Chapter 12
Supercritical Fluids and Their Applications in Power Generation

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ABSTRACT
Supercritical fluids have been studied and used as the working fluids in power generation system for both high- and low-grade heat conversions. Low-grade heat sources, typically defined as below 300 °C, are abundantly available as industrial waste heat, solar thermal, and geothermal, to name a few. However, they are under-exploited for power conversion because of the low conversion efficiency. Technologies that allow the efficient conversion of low-grade heat into mechanical or electrical power are very important to develop. First part of this chapter investigates the potential of supercritical Rankine cycles in the conversion of low-grade heat to power, while the second part discusses supercritical fluids used in higher grade heat conversion system. The selection of supercritical working fluids for a supercritical Rankine cycle is of key importance. This chapter discusses supercritical fluids fundamentals, selection of supercritical working fluids for different heat sources, and the current research, development, and commercial status of supercritical power generation systems.

INTRODUCTION
Currently, two-thirds of the world’s electricity demand is met by non-renewable fossil fuels which has led to serious environmental problems and a widespread energy crisis. In trying to limit the emissions from the electricity generating sector, new energy resources as well as radically new technologies should

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be developed and/or current technologies be improved so that the power output per unit of pollution is reduced.

Renewable energy sources, such as solar thermal and geothermal, and vast amounts of industrial waste heat are potentially promising energy sources capable, in part, to meet the world electricity demand. However, the above mentioned energy sources are available largely at moderate temperatures. The conventional steam Rankine cycle works only efficiently at above 300 °C, and the conversion efficiency becomes uneconomically low for the low-grade heat sources conversion. In this context, developing other technologies that allow the efficient conversion of low-grade heat into mechanical or electrical power is of great significance.

The objective of this chapter is to discuss the potential of using supercritical fluids to convert low and higher grade thermal energy, for which, discussion of the desired properties of the working fluid candidates, performance of the supercritical cycles, and supercritical cycle optimization were carried out. Other objectives of this work include screening the working fluids for supercritical Rankine cycles, comparing the performance of supercritical Rankine cycles with other thermodynamic cycles, and suggesting some feasible applications of the supercritical Rankine cycle.

BACKGROUND

In a supercritical thermodynamic power cycle, the working fluid is compressed to its supercritical pressure and heated to supercritical state directly, bypassing the two-phase vaporization that a conventional Rankine cycle would have. Professor Martyn Poliakoff from University of Nottingham demonstrated the instant transformation of CO₂ from liquid to its supercritical state very clearly in a video (“Supercritical fluids - YouTube,” n.d.).

For low-grade heat conversion, various thermodynamic cycles such as the organic Rankine cycle, supercritical Rankine cycle, Kalina cycle, Goswami cycle, and trilateral flash cycle have been proposed and studied. Although there are broad claims of 15–50% more power output for the same heat input for Kalina cycles relative to organic Rankine cycles, data from actual cycles in operation and simulations under identical conditions of ambient temperature and cooling systems showed that the difference in performance is only 3% in favor of Kalina cycle (DiPippo, 2004). However, the organic Rankine cycle is much less complex and need less maintenance. The focus of this chapter regarding low-grade heat conversion is a derivative of organic Rankine cycle, which is supercritical Rankine cycle. Supercritical Rankine cycle has been reported to generally have higher efficiency than an organic Rankine cycle, especially when the heat source is sensible heat (Chen et al., 2011).

A conceptual configuration and a P–h diagram of a supercritical Rankine cycle are shown in Figure 1(a) and Figure 1(b). In this conceptual configuration, the working fluid is pumped above its critical pressure (a->b), and then heated isobarically from liquid directly to supercritical vapor (b->c); the supercritical vapor is expanded in the turbine to extract mechanical work (c->d); after expansion, the fluid is condensed in the condenser by dissipating heat to a heat sink (d->a); the condensed liquid is then pumped to the high pressure again, which completes the cycle. The major difference between a subcritical and a supercritical Rankine cycle lies in the heating process of the working fluid as seen in Figure 2. In a supercritical Rankine cycle, the working fluid is heated directly from the liquid state into the supercritical state, bypassing the two-phase region (b->c in Figure 2). By bypassing the isothermal boiling process, the supercritical Rankine cycle allows the working fluid to have a better thermal match.
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