

**Proceedings of ASME Turbo Expo 2023:  
Turbomachinery Technical  
Conference and Exposition**

**(GT2023)**

**Volume 12**

**June 26-30, 2023  
Boston, Massachusetts**

**Conference Sponsor**  
International Gas  
Turbine Institute

**THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS**

Two Park Avenue \* New York, N.Y. 10016

© 2023, The American Society of Mechanical Engineers, 2 Park Avenue, New York, NY 10016, USA  
(www.asme.org)

All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher.

INFORMATION CONTAINED IN THIS WORK HAS BEEN OBTAINED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS FROM SOURCES BELIEVED TO BE RELIABLE. HOWEVER, NEITHER ASME NOR ITS AUTHORS OR EDITORS GUARANTEE THE ACCURACY OR COMPLETENESS OF ANY INFORMATION PUBLISHED IN THIS WORK. NEITHER ASME NOR ITS AUTHORS AND EDITORS SHALL BE RESPONSIBLE FOR ANY ERRORS, OMISSIONS, OR DAMAGES ARISING OUT OF THE USE OF THIS INFORMATION. THE WORK IS PUBLISHED WITH THE UNDERSTANDING THAT ASME AND ITS AUTHORS AND EDITORS ARE SUPPLYING INFORMATION BUT ARE NOT ATTEMPTING TO RENDER ENGINEERING OR OTHER PROFESSIONAL SERVICES. IF SUCH ENGINEERING OR PROFESSIONAL SERVICES ARE REQUIRED, THE ASSISTANCE OF AN APPROPRIATE PROFESSIONAL SHOULD BE SOUGHT.

ASME shall not be responsible for statements or opinions advanced in papers or . . . printed in its publications (B7.1.3). Statement from the Bylaws.

For authorization to photocopy material for internal or personal use under those circumstances not falling within the fair use provisions of the Copyright Act, contact the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923, tel: 978-750-8400, www.copyright.com.

Requests for special permission or bulk reproduction should be addressed to the ASME Publishing Department, or submitted online at: <https://www.asme.org/publications-submissions/journals/information-for-authors/journalguidelines/rights-and-permissions>

