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A Retrofit for Geothermal Organic Rankine Cycles based on Concentrated Solar Thermal Systems

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Abstract

In this study, a solar thermal retrofit unit for geothermal ORC power plants is analysed under thermodynamic and technical aspects. For the retrofit, the ORC module is extended by a solar superheater and the additional heat input is realized by parabolic trough collectors. The evaluation of the entire system is based on simulations over the period of one year. Therefore, a case study considering geothermal conditions of the Aydin-Salavatli field in the Büyük Menderes Graben in Turkey is conducted. Quasi-stationary simulations of the system are performed considering off-design behaviour of the power plant components. The calculations are based on hourly climate data. The obtained operational parameter of the ORC and solar-field emphasise the technical feasibility of the selected superheating concept in the context of thermal stability of the working fluid. For the considered solar-field sizes, the annually generated electricity is increased up to 4.5 % compared to the stand-alone geothermal power plant.

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Keywords: Organic Rankine Cycle; geothermal; solar; hybrid; retrofit; off-design calculations

1. Introduction

Geothermal energy resources of low and medium enthalpy are available in countries like Turkey, Italy, Indonesia or the United States. For these kind of resources, binary cycles like the Organic Rankine Cycle (ORC) are suitable as

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energy conversion systems [1,2]. Mostly, binary power plants are equipped with an air-cooled condenser. In case of high ambient temperatures, this condensation concept leads to a remarkable reduction of the net and the gross power output. In order to weaken or even overcompensate these power losses, solar thermal energy can be coupled to the ORC. In this context, off-design simulations are mandatory for an evaluation of potential power plant concepts under consideration of a variable ambient temperature and solar insolation [3]. In general, hybrid power plants are a promising approach to achieve considerable synergetic effects by combining geothermal and alternative renewable resources [4–6]. In particular, coupling solar thermal and geothermal energy can be realized in several ways like superheating of the working fluid, a split of the ORC mass flow or using a supercritical concept [3,7–12].

In this paper, a thermodynamic analysis of a retrofit based on a solar thermal unit is conducted. The ORC working fluid is superheated at the inlet of the turbine by an additional heat input. This approach is associated with minor modifications of the existing geothermal power plant. For the performed case study, typical geothermal conditions in south-western Turkey are considered. This region shows the highest number of existing and planned geothermal power plants in Turkey [13]. The simulation model of the ORC is linked to a detailed optical and thermal model of the solar field. The overall system performance of the retrofit system is determined by conducting a steady-state one-year simulation based on hourly climate data. The solar-field size, the operational temperature and the heat transfer fluid are determined in respect to thermodynamic and technical aspects. For an accurate estimation of the system performance, the prediction of the off-design behaviour of the turbine is of high relevance. In order to evaluate the retrofit solution, the annually generated amount of electricity is determined.

2. Methods

2.1. ORC model

For the simulations, geothermal conditions related to the Aydin-Salavatli field in the Büyük Menderes Graben are chosen [14]. For exploiting such medium-enthalpy geothermal resources, air-cooled ORC power systems are widely used in Turkey. Based on existing power plants, n-butane is chosen as a working fluid for the considered ORC. The entire system including the retrofit unit with collector field and solar thermal superheater is shown in Fig. 1.

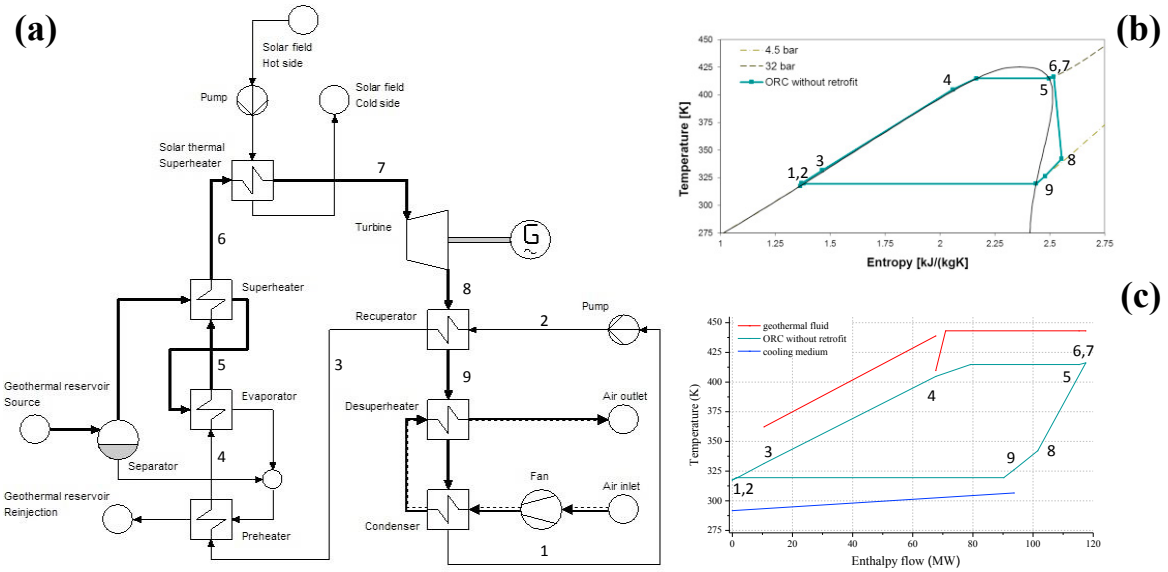

Fig. 1.(a) scheme of the geothermal power plant including the solar thermal retrofit unit;
(b) temperature-entropy-diagram of the ORC at design conditions; (c) temperature-enthalpy flow-diagram of the ORC at design conditions.