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Thermodynamic analysis of a binary power cycle for different EGS geofluid temperatures

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ABSTRACT

Enhanced Geothermal Systems show promise for meeting growing energy demands. The Organic Rankine Cycle (ORC) can be used to convert low and medium-temperature geothermal energy to electricity, but the working fluid must be carefully selected for the ORC system design. This paper compares the system performance using R134a, isobutane, R245fa and isopentane for four typical geofluid temperatures below 200 °C. Three type (subcritical, superheated and transcritical) power generation cycles and two heat transfer control models (total heat control model and vaporization control model) are used for different EGS source temperatures and working fluids. This paper presents a basic analysis method to select the most suitable working fluid and to optimize the operating and design parameters for a given EGS resource based on the thermodynamics.

1. Introduction

People have utilized geothermal energy to generate power for more than 100 years since geothermal steam at the vapor-dominated field in Larderello, Italy, was first used to produce electricity in 1904. Conventional geothermal resources provide a wide range of uses for power production and direct applications. A large scientific and industrial community has been involved in developing enhanced geothermal systems (EGS) for unconventional systems in the last 20 years [1,2]. Field testing of EGS systems, designed to extract and utilize the earth stored thermal energy at depths ranging from 2 to 6 km, has been successfully demonstrated in the United States, Europe and Japan. Such progress is leading to the goal of operating a commercial-sized EGS reservoir. The U.S. Department of Energy has broadly defined Enhanced (or engineered) Geothermal Systems as engineered reservoirs that have been created to extracted economical amounts of heat from low permeability and/or porosity geothermal resources [3].

The heat stored in the earth at depths accessible to present drilling methods is at temperatures from 100 °C to 650 °C. Identification of the most appropriate conversion system is one of the key needs for efficient geothermal energy utilization. There are several energy conversion technologies commercially available at various stages of maturity. These include single and multistage steam flashing [4], direct steam expansion, organic binary Rankine cycles [4,5], and two-phase flow expanders. These are adapted from conventional hydrothermal geothermal power plants with some appropriate modifications [5].

In general, binary cycles are used for geothermal energy conversion systems because direct use of the geothermal fluid as the working fluid in an energy conversion cycle is not efficient from a thermodynamic point of view. In the binary cycle, the geothermal heat is transferred to a low-boiling point working fluid with the heat then converted to work through an ORC. The key challenges of the ORC are the selection of an appropriate working fluid and the parameters to achieve the optimum objective function. The choice of working fluid is affected by the temperature, heat source type and objective function [6]. Papadopulos [7] presented a systematic design approach to select the optimal working fluid for the ORC based on CAMD and process optimization techniques. The methodology systematically identified both novel and conventional molecular structures that enable optimum ORC performance. This is a general method to select the ORC working fluid for the case

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