Supercritical CO_2 Power Cycles Symposium

Parameterized Study of Partially-Recuperated Supercritical CO_2 Power Cycle Performance

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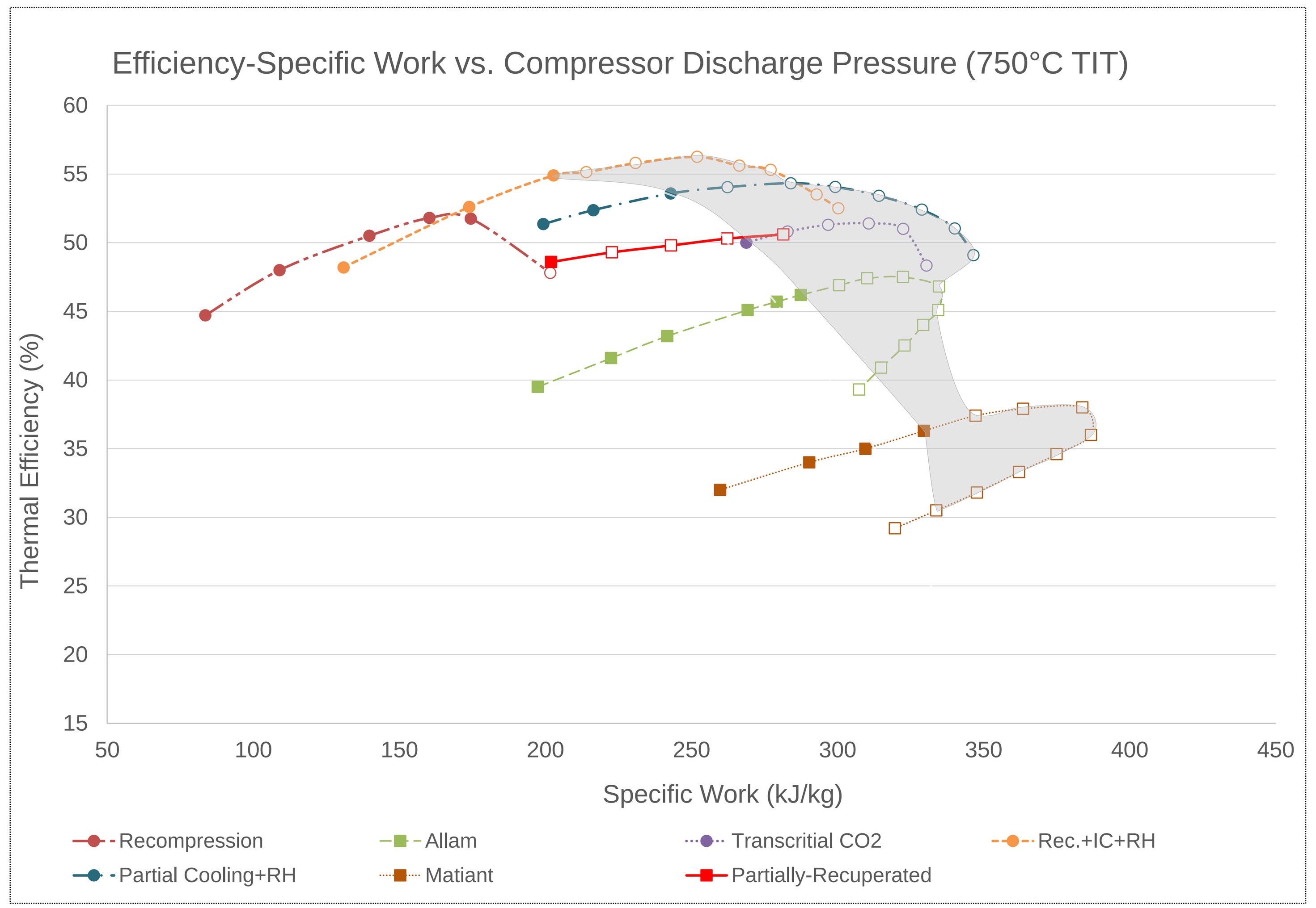
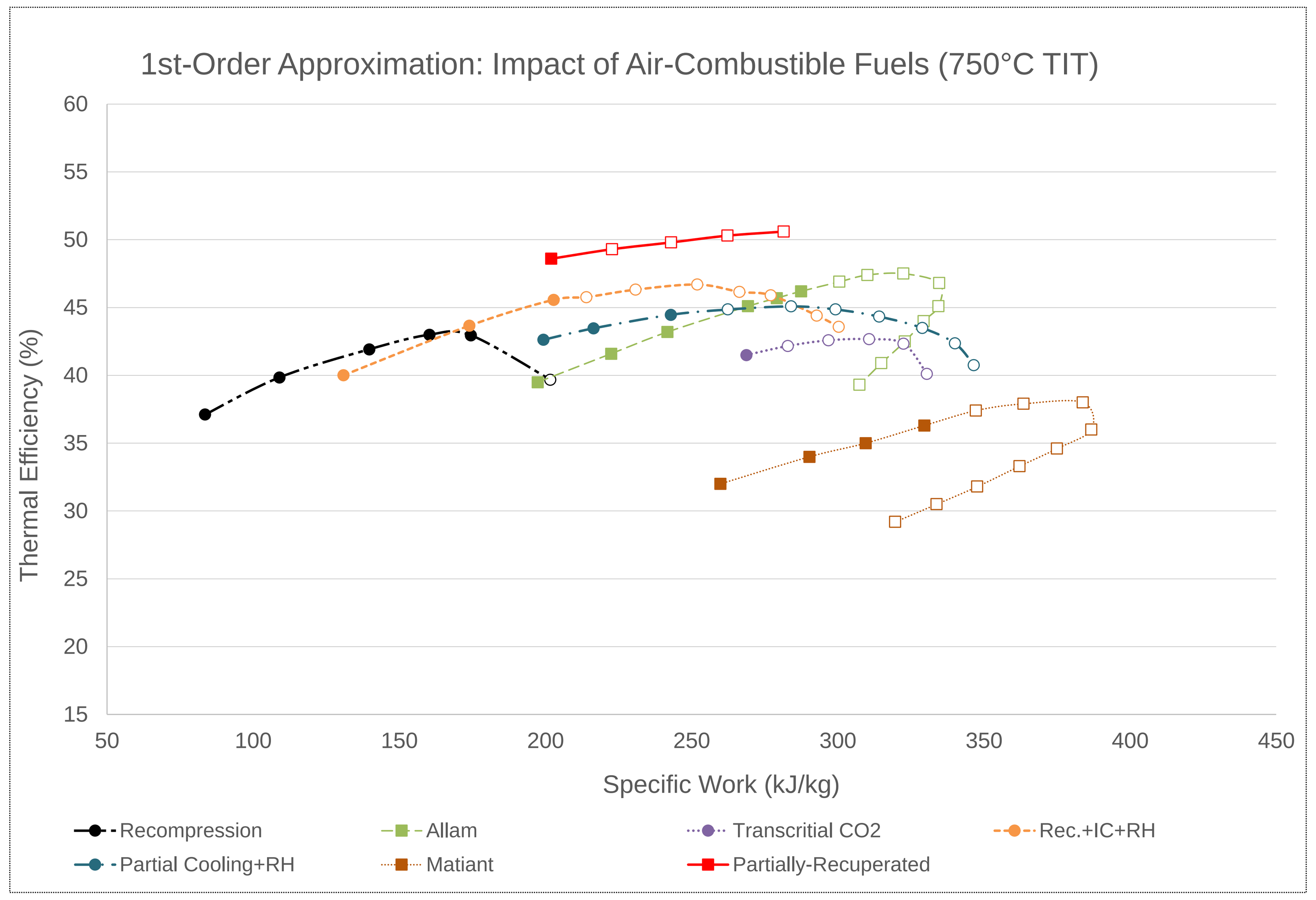
ABSTRACT