ISBN: 978-0-7918-8707-3

## TABLE OF CONTENTS

Supercritical Carbon Dioxide Shock Behaviour Near the Critical Point.....	1
<i>Jinhong Wang, Teng Cao, Ricardo Martinez-Botas</i>	
Full-Scale Demonstration and Validation of a 35 MW Transcritical CO <sub>2</sub> Heat Pump.....	12
<i>Leonhard Wolscht, Reto Somaini, Emmanuel Jacquemoud, Philipp Jenny</i>	
A Comparison of Flow Path Designs for Axial Turbines Operating with Pure CO <sub>2</sub> and CO <sub>2</sub> Mixtures .....	22
<i>Salma I. Salah, Martin T. White, Abdulnaser I. Sayma</i>	
Simulation of Methane Oxyc Combustion in Supercritical Carbon Dioxide .....	35
<i>Marc T. Henry De Frahan, Mohammad J. Rahimi, Olga Doronina, Bruce A. Perry, Shashank Yellapantula, Ian Cormier, Marc Day, Michael James Martin</i>	
Effects of Supercritical CO <sub>2</sub> Fluid Properties on Heat Exchanger Design .....	43
<i>Afonso Lugo, Teemu Turunen-Saaresti, Jonna Tiainen</i>	
Oxidation Performance of Fe-Ni-Co-Cr-Mn High Entropy Alloy and its Al-Containing Variants in Supercritical CO <sub>2</sub> .....	52
<i>Margarita Ilinich, Xiao Huang, Kouros Zanganeh</i>	
Optimization of an HPT Blade and Sector-Based Annular Rig Design for Supercritical CO <sub>2</sub> Power Cycle Representative Testing .....	61
<i>Logan Tuite, James Braun, Guillermo Paniagua</i>	
Numerical Investigation of Flow Characteristics in a Supercritical Carbon Dioxide Turbine for 20 Megawatt Brayton Cycle.....	76
<i>Guoying Yang, Rui Yang, Qinghua Deng, Bozhou Xu, Jun Li, Zhenping Feng</i>	
Development and Validation of a Segregated Conjugate Heat Transfer Procedure on a sCO <sub>2</sub> Dry Gas Seal Test Bench.....	89
<i>Isacco Rafanelli, Giulio Generini, Antonio Andreini, Tommaso Diurno, Gabriele Girezzi, Andrea Paggini</i>	
Guidelines for the Aerodynamic Design of sCO <sub>2</sub> Centrifugal Compressor Stages.....	101
<i>Alessandro Romei, Paolo Gaetani, Giacomo Persico</i>	
Investigation of the Applicability of Methods Approved for Steam to the Design of Labyrinth Seals in Turbines Operated With CO <sub>2</sub> in Supercritical State.....	113
<i>Katharina Tegethoff, Christian Musch, Stefan Glos, Sebastian Schuster, Dieter Brillert</i>	
Integrated Aerodynamic and Mechanical Design of a Large-Scale Axial Turbine Operating With Supercritical Carbon Dioxide Mixtures.....	122
<i>Abdelrahman Abdeldayem, Andrea Paggini, Tommaso Diurno, Claudio Orazi, Martin White, Marco Ruggiero, Abdulnaser Sayma</i>	
Modeling a Water-Cooled Printed Circuit Heat Exchanger Condensing CO <sub>2</sub> for Use in sCO <sub>2</sub> Cycle System Optimization Studies .....	136
<i>Eric Liese, Sandeep Pidaparti</i>	
The Prediction of Condensation Characteristics of Supercritical Carbon Dioxide in the Laval Nozzle During Supersonic Flow.....	143
<i>Zhe Huang, Xin Shen, Laijie Chen, Hua Ouyang, Zhaohui Du</i>	

