receivers; thermodynamic optimization; solar energy



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1. Introduction

Achieving global net-zero emissions by 2050 and limiting the temperature rise to below 1.5 °C have become the main goals for scientists around the world [1]. To do this, it is necessary to accelerate the process of reducing carbon emissions, reducing deforestation, accelerating the transition to electric vehicles and encouraging investment in renewable energy technologies to increase efficiency and operational flexibility [2]. Several actions have been taken by countries around the world, and among these, the European Green Deal is the transformation plan of the European economy for a sustainable future [3]. It aims to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to become a net-zero-emission, sustainable and resilient economy by 2050. The penetration of renewable energy sources (RES) in distributed electricity generation plays a fundamental role in achieving the objectives set by the European Union.

In this context, concentrating solar power (CSP) is seen as one of the most promising technologies for electricity production for the coming decades compared to other intermittent renewable electricity sources, such as wind and photovoltaics [4]. Amongst the reasons for this, its reliability and flexibility stand out. However, the key point of the technology is that its operation is not limited to when the sun is shining when integrated with thermal energy storage (TES) systems [5]. Furthermore, the water requirements of solar plants are reduced when coupled to dry-cooling systems [6]. Cost reductions attained

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Power Cycles and Energy Efficiency Edward Jack Hoffman, 1996 This unique book provides a fresh perspective on the thermodynamics of the classic energy cycles The author considers modifications of various power cycles that have the potential to double the efficiency of electric power generation The book offers a detailed discussion of nonadiabatic behavior during compression and expansion which is a topic of central importance in the enhancement of efficiency Handbook of Energy Efficiency and Renewable Energy D. Yogi Goswami, Frank Kreith, 2007-05-07 Brought to you by the creator of numerous bestselling handbooks the Handbook of Energy Efficiency and Renewable Energy provides a thorough grounding in the analytic techniques and technological developments that underpin renewable energy use and environmental protection The handbook emphasizes the engineering aspects of energy conservation and renewable energy Taking a world view the editors discuss key topics underpinning energy efficiency and renewable energy systems They provide content at the forefront of the contemporary debate about energy and environmental futures This is vital information for planning a secure energy future Practical in approach the book covers technologies currently available or expected to be ready for implementation in the near future It sets the stage with a survey of current and future world wide energy issues then explores energy policies and incentives for conservation and renewable energy covers economic assessment methods for conservation and generation technologies and discusses the environmental costs of various energy generation technologies The book goes on to examine distributed generation and demand side management procedures and gives a perspective on the efficiencies economics and environmental costs of fossil and nuclear technologies Highlighting energy conservation as the cornerstone of a successful national energy strategy the book covers energy management strategies for industry and buildings HVAC controls co generation and advances in specific technologies such as motors lighting appliances and heat pumps It explores energy storage and generation from renewable sources and underlines the role of infrastructure security and risk analysis in planning future energy transmission and storage systems These features and more make the Handbook of Energy Efficiency and Renewable Energy the tool for designing the energy sources of the future Energy Conservation Update, 1979 **CRC Handbook of Energy Efficiency** Frank Kreith, Ronald E. West, 1996-10-24 Addressing the needs of engineers energy planners and policy makers CRC Handbook of Energy Efficiency provides up to date information on all important issues related to efficient energy use including Efficient energy technologies Economics Utility restructuring Integrated resource planning Energy efficient building design Industrial energy conservation Wind energy Solar thermal systems Photovoltaics Renewable energy Cogeneration Fossil fuel cost projections The rapid changes that characterize the technology of energy generation systems and the forthcoming competition among energy producers make this handbook a must for anyone involved in the science technology or policy of energy The 53 expert contributors from industry government and universities and the 600 figures and tables make CRC Handbook of Energy Efficiency a professional and valuable

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Fundamentals of Engineering Thermodynamics Michael J. Moran, Howard N. Shapiro, Daisie D. Boettner, Margaret B. Bailey, 2010-12-07 This leading text in the field maintains its engaging readable style while presenting a broader range of applications that motivate engineers to learn the core thermodynamics concepts Two new coauthors help update the material and integrate engaging new problems Throughout the chapters they focus on the relevance of thermodynamics to modern engineering problems Many relevant engineering based situations are also presented to help engineers model and solve these problems *Thermodynamics and Energy Conversion Principles* Kaushal Dhawan, 2025-02-20 *Thermodynamics and Energy Conversion Principles* is a comprehensive guide to understanding how energy transforms from one form to another Crafted by experts in physics engineering and related fields this book covers both fundamental principles and practical applications of energy conversion We start with the basics of thermodynamics explaining concepts such as energy work and temperature before delving into the core laws of thermodynamics that govern energy behavior Beyond theory we explore real world applications like power plants refrigerators and heat engines discussing various cycles such as the Rankine cycle used in steam power plants and analyzing their efficiency Modern advancements in energy conversion including renewable sources like solar and wind power are also covered We address challenges like energy storage and efficient energy use providing a strong foundation for understanding and solving global issues like climate change *Thermodynamics and Energy Conversion Principles* is an invaluable resource for students researchers and anyone interested in how energy is converted and utilized in our world It combines theoretical knowledge with practical insights to foster sustainable energy solutions

