Announcing the Final Examination of Mahmood Mohagheghi for the degree of Doctor of Philosophy

Time & Location: April 6, 2015 at 3:00 PM in Engineering 2 202 A
Title: THERMODYNAMIC ANALYSIS AND OPTIMIZATION OF SUPERCRITICAL CARBON DIOXIDE BRAYTON CYCLES

This dissertation is intended to perform thorough thermodynamic analyses and optimization of supercritical carbon dioxide (S-CO2) Brayton cycles for high temperature concentrated solar power (CSP) and waste heat recovery (WHR) applications. A modeling tool has been developed, which enables one to predict and analyze the thermodynamic performance of the S-CO2 Brayton cycles in various configurations employing recuperation, recompression, intercooling and reheating. The modeling tool is fully flexible in terms of encompassing the entire feasible design domain and rectifying possible infeasible solutions. A robust optimization tool has also been developed by employing the principles of genetic algorithm.

Two optimization schemes, i.e. single-objective and multi-objective, are considered in optimizing the S-CO2 cycles for high temperature solar tower applications. In order to reduce the size and cost of solar block, the global maximum efficiency of the power block should be realized. Therefore, the single-objective optimization scheme is considered to find the optimum design points that correspond to the global maximum efficiency of S-CO2 cycles. Four configurations of S-CO2 Brayton cycles are investigated, and the optimum design point for each configuration is determined. Ultimately, the effects of recompression, reheating, and intercooling on the thermodynamic performance of the recuperated S-CO2 Brayton cycle are analyzed. The results reveal that the main limiting factors in the optimization process are maximum cycle temperature, minimum heat rejection temperature, and pinch point temperature difference. The maximum cycle pressure is also a limiting factor in all studied cases except the simple recuperated cycle. The optimized cycle efficiency varies from 55.77% to 62.02% with consideration of reasonable component performances as we add recompression, reheat and intercooling to the simple recuperated cycle (RC). Although addition of reheating and intercooling to the recuperated recompression cycle (RRC) increases the cycle efficiency by about 3.45 percent points, the simplicity of RC and RRC makes them more promising options at this early development stage of S-CO2 cycles, and are used for further studies in this dissertation.

The results of efficiency maximization show that achieving the highest efficiency does not necessarily coincide with the highest cycle specific power. In addition to the efficiency, the specific power is also an important parameter when it comes to investment and decision making since it directly affects the power generation capacity, the size of components and the cost of power blocks. Consequently, the multi-objective optimization scheme is devised to simultaneously maximize both the cycle efficiency and specific power in the RC and RRC. The optimization results are presented in the form of two optimum trade-off curves, also known as Pareto fronts, which enable decision makers to choose their desired compromise between the objectives. Moreover, the comparison of the Pareto optimal fronts associated with the studied configurations reveals the optimum operational region of the RRC where it presents superior performance over the RC.

Considering the extensive potential of waste heat recovery from energy intensive industries and stand-alone gas turbines, this dissertation also investigates the optimum design point of S-CO2 Brayton cycles for a wide range of waste heat source temperatures (500 K to 1100 K). The utilization of heat in WHR applications is fundamentally different from that in closed loop heat source applications. The temperature pinching issues are recognized in the waste recovery heat exchangers, which brings about a trade-off between the cycle efficiency and amount of recovered heat. Therefore, maximization of net power output for a given waste heat source is of paramount practical interest rather than the maximization of cycle efficiency. The results demonstrate that by changing the heat source temperature from one application to another, the variation of optimum pressure ratio is insignificant. However, the optimum CO2 to waste gas mass flow ratio and turbine inlet temperature should properly be adjusted. The RRC provides minor increase in power output as compared to RC. Although cycle efficiencies as high as 34.8% and 39.7% can be achieved in RC and RRC respectively, the overall conversion efficiency is less than 26% in RRC and 24.5% in RC.

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Approved for distribution by Dr. Jayanta Kapat, Committee Chair, on April 6, 2015.

The public is welcome to attend.