Selected papers from the 5th European conference on supercritical CO_2 for energy systems

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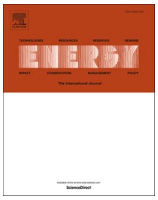

Selected papers from the 5th European conference on supercritical CO_2 for energy systems☆

The 5th European Conference on Supercritical CO_2 (sCO_2) for Energy Systems was held in Prague from 14 to 16 March 2023. The event was organised by the European sCO_2 Research & Development Alliance, whose aim is to provide a platform for exchanging knowledge on sCO_2 technologies in the energy sector for academia and industry, as well as to promote this topic to a wider audience. The Conference brought together more than 100 participants worldwide with expertise from research to policy development. A keynote speech, a panel discussion with participants from industry and academia, and more than 30 podium presentations took place. Based on the recommendations of the Alliance, the Conference Committee proposed a number of high-quality peer-reviewed contributions for archival publication in ENERGY. Seven papers passed the additional and independent ENERGY review process, covering a broad spectrum of the sCO_2 energy research area, as follows.

1. Turbomachinery

Persico et al. [1] focused on the design and fluid-dynamic analysis of the CO2OLHEAT compressor. The thermodynamic optimization of the cycle led to an overall pressure ratio slightly above 2.5, delivered with a two-stage centrifugal compressor. As typically found in sCO_2 power systems, the thermodynamic state of the fluid at the machine intake (P = 85 bar; T = 32 °C) is close to the critical point and to the saturation curve; therefore, the first stage of the machine demands a dedicated aero-thermodynamic design, which can account for the effects of non-ideal thermodynamics and of the potential onset of two-phase flows. The paper discusses the conceptual aero-mechanical design of the compressor and then focuses on its performance assessment over the full operating range via Computational Fluid Dynamics.

Ren et al. [2] introduced an extension of the through-flow method by considering real gas equations of state (EOSs). This is implemented in an in-house through-flow program called tFlow. This enables the method to support a more reliable calculation regarding, for instance, with carbon dioxide (CO_2) in a high-pressure region, where the gas does not behave like an ideal gas. The incorporation of real gas EOSs is validated with two-dimensional (2D) calculations of nozzle flows and with quasi-three-dimensional (3D) calculations of supercritical CO_2 (sCO_2) centrifugal compressors. A straightforward method for modifying the Riemann inlet boundary conditions for real gases is presented enabling a quick extension of through-flow codes to real gases and providing a stable solution process. Look-up tables (LUTs) are used instead of common high-degree polynomials to solve the real gas thermodynamic properties and reduce the computation time by a factor of about 20.

2. Natural circulation loops

Draskic et al. [3] investigated the steady-state behavior of natural circulation loops (NCLs). Experimental results are presented with CO2 at supercritical pressures in the range of 80–120 bar and temperatures in the range of 20–65 °C. Distinct thermodynamic states are reached by traversing a set of isochors. In addition to the experimental study, an equation for predicting the steady state of NCLs at supercritical pressures is proposed, and its accuracy is assessed with the data from experiments. Subsequently, the findings are put forward in aid of the development of safe, novel supercritical natural circulation facilities.

3. Techno-economic study

Pidaparti et al. [4] detailed techno-economic optimization results of natural gas-fired, utility-scale power plants based on the direct sCO2 power cycle. The study considered multiple plant configurations with varying levels of thermal integration with the plant air separation unit (ASU) to shows the systematic impact of thermal integration on plant performance and economics. Several design variables for each power cycle configuration were identified and optimized to minimize the levelized cost of electricity (LCOE). The optimized direct sCO_2 power plants achieved ~48 % plant efficiency (HHV basis), which is similar or slightly higher plant efficiencies than state-of-the-art natural gas combined power plants based on the F-class gas turbine with carbon capture and storage (CCS). The LCOE of the optimized direct sCO2 plants is 13–17 % higher than the reference NGCC plants with CCS due to high capital costs associated with the ASU and sCO2 power block, though there is significant room for improvement due to high uncertainty in component capital costs for these new plants.

4. Dynamic cycle modelling

Wolscht et al. [5] presented a detailed Modelica model of the high-temperature CO_2 heat pump, focusing on the thermodynamic states of the refrigerant during load variations of the system. In a consecutive step, the model is validated against testbed data of a heat pump from MAN ES with over 35 MW heat supply and a lift from 40 to 100 K. The model results match the testbed data with an accuracy of over 95 % and demonstrate a full coverage of the performance map minimum to

☆ The 6th European Conference on Supercritical CO_2 (sCO_2) for Energy Systems will be held from 9 to 11 April 2025 in Delft, Netherlands. More information on the event and the European sCO_2 Research & Development Alliance is available at the conference website: www.sCO2.eu.

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maximum speed, providing water-side supply temperatures of 50–109 °C. Realistic dynamics in fast load balancing operation are demonstrated where power consumption was varied by 80 % compared to maximum power within 30 s. Models of this kind are essential for an accurate prediction how decarbonized energy networks react by linking electricity and heat supply together. These predictions are ultimately useful to upgrade or optimize complex control strategies.

Kriz et al. [6] described a one-dimensional, thermo-hydraulic model of the sCO2 cycle Sofia developed to investigate optimal control methods and the behaviour of the cycle during operation. This dynamic model includes all devices such as turbomachinery, heat exchangers, valves, and piping, including heat loss, in line with the concept of the 1 MWe sCO2 cycle, to be realised in the site of a fossil power plant in the Czech Republic. The model assembly and calculations were conducted using the commercial Modelica-based library ClaRa + using the simulation environment Dymola and in combination with another Modelica-based library, UserInteraction. The real-time simulations, with some parameter changes during the calculation, are made and described in this paper.

Hofer et al. [7] studied a supercritical carbon dioxide (sCO_2) heat removal system that is based on multiple closed Brayton cycles with sCO_2 as the working fluid. In their study, different sudden failures modes are considered during the accident progress, e.g. failure of single sCO_2 cycles, control systems and valves. These abnormal conditions were investigated with the thermal-hydraulic system code ATHLET for a generic Konvoi pressurized water reactor. In most cases, the failure of a single sCO_2 cycle can be compensated. On the one hand, failure of the fans of the gas cooler leads to a pressure increase, which may be mitigated by an inventory control system or cycle shutdown. On the other hand, unintended fan speed-up can cause compressor surge without adequate countermeasures.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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