ECOS 2012 The 25th International Conference on Efficiency, Cost, Optimization and Simulation of Energy Conversion Systems and Processes (Perugia, June 26th-June 29th, 2012) Umberto Desideri, Enrico Sciubba, Giampaolo Manfrida, 2012 The 8 volume set contains the Proceedings of the 25th ECOS 2012 International Conference Perugia Italy June 26th to June 29th

2012 ECOS is an acronym for Efficiency Cost Optimization and Simulation of energy conversion systems and processes summarizing the topics covered in ECOS Thermodynamics Heat and Mass Transfer Exergy and Second Law Analysis Process Integration and Heat Exchanger Networks Fluid Dynamics and Power Plant Components Fuel Cells Simulation of Energy Conversion Systems Renewable Energies Thermo Economic Analysis and Optimisation Combustion Chemical Reactors Carbon Capture and Sequestration Building Urban Complex Energy Systems Water Desalination and Use of Water Resources Energy Systems Environmental and Sustainability Issues System Operation Control Diagnosis and Prognosis Industrial Ecology

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Energy, 1976 **Energy Management and IT Applications** Mr. Rohit Manglik, 2024-03-01 Focuses on optimizing energy usage with the help of modern IT tools energy auditing smart metering and energy saving technologies

Organic Rankine Cycle for Energy Recovery System Andrea De Pascale, 2020-06-18 The rising trend in the global energy demand poses new challenges to humankind The energy and mechanical engineering sectors are called to develop new and more environmentally friendly solutions to harvest residual energy from primary production processes The Organic Rankine Cycle ORC is an emerging energy system for power production and waste heat recovery In the near future this technology can play an increasing role within the energy generation sectors and can help achieve the carbon footprint reduction targets of many industrial processes and human activities This Special Issue focuses on selected research and application cases of ORC based waste heat recovery solutions Topics included in this publication cover the following aspects performance modeling and optimization of ORC systems based on pure and zeotropic mixture working fluids applications of waste heat recovery via ORC to gas turbines and reciprocating engines optimal sizing and operation of ORC under combined heat and power and district heating application the potential of ORC on board ships and related issues life cycle analysis for biomass application ORC integration with supercritical CO₂ cycle and the proper design of the main ORC components including fluid dynamics issues The current state of the art is considered and some cutting edge ORC technology research activities are examined in this book

Fossil Energy Update

,1985 **Carnot Cycle and Heat Engine Fundamentals and Applications** Michel Feidt,2020-07-03 This book results from a Special Issue related to the latest progress in the thermodynamics of machines systems and processes since the premonitory work of Carnot Carnot invented his famous cycle and generalized the efficiency concept for thermo mechanical engines Since that time research progressed from the equilibrium approach to the irreversible situation that represents the general case This book illustrates the present state of the art advances after one or two centuries of consideration regarding applications and fundamental aspects The research is moving fast in the direction of economic and environmental aspects This will probably continue during the coming years This book mainly highlights the recent focus on the maximum power of engines as well as the corresponding first law efficiency upper bounds *The Physics of Energy (Volume 1)* N.B. Singh, The Physics of Energy is an accessible and engaging exploration of the concept of energy and its role in shaping the world we live in The book covers a wide range of energy types from the power of the Sun to the energy in food and machines explaining how energy works in simple terms It connects scientific principles to everyday experiences making complex topics easy to understand for readers of all backgrounds Whether you re curious about the forces that drive the universe or how energy impacts your daily life this book offers a clear insightful and approachable guide to the fundamental concept of energy

Solar Energy Storage Bent Sorensen,2015-06-03 While solar is the fastest growing energy source in the world key concerns around solar power s inherent variability threaten to de rail that scale up Currently integration of intermittent solar resources into the grid creates added complication to load management leading some utilities to reject it altogether while other operators may penalize the producers via rate increases or force solar developers to include storage devices on site to smooth out power delivery at the point of production However these efforts at mitigation unfold it is increasingly clear to parties on all sides that energy storage will be pivotally important in the drive to boost the integration of variable renewable sources into power infrastructures across the globe Thoughtfully implemented storage technologies can reduce peak demand improve day to day reliability provide emergency power in case of interrupted generation reduce consumer and utility costs by easing load balance challenges decrease emissions and increase the amount of distributed and renewable energy that makes it into the grid While energy storage has long been an area of concern for scientists and engineers there has been no comprehensive single text covering the storage methods available to solar power producers which leaves a lamentable gap in the literature core to this important field Solar Energy Storage aims to become the authoritative work on the topic incorporating contributions from an internationally recognized group of top authors from both industry and academia focused on providing information from underlying scientific fundamentals to practical applications and emphasizing the latest technological developments driving this discipline forward Expert contributing authors explain current and emergent storage technologies for solar thermal and photovoltaic applications Sheds light on the economic status of solar storage facilities including case studies of the particular challenges that solar energy systems present to remote locations Includes information

