Analysis of Supercritical CO₂ Brayton Cycle Heat Exchanger Size and Capital Cost with Variation of Layout Design

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Abstract:
In the past decade, multiple studies (both experimentally and computationally at National laboratories and other research facilities) have been performed to recognize potential improvements to increase overall efficiency for the supercritical carbon dioxide (CO₂) Brayton cycle.¹²³⁴ There are many alternatives cycle layouts that include different combinations of intercooling, reheating, recompression, recuperation, and fluid bypass.⁴⁵ The exact layout design for maximum efficiency is directly dependent upon the type of application and associated thermal source temperatures (fossil, nuclear, solar, etc.), however the recompressing sCO₂ cycle layout has been generally agreed to be the most efficient, as noted by Ahn et al.⁴ and Dostal et al.⁶. In this layout, the working fluid is split between the high and low temperature recuperators, maximizing the heat recovery through the compensation for vastly different specific heat capacities of the fluid.⁴

These studies suggest that to achieve substantial improvements in total cycle efficiencies from traditional steam-power, high performance exchangers are required such as compact printed circuit heat exchangers (PCHE). To achieve significant recuperation and yield high cycle efficiency, these heat exchangers must be designed to have high effectiveness (e.g. very close approach temperatures). As the heat transfer effectiveness nears a value of one, the required heat transfer area increases exponentially, which directly translates into an increase in capital cost of these heat exchangers.⁷ Since these heat exchangers are a substantial portion of the total investment for an overall power plant, it is important to understand the balance between capital cost and cycle efficiency.

In this paper, the effect of heat exchanger capital cost will be investigated as a function of the three different supercritical CO₂ Brayton power cycle layouts. These layouts include the recompression cycle, partial condensation cycle with improved regeneration, and the cascaded reheat cycle. For a proper comparison of heat exchanger capital cost, each power cycle layout will be designed to achieve a net electrical output from the turbine(s) of 10 MWₑ. The temperatures, pressures, flow rate, and other cycle parameters will be allowed to vary between the three different cycle layouts in order to achieve the 10 MWₑ output with an optimized efficiency for a given cycle. Each heat exchanger will be required to achieve a 90% or greater effectiveness. The normalized size and capital investments of the heat exchangers (total for each cycle) will be estimated based upon fabrication capabilities and techniques of Vacuum Process Engineering, Inc.. It is important for cycle designers to understand the major investments of heat exchangers depends on the cycle layout being utilized, even with the same net electrical power output.

¹ Wright, S.A. et al., 2010. Operation and Analysis of a Supercritical CO₂ Brayton Cycle, Albuquerque, NM and Livermore, CA. SAND2010-0171 87185-MS1136