ME- PhD Thesis Defense

MODELING OF SUPERCRITICAL CARBON DIOXIDE CENTRIFUGAL COMPRESSORS FOR BRAYTON POWER CYCLES

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ABSTRACT

Supercritical CO_2 (sCO_2) cycles are viewed as potential replacements to steam-based power generation owing to several perceived advantages. Their successful deployment depends on several factors - one important aspect being the realization of high efficiency turbo-compressors. Although the work of compression is reduced in a sCO_2 Brayton cycle compared to an ideal gas cycle, the compression work is still a notable fraction of the turbine work. Consequently, a mild decrease in the achievable compression efficiency can strongly affect the overall cycle performance adversely. Modelling and analysis of sCO_2 centrifugal compressors is, therefore, an important exercise. In the first part of this work, we show that 3D Computational Fluid Dynamics (CFD) in conjunction with real gas tables can satisfactorily model flows in real gas sCO_2 centrifugal compressors. We also show that the existing loss models can be used to satisfactorily model the losses in the rotor. However, loss models for the vaneless diffuser (VLD) in case of real gas supercritical CO_2 is currently unavailable. Hence, in the first step, the vaneless diffuser governing equations are derived for real gas flows from first principles. The set of VLD differential equations require the skin friction coefficient as input. From CFD data, the existing skin friction coefficient estimates are found to be inaccurate. Therefore, in the second step, the skin friction coefficient functional relationship is established using an Artificial Neural Network (ANN) approach for real gas sCO_2 flows. A two-hidden layer ANN was found to satisfactorily capture the skin friction coefficient functional relationship for real gas sCO_2 flows in vaneless diffusers. The 500 kW and 5 MW net power scales are perceived as the lower and upper bounds for sCO2 waste heat recovery in conjunction with centrifugal compressors (axial compressors are used for higher power scales). In the final part of this work, the achievable centrifugal compressor efficiencies are estimated for these two representative Waste Heat Recovery (WHR) power scales- 500 kW and 5 MW net power. The 1D loss analysis shows that an overall single stage centrifugal compressor efficiency of 89.7 % is achievable for the 5 MW scale. The achievable singe stage compressor efficiency in case of the 500 kW WHR power scale is only 65.9 % due to high windage and vaneless diffuser losses. A two-stage intercooled compression process is subsequently examined as an alternative for the 500 kW scale. In the case of the two-stage intercooled compression process, the ratio of the single stage isentropic power to the actual net power consumed is found to be 82.2 %, which is a marked improvement compared to the single stage compressor isentropic efficiency. These design studies are expected to pave way for commercialization of the sCO_2 Brayton cycle as an alternative to steam-based power cycles for WHR.

ABOUT THE SPEAKER

Lakshminarayanan Seshadri is a PhD student in the Dept. of Mechanical Engineering, IISc Bengaluru. He obtained his BTech in Mechanical Engineering and MTech in Thermal Engineering under a Dual Degree Program with Minors in Physics from the Indian Institute of Technology Madras in 2018. He joined the PhD program at IISc in August 2018. Thermodynamic modelling and loss analysis of real gas flows in centrifugal compressors for supercritical CO_2 Brayton power cycles constitutes his primary research interest.