on chemical storage mechanisms mechanical storage tactics pumped hydro thermal storage and storage strategies for systems of all sizes from centralized utilities to distributed generation Introduction to Sustainable Energy Transformation Henryk Anglart, 2021-11-18 This textbook provides an accessible introduction to various energy transformation technologies and their influences on the environment Here the energy transformation is understood as any physical process induced by humans in which energy is intentionally transformed from one form to another This book provides an accessible introduction to the subject covering the theory principles of design operation and efficiency of the systems in addition to discerning concepts such as energy entropy exergy efficiency and sustainability It is not assumed that readers have any previous exposure to such concepts as laws of thermodynamics entropy exergy fluid mechanics or heat transfer and is therefore an ideal textbook for advanced undergraduate students Key features Represents a complete source of information on sustainable energy transformation systems and their externalities Includes all existing and major emerging technologies in the field Chapters include numerous examples and problems for further learning opportunities *Integration of Alternative Sources of Energy* Felix A. Farret, M. Godoy Simoes, 2006-04-20 A unique electrical engineering approach to alternative sources of energy Unlike other books that deal with alternative sources of energy from a mechanical point of view *Integration of Alternative Sources of Energy* takes an electrical engineering perspective Moreover the authors examine the full spectrum of alternative and renewable energy with the goal of developing viable methods of integrating energy sources and storage efficiently Readers become thoroughly conversant with the principles possibilities and limits of alternative and renewable energy The book begins with a general introduction and then reviews principles of thermodynamics Next the authors explore both common and up and coming alternative energy sources including hydro wind solar photovoltaic thermosolar fuel cells and biomass Following that are discussions of microturbines and induction generators as well as a special chapter dedicated to energy storage systems After setting forth the fundamentals the authors focus on how to integrate the various energy sources for electrical power production Discussions related to system operation maintenance and management as well as standards for interconnection are also set forth Throughout the book diagrams are provided to demonstrate the electrical operation of all the systems that are presented In addition extensive use of examples helps readers better grasp how integration of alternative energy sources can be accomplished The final chapter gives readers the opportunity to learn about the HOMER Micropower Optimization Model This computer model developed by the National Renewable Energy Laboratory NREL assists in the design of micropower systems and facilitates comparisons of power generation techniques Readers can download the software from the NREL Web site This book is a must read for engineers consultants regulators and environmentalists involved in energy production and delivery helping them evaluate alternative energy sources and integrate them into an efficient energy delivery system It is also a superior textbook for upper level undergraduates and graduate students

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Table of Contents Power Cycles Energy Efficiency

1. Understanding the eBook Power Cycles Energy Efficiency
 - The Rise of Digital Reading Power Cycles Energy Efficiency
 - Advantages of eBooks Over Traditional Books
2. Identifying Power Cycles Energy Efficiency
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Power Cycles Energy Efficiency
 - User-Friendly Interface
4. Exploring eBook Recommendations from Power Cycles Energy Efficiency
 - Personalized Recommendations
 - Power Cycles Energy Efficiency User Reviews and Ratings
 - Power Cycles Energy Efficiency and Bestseller Lists
5. Accessing Power Cycles Energy Efficiency Free and Paid eBooks

- Power Cycles Energy Efficiency Public Domain eBooks
- Power Cycles Energy Efficiency eBook Subscription Services
- Power Cycles Energy Efficiency Budget-Friendly Options
- 6. Navigating Power Cycles Energy Efficiency eBook Formats
 - ePub, PDF, MOBI, and More
 - Power Cycles Energy Efficiency Compatibility with Devices
 - Power Cycles Energy Efficiency Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Power Cycles Energy Efficiency
 - Highlighting and Note-Taking Power Cycles Energy Efficiency
 - Interactive Elements Power Cycles Energy Efficiency
- 8. Staying Engaged with Power Cycles Energy Efficiency
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Power Cycles Energy Efficiency
- 9. Balancing eBooks and Physical Books Power Cycles Energy Efficiency
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Power Cycles Energy Efficiency
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Power Cycles Energy Efficiency
 - Setting Reading Goals Power Cycles Energy Efficiency
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Power Cycles Energy Efficiency
 - Fact-Checking eBook Content of Power Cycles Energy Efficiency
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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