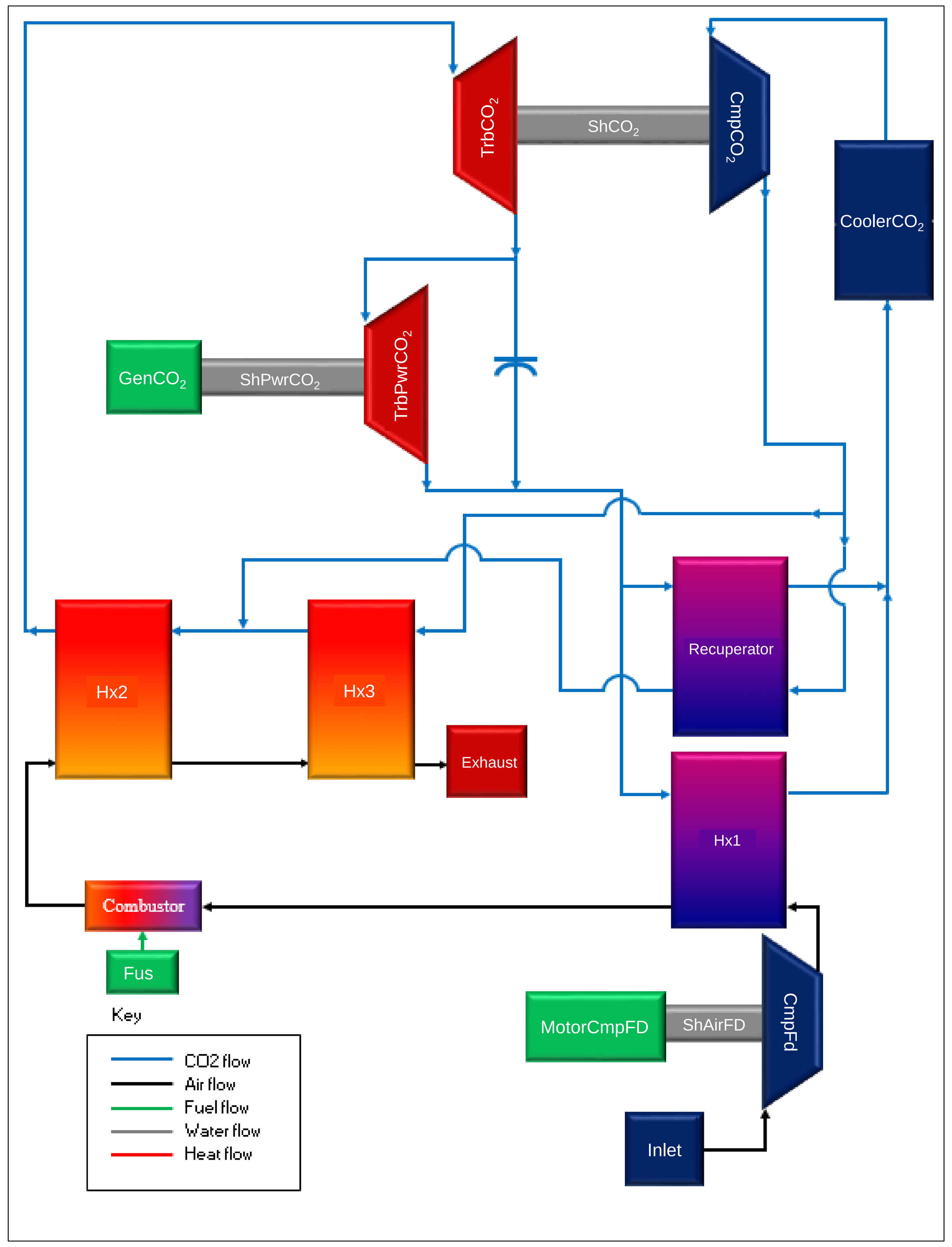
Systematic analysis conducted by Sánchez et al. provides a standard methodological framework for comparing cycles based on maximization of material capability. The present work analyzes the Peregrine Turbine Technologies' Partially Recuperated (PR) sCO_2 power cycle using assumptions comparable to those set forth by Sánchez et al. An NPSS model characterizes cycle performance across a range of compressor discharge pressures for 750°C TIT. The model code generates parameterized performance curves for the PR cycle and highlights the cycle's relative strengths in the context of the cycles investigated performed by Sánchez et al, particularly when used with air-combustible fuels. Future work intends to analyze enhancements such as reheat and intercooling.





