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Supercritical Rankine cycle coupled with ground cooling for low temperature power generation

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Abstract

This paper presents an application of an earth-air-heat-exchanger (EAHE) as condenser in low to medium temperature power generation plants. A supercritical Rankine cycle (SRC) utilizing organic refrigerants as working fluids was used as the power cycle for the plant. The heat source temperature was varied from 125-175^{0}C. The condenser was coupled to an EAHE system buried at a depth of 2 m under the surface of the earth. Its effect on the power cycle efficiency over a period of six months has been studied. It was observed that the soil temperature 10 cm from the surface (horizontal direction) of the underground pipe increased by almost 2^{0}C during this time. This temperature change decreased with distance from the pipe. The soil temperature profile varied with time, distance from the pipe and location along the length of the pipe. The efficiency of the SRC increased by 1% and the daily fluctuations were reduced when EAHE was used.

Keywords: Low temperature power generation, Supercrtitical organic Rankine cycle, Earth-air-heat-exchanger

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1. Introduction

Low grade heat sources are available in very large amounts all over the world in various forms such as geothermal, waste heat and low to medium temperature solar thermal. These sources cannot be utilized efficiently with the traditional

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methods of power generation that use steam Rankine cycle. So, new methods are being investigated to improve the efficiency of power generation from such heat sources. Alternative configurations for the thermodynamic cycles have been proposed for low temperature sources. Organic Rankine cycles (ORC) are usually preferred over other configurations because of their simplicity and cost effectiveness[1].

A number of organic fluids have been examined for use as working fluids in an ORC [2-7]. A supercritical Rankine cycle (SRC) is similar to an ORC, however, the maximum pressure in a SRC is greater than the critical pressure of the fluid. Figure 1 shows the ORC and SRC cycles on a T-S diagram. It can be observed that the heating profile in the case of SRC is much straighter than that of ORC and hence better thermal match is obtained with the heat source. It was observed that organic fluids provide higher efficiency in SRC compared to a conventional ORC [2, 4, 8-13].

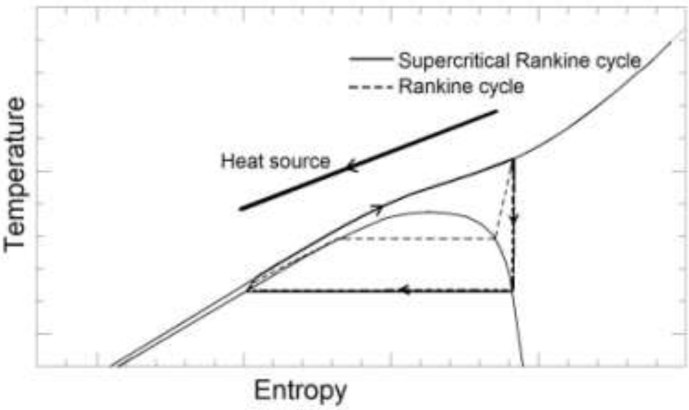

Figure 1. T-S diagram of SRC compared to Rankine cycle.

The efficiency of SRC depends largely on the source and sink temperatures. Since the source temperature is not very high, in order to obtain high efficiency the sink temperature must be lowered as much as possible. Using water cooling in the condenser generally provides low sink temperature, however water may not be available at all sites in which case air cooling needs to be considered. For locations where the ambient air temperature is high, ground cooling may be combined with the air cooled condenser. Since the underground temperature does not vary as much as the ambient air temperature [14, 15], passing the ambient air through underground tunnels may be used to cool the air, which can then be used in the condenser of the SRC. Earth-to-air heat exchangers have been widely used for air conditioning applications [15-27]. They have been used for cooling the ambient air in the summer and heating in the winter [14, 18, 22, 28-32]. The performance of EAHE depends chiefly on the geometric parameters (length, radius etc) and environmental conditions, such as depth and soil type. The geometric parameters can be varied depending on the load requirement. The lag between the ambient and underground temperatures increases with depth. Thus, it appears that if the system is positioned at more depth, the outlet temperature should be lower in cooling mode and hotter in heating mode. However, it was observed that this effect reaches a saturation level after certain depth and increase in depth does not provide any significant improvement in performance [22, 30, 33]. Simulation studies have shown that a depth greater than 4 m does not improve the performance [15, 25, 26, 30]. The experimental implementations EAHE have generally been done at the depths of 0.5-2 m [21, 34-36].

In this paper, a supercritical Rankine cycle having a condenser coupled with ground cooling has been investigated for low temperature power generation. Efficiency of the SRC for different working fluids under the given conditions is obtained and the effect of using ground cooling on the efficiency is studied. Finally, the variation of underground soil temperature profile due to the earth-air-heat-exchanger is analysed. Soil properties given in [37-39] are used for the analysis.

Nomenclature

A	Differential area	*Subscript*	
Cp	Specific heat	e	Earth
h	Convective heat transfer coefficient	n	Element from the inlet
m	Mass flow rate	s	Surface of the tube