Experimental and Computational Heat Transfer Study of sCO <sub>2</sub> Single-Jet Impingement .....	154
<i>John Richardson, Ryan Wardell, Erik Fernandez, Jayanta S. Kapat</i>	
Supercritical CO <sub>2</sub> Compressor and Expander Design for Industrial Waste-Heat Valorization .....	172
<i>Lorenzo Toni, Valentina Bisio, Alberto Milani, Davide Biliotti, Ernani Fulvio Bellobuono, Roberto Valente, Matteo Dozzini, Manuele Bigi, Giulio Generini</i>	
sCO <sub>2</sub> Bottoming Cycle for Off-Shore Applications - An Optimization Study .....	183
<i>Giacomo Persico, David T. Sanchez, Dario Alfani, Paolo Silva, Rene Vijgen, Marco Ruggiero, Stefan Glos, Renaud Le Pierres, Ulrich Schmitz, Rasmus Rubycz, Albannie Cagnac, Scott Macadam, Dominique H. Orhon</i>	
Observations in the High-Temperature Creep Performance of Diffusion Bonds for sCO <sub>2</sub> Heat Exchangers .....	194
<i>John Shingledecker, Vikash Kumar, Alex Bridges</i>	
Techno-Economic Performance of the Allam-Fetvedt Cycle With Oxygen Storage .....	201
<i>Owen Pryor, J. Jeffrey Moore, Ian Cormier, Jeremy Fetvedt, Maksym Burlaka, Vlad Goldenberg</i>	
Manufacturing and Hydro Testing of a 10 MWe sCO <sub>2</sub> Axial Turbine .....	212
<i>John D. Klaerner, J. Jeffrey Moore, Kyle Robinson, Jonathan L. Wade, Aaron McClung</i>	
One Dimensional Model to Predict the Total Pressure Loss of Volute for Inward Flow Radial Supercritical CO <sub>2</sub> Turbines .....	224
<i>Syed Jiaul Hoque, Pramod Kumar, Pramod Chandra Gopi</i>	
An Experimental Investigation of Heat Transfer for Supercritical Carbon Dioxide Cooling in a Staggered Pin Fin Array .....	237
<i>Ryan J. Wardell, John Richardson, Marcel Otto, Matthew Smith, Erik Fernandez, Jayanta Kapat</i>	
Development of a 300 MWe Utility Scale Oxy-Fuel sCO <sub>2</sub> Turbine .....	249
<i>J. Jeffrey Moore, Josh Neveu, Jason Bensmiller, Cole Replogle, Jianliang Lin, Jeremy Fetvedt, Ian Cormier, Jayanta Kapat, Erik Fernandez, Guillermo Paniagua</i>	
Evaluation of Empirical Loss Models for Base Drag Prediction of sCO <sub>2</sub> Axial Turbine Aerofoils .....	262
<i>R. Senthil Kumaran, Sharath P. P., Dilipkumar B. Alone, Pramod Kumar</i>	
Influence of Geometrical and Operational Parameters on the Leakage Flow of a Radial Labyrinth Seal for Application in Inward Flow Radial Supercritical CO <sub>2</sub> Turbine .....	276
<i>Saurabh Deorao Lanjewar, Arockia Fenil, Pramod Kumar, Pramod Chandra Gopi</i>	
Assessment of Part-Load Operation Strategies of Supercritical Power Cycles Using Carbon Dioxide Mixtures in CSP Plants, Including Air-Cooled Condenser Optimisation .....	286
<i>Pablo Rodriguez-de Arriba, Francesco Crespi, David Sanchez Martinez, Lourdes Garcia Rodriguez</i>	
Effect of Impurities on the Compatibility of Steels in Supercritical CO <sub>2</sub> at 450 degrees-650 degrees C .....	298
<i>Bruce A. Pint, Michael J. Lance, Rishi Pillai, James R. Keiser</i>	
Test Rig Concept for Evaluating the Performance of a CO <sub>2</sub> Immersed Electromechanical Rotor System Utilizing Gas Bearings: Part-2 Thermal Systems & Flow Loop Design .....	306
<i>Rahul A. Bidkar, Uttara Kumar, Xiaohua Zhang, Neelesh Sarawate, John Powers, Nevin M. Anandika, Bugra Ertas</i>	

Heat Transfer Coefficient Dependence on Coolant Temperature For Supercritical CO2 Leading-Edge Jet Impingement .....	319
<i>Weston Olson, Erik Fernandez, Ladislav Vesely, Jayanta Kapat</i>	
Test Rig Concept for Evaluating the Performance of a CO2 Immersed Electro-Mechanical Rotor System Utilizing Gas Bearings: Part-1 Mechanical and Electric Machine Design .....	331
<i>Bugra Ertas, John Powers, Keith Gary, Dave Torrey, Joseph Zierer, Peggy Baehmann, Vandana Rallabandi, Tom Adcock, Nevin Anandika, Rahul A. Bidkar</i>	
Multi-Phase Rotary Pressure Exchanger as a Novel Compressor-Expander for Increasing Efficiency of Trans-Critical CO2 Heat Pumps.....	346
<i>Azam Thatte</i>	
A Numerical Heat Transfer Investigation of Lattice Structures As an Alternative AM-Enabled Design for Cooled sCO2 Airfoils .....	359
<i>Marcel Otto, Ryan Wardell, Parker O'Neal, Ladislav Vesely, Jayanta Kapat</i>	
Super-Critical Carbon Dioxide Power Cycle for Waste Heat Recovery Utilizing Hermetic Oil-Free Turbomachinery: Cycle and Conceptual Turbomachinery Design .....	371
<i>Bugra Ertas, Joseph Zierer, Aaron McClung, Dave Torrey, Rahul A. Bidkar, Doug Hofer, Vandana Rallabandi, Rajkeshar Singh, Xiaohua Zhang</i>	

**Author Index**