Above Left: Sánchez et al identified five cycles, Recompression+IC+RH (orange), Partial Cooling+RH (blue), Transcritical (purple), Allam (green), and Matiant (copper), which delineate a boundary of Efficiency and Specific Work performance attainable in the future via design and material advancements for 750 °C TITs. The plot retains the standard Recompression cycle (black) for reference. Analysis conducted via NPSS cycle model indicates that Peregrine's PR cycle will also maximize future design and material advancements. Each marker on the PR cycle's curve (red) represents a 7.8 MPa increment in compressor discharge pressure. The NPSS model uses isentropic sCO2 turbomachinery efficiency rather than polytropic efficiency used by Sanchez et al. A polytropic efficiency rating for a given compressor or turbine will be slightly higher than its isentropic efficiency. The NPSS model of the PR cycle used 90% isentropic efficiency for turbines and 89% isentropic efficiency for the sCO2 compressor, rather than 90% and 89% polytropic, respectively.Running the model with a 1% reduction in compressor isentropic efficiency reduces cycle thermal efficiency by 0.4%. A 1% reduction in turbines' isentropic efficiencies decrements cycle thermal efficiency by 1%. The model also differs from Sánchez's assumptions in that the PR curve's solid red marker represents 42.9 MPa peak pressure opposed to 40 MPa. However, the PR cycle's curve reaches into the established boundary with ample margin. Thermal efficiency and specific work enhancements via reheat and intercooling will be modeled in future work.

