ME – PhD Thesis Defense

Supercritical CO_2 Power Cycles and Turbomachinery Development for Renewable Energy and Waste Heat Recovery

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

December 10, 2021 at 11:00 AM
Meeting link: Click here to join the meeting **(Microsoft Teams)**

ABSTRACT

Supercritical carbon dioxide (sCO_2) power cycles have transitioned from the kilowatt level pilot facilities to the megawatt level demonstration plants. Theoretical studies and commercial benefits associated with sCO_2, 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 sCO_2 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. sCO_2 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 sCO_2 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 sCO_2. A greater focus is placed in previous studies on GT exhaust heat for sCO_2 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 sCO_2 turbomachinery development and testing, with emphasis on the sCO_2 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 sCO_2 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 sCO_2 axial turbine and blade development. Best in class sCO_2 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 cascade Wind Tunnel (WT) test at Politecnico di Milano, Italy. 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 sCO_2 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 sCO_2 cycles, turbomachinery development, and analysis by considering practical conditions, including comparisons with operating steam turbine power plants. The research culminates with case studies describing the development of sCO_2 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.