

## 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-CO<sub>2</sub>) 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-CO<sub>2</sub> 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

# Power Cycles Energy Efficiency

**AW Rasmussen**



## **Power Cycles Energy 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

*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

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

*Thermal Energy Systems* Steven G. Penoncello, 2018-09-19 Thermal Energy Systems Design and Analysis Second Edition presents basic concepts for simulation and optimization and introduces simulation and optimization techniques for system modeling This text addresses engineering economy optimization hydraulic systems energy systems and system simulation Computer modeling is presented and a companion website provides specific coverage of EES and Excel in thermal fluid design Assuming prior coursework in basic thermodynamics and fluid mechanics this fully updated and improved text will guide students in Mechanical and Chemical Engineering as they apply their knowledge to systems analysis and design and to capstone design project work

**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

*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

**Comprehensive Energy Systems** Ibrahim Dincer, 2018-02-07 Comprehensive Energy Systems Seven Volume Set provides a unified source of information covering the entire spectrum of energy one of the most significant issues humanity has to face This comprehensive book describes traditional and novel energy systems from single generation to multi generation also covering theory and applications In addition it also presents high level coverage on energy policies strategies environmental impacts and sustainable development No other published work covers such breadth of topics in similar depth High level sections include Energy Fundamentals Energy Materials Energy Production Energy Conversion and Energy Management Offers the most comprehensive resource available on the

topic of energy systems Presents an authoritative resource authored and edited by leading experts in the field Consolidates information currently scattered in publications from different research fields engineering as well as physics chemistry environmental sciences and economics thus ensuring a common standard and language

**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 CO<sub>2</sub> 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

*Carbon Capture, Storage and Utilization* Malti Goel, M. Sudhakar, R.V. Shahi, 2019-02-21 Carbon capture and storage CCS is among the advanced energy technologies suggested to make the conventional fossil fuel sources environmentally sustainable It is of particular importance to coal based economies This book deals at length with the various aspects of carbon dioxide capture its utilization and takes a closer look at the earth processes in carbon dioxide storage It discusses potential of Carbon Capture Storage and Utilization as innovative energy technology towards a sustainable energy future Various techniques of carbon dioxide recovery from power plants by physical chemical and biological means as well as challenges and prospects in biomimetic carbon sequestration are described Carbon fixation potential in coal mines and in saline aquifers is also discussed Please note This volume is Co published with The Energy and Resources Institute Press New Delhi Taylor Francis does not sell or distribute the Hardback in India Pakistan Nepal Bhutan Bangladesh and Sri Lanka

*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

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systems The development of intelligent energy systems for efficient energy processes and mitigation technologies for the reduction of environmental pollutants is explored in depth and environmental social and economic impacts are also addressed Topics covered include Volume 1 Renewable Energy Biomass resources and biofuel production Bioenergy Utilization Solar Energy Wind Energy Geothermal Energy Tidal Energy Volume 2 Clean Energy Conversion Technologies Steam Vapor Power Generation Gas Turbines Power Generation Reciprocating Engines Fuel Cells Cogeneration and Polygeneration Volume 3 Mitigation Technologies Carbon Capture Negative Emissions System Carbon Transportation Carbon Storage Emission Mitigation Technologies Efficiency Improvements and Waste Management Waste to Energy Volume 4 Intelligent Energy Systems Future Electricity Markets Diagnostic and Control of Energy Systems New Electric Transmission Systems Smart Grid and Modern Electrical Systems Energy Efficiency of Municipal Energy Systems Energy Efficiency of Industrial Energy Systems Consumer Behaviors Load Control and Management Electric Car and Hybrid Car Energy Efficiency Improvement Volume 5 Energy Storage Thermal Energy Storage Chemical Storage Mechanical Storage Electrochemical Storage Integrated Storage Systems Volume 6 Sustainability of Energy Systems Sustainability Indicators Evaluation Criteria and Reporting Regulation and Policy Finance and Investment Emission Trading Modeling and Analysis of Energy Systems Energy vs Development Low Carbon Economy Energy Efficiencies and Emission Reduction Key features Comprising over 3 500 pages in 6 volumes HCES presents a comprehensive overview of the latest research developments and practical applications throughout all areas of clean energy systems consolidating a wealth of information which is currently scattered across a wide variety of literature sources In addition to renewable energy systems HCES also covers processes for the efficient and clean conversion of traditional fuels such as coal oil and gas energy storage systems mitigation technologies for the reduction of environmental pollutants and the development of intelligent energy systems Environmental social and economic impacts of energy systems are also addressed in depth Published in full colour throughout Fully indexed with cross referencing within and between all six volumes Edited by leading researchers from academia and industry who are internationally renowned and active in their respective fields Published in print and online The online version is a single publication i e no updates available for one time purchase or through annual subscription      **Fossil Energy Update** ,1985

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