Journal of ELECTRONIC MATERIALS, Vol. 42, No. 7, 2013
DOI: 10.1007/s11664-012-2434-6

Megawatt-Scale Application of Thermoelectric Devices in Thermal Power Plants

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Despite the recent investment in renewable and sustainable energy sources, over 95% of the UK's electrical energy generation relies on the use of thermal power plants utilizing the Rankine cycle. Advanced supercritical Rankine cycle power plants typically have a steam temperature in excess of 600°C at a pressure of 290 bar and yet still have an overall efficiency below 50%, with much of this wasted energy being rejected to the environment through the condenser/cooling tower. This paper examines the opportunity for large-scale application of thermoelectric heat pumps to modify the Rankine cycle in such plants by preheating the boiler feedwater using energy recovered from the condenser system at a rate of approximately 1 MW_{th} per °C temperature rise. A derivation of the improved process cycle efficiency and breakeven coefficient of performance required for economic operation is presented for a typical supercritical 600-MW_e installation.

Key words: Regenerative Rankine cycle, heat pump, power plant, regeneration, energy scavenging

INTRODUCTION

Despite today's emphasis on many different forms of renewable generation[1] of electrical energy, approximately 95% of the UK's electricity is produced by generators driven by turbines[2] employed in the Rankine cycle.[3,4] The prime movers continue to be fossil fuels such as coal and gas, with significant contributions from nuclear and biomass combustion. The ideal Rankine cycle[5] is a variation on the Carnot cycle. The *T–s* diagram for the basic Rankine cycle is shown in Fig. 1, with the physical plant required to implement each of the phases of the cycle accompanying in Fig. 2. At the end of the isentropic expansion stage of the Carnot cycle during which work has been extracted (point 4), the liquid–vapor mixture is condensed to a solely liquid saturated state (point 1). The saturated liquid is then subject to isentropic compression and re-injected into the steam generator (point 2), where it is subject to constant-pressure heating, taking it to a saturated vapor state (point 2A $\rightarrow$ 3). It should be noted that the Rankine cycle cannot achieve the same theoretical efficiency as the Carnot cycle. A physical interpretation for the efficiency difference may be gained by considering that, for the Rankine cycle, the *average* temperature at which heat energy is added is lower than for the Carnot cycle, for equal upper and lower cycle temperature limits.

Principal energy losses from the power plant Rankine cycle are via the flue, carrying residual energy in the combustion products, and via the condenser, where the feedwater vaporization energy is rejected from the cycle. Note that the steam usually visible from the cooling towers when the plant is operational is not from the working fluid itself but due to the rejection via the condenser of the waste heat which could not be converted into useful work by the turbine. This paper considers how thermoelectric heat pumps may be used on an industrial scale to recover a portion of this waste

Originally presented at the ICT 2012.
(Received July 5, 2012; accepted December 28, 2012; published online February 12, 2013)