Above Right: The figure at above-right gives a first-order approximation of the impact of air-combustible fuels on other cycles' thermal efficiencies. Brun, Freidman, and Dennis posit that a recompression cycle paired with an advanced Pulverized-Coal Circulating Fluidized Bed boiler can reach approximately 80% heat addition. In other words, fully-recuperated, indirect-fired cycles with an advanced boiler design may require 20% greater fuel consumption to develop the heat energy necessary for a given shaft power.



PEREGRINE'S PARTIALLY RECUPERATED (PR) CYCLE:

An indirect fired sCO_2 cycle, the Partially Recuperated (PR) cycle optimizes recuperation alongside two flow splits to enhance thermal efficiency when used with air-combustible fuels. The cycle schematic in the figure at left illustrates the flow split of turbine exhaust between an sCO_2-to-sCO_2 recuperator and an sCO_2-to-air heat exchanger (HX1). HX1 delivers heat from hot, expanded sCO_2 to the compressed air entering the combustor. By recycling lower-grade heat from sCO2 to air, HX1 reduces fuel consumption required to heat intake air to design point combustor outlet temperature.

The cycle also splits compressor discharge into two flows between the recuperator's cool side and an air-to-sCO_2 heat exchanger– HX3. Low temperature compressed flow entering HX3 recovers lower-grade heat from hot flue leaving the primary heat exchanger, HX2. In other indirect-fired cycles, full recuperation increases the temperature of sCO_2 entering the primary heat exchanger. The split flows of the PR cycle increase the temperature window for heat addition, an invaluable feature for fossil fuel and waste heat recovery applications where maximizing capture of heat of combustion or lower-grade process heat can prove challenging for indirect-fired sCO_2 cycles with full recuperation.

In practice, the compressor could be powered by an air breathing turbine. Converting heat directly to mechanical energy would eliminate exergy destruction associated with an electrically-driven compressor. Replacing the compressor and motor with a co-shaft turbo-compressor pair increases thermal efficiency by about 0.5%.

REFERENCES

K. Brun, P. Friedman, and R. Dennis, *Fundamentals and applications of supercritical carbon dioxide (sCO2) based power cycles*. Oxford: Woodhead Publishing, 2017.

Sánchez et al, "Analysis of the Thermodynamic Potential of Supercritical Carbon Dioxide Cycles: A Systematic Aproach." GT2017-64418, in: ASME Turbo Expo, Charlotte, NC, USA, June 26-30, 2017.

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