



ME PhD Thesis Colloquium



Supercritical CO₂ Power Cycles and Turbomachinery Development for Renewable Energy and Waste Heat Recovery

Mr. Sharath S, PhD Student (ERP), Department of Mechanical Engineering, IISc

ABSTRACT

Supercritical carbon dioxide (sCO₂) power cycles have transitioned from the kilowatt level pilot facilities to the megawatt level demonstration plants. Theoretical studies and commercial benefits associated with sCO₂, such as high efficiency, compact turbomachinery, fuel agnostic heat source, zero or minimum water usage, reduced footprint, cost, etc., have been comprehensively documented. Currently, with renewable energy gaining traction, the baseload steam and gas turbines are forced to operate as peak load plants with the need for increased operational flexibility. Therefore, the industrial power production segment (< 150 MW) is slowly gaining increasing attention worldwide, emphasizing the utilization of sCO₂ technology. Waste Heat Recovery (WHR) is another important segment receiving wide attention as it contributes to energy efficiency in an increasingly climate-conscious world. Industrial WHR such as those from steel, cement, process plants, and gas turbine (GT) exhaust is equivalent to 63% of global primary energy consumption. sCO₂ plays a significant role in WHR due to higher cycle efficiency, smaller footprint, and eventual lower capital cost than alternate waste heat to power conversion systems. A significant number of the sCO₂ cycle studies and pilot plants have focused on low ambient conditions (32 °C compressor inlet) and higher turbine inlet temperature 'TIT' (>600 °C) for renewable energy applications. The ambient temperature influence is not trivial in real gas cycles such as sCO₂. A greater focus is placed in previous studies on GT exhaust heat for sCO₂ WHR and almost insignificant work in Industrial WHR.

This thesis addresses the crucial gaps by proposing a Recompression cycle for renewable power generation and a Simple Recuperated cycle for WHR with higher ambient temperature (>40 °C) and TIT within 600 °C. Despite the reduction in thermal efficiency, limiting TIT has significant benefits. It enables leveraging cost-effective industrial steam turbine technology while still addressing large segments of renewable energy and industrial WHR. The second part of the thesis focuses on sCO₂ turbomachinery development and testing, with emphasis on the sCO₂ turbine. Kilowatt level pilot facilities have focused on radial turbines which are not scalable above 5 MW, where axial turbines are needed. Presently, there is very little published research on megawatt scale axial sCO₂ turbine due to proprietary nature. Additionally, the focus on axial turbine development has been mainly for high-temperature applications requiring a range of new technologies and materials to be proven. This work presented in the thesis is among the first in sCO₂ axial turbine and blade development. Best in class sCO₂ turbine blade profiles have been developed by employing novel optimization methods and Q3D, 3D solvers. This is followed by validation of blade performance in a linear Wind Tunnel (WT) cascade test. Subsequently, CFD based 3D loss tuned using experimental data is utilized in the in house developed mean-line code coupled to an industry-standard throughflow solver to generate the turbine flowpath. The last part of the thesis proposes a new analytical optimization model for sCO₂ Brayton cycles utilizing Jacobian transformations and real gas thermodynamics. The model has vital utility in transient dynamic analysis and real-time control of power and refrigeration cycles. In summary, the research comprehensively covers sCO₂ cycles, turbomachinery development, and analysis by considering practical conditions, including comparisons with operating steam turbine power plants. The research culminates with a case study describing the development of a sCO₂ cycle and turbomachinery for a 10 MW renewable power generation, and a 15 MW steel coke oven plant industrial WHR.

ABOUT THE SPEAKER

Sharath S is a PhD student enrolled in the Dept. of Mechanical Engineering, IISc Bangalore. He has a Bachelor's degree from Malnad College of Engineering (VTU), Hassan and Master's from Manipal Academy of Higher Education, both in Mechanical Engineering. He has over 17 years of experience across Aerospace, Oil & Gas and Energy sectors having worked in technical and managerial roles at Vikram Sarabhai Space Centre (ISRO) in Trivandrum, GE Global Research in Bangalore and Triveni Turbines Ltd., Bangalore.



[\(Click here to join the Thesis Colloquium\)](#)

February 11, 2021, 11:00 AM, Microsoft Teams