Applied Thermal Engineering 42 (2012) 25–33

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Efficiency enhancement of combined cycles by suitable working fluids and operating conditions

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ARTICLE INFO

Article history:
Received 17 August 2011
Accepted 19 February 2012
Available online 28 February 2012

Keywords:
Brayton cycle
Combined cycle
Organic working fluids
Organic Rankine Cycle
Quasi-critical condensation
Thermal efficiency

ABSTRACT

Solar energy based combined cycle power plants are becoming important as an efficient option among conventional thermal power plants. However conventional thermal efficiency can be significantly improved. This research study is centred on combined cycle efficiency enhancement by researching the capacity of several working fluids such as N2, air, or He for the topping cycle which is a closed Brayton cycle (CBC) and a bottoming cycle which is a Rankine cycle (RC) operating with xenon, ethane or ammonia as working fluids. The applied strategy, which aims to increase the ideal thermal efficiency, is based on the concepts of quasi-critical condensation pressure, residual heat recovery and properly selected working fluids. The decision to propose N2, air, or He, as working fluid for the Brayton part of the CC stems from the fact that they yield high efficiency at high temperatures with acceptable power ratio. A performance study of several organic and nonorganic working fluids such as ethane, xenon and ammonia for the bottoming Rankine cycle and N2, air, or He, for topping CBC is performed. The consequences are a significant positive increment in thermal efficiency in comparison with conventional CC power plants.

1. Introduction

The objective of the research study is to determine whether a CC composed by a CBC and a RC power plant could be viable using high temperatures solar concentrated energy and/or fossil fuel (natural gas), operating with N2, air, or He at the topping cycle or CBC as working fluid while using ethane, xenon or ammonia as working fluid at the bottoming cycle or RC under acceptable thermal efficiencies. The scheme consists of a top CBC engine mounted at the focus of a solar tower type concentrator, together with a heat exchanger transferring the waste heat from the gas turbine to a working fluid (organic or not) of the bottoming cycle that would operate under a RC or an ORC depending on the operating fluid characteristics.

Gas turbines are cheaper, simpler engines and are able to support higher temperatures. Solar heat can be used to replace or complement the combustors of gas turbines [1], potentially providing a reliable and cheaper overall system. Gas turbines also permit much higher cycle temperatures, which contribute to thermal efficiency enhancement.

Some previous studies on solar CC power plants have been performed during the last two decades. In [2] an energy source based on the parabolic troughs has been investigated providing the latent-heat part of the input for a RC, with a topping CBC providing the other part. Such approach is relevant for parabolic trough systems, but as the top temperature is relatively low it is not appropriate in the case of point-focus concentrators, where the temperatures can be higher than 1000 °C. In [3] a similar configuration is mentioned, with the benefit of a bottoming cycle configuration, such as the Kalina cycle, which contributes to reducing irreversibilities in the combined-cycle heat exchanger.

A CC based on a solar-fired CBC and a steam RC has been studied by [4]. According such study, the consideration of alternative fluids in the bottoming cycle is realised mainly to resolve pinch-point issues in the steam generator, associated with irreversibility given at thermal storage.

Although the ORC is a well-known option for conversion of low grade heat to mechanical work, these systems have been used with solar ponds in [5] and low-temperature parabolic troughs in some applications including USA and Spain among others, but neither of these projects claim to have achieved satisfactory thermal-to-electric conversion efficiencies, due mostly to the low (<96 °C and <180 °C, respectively) temperatures of the heat source.

In [6] the study of organic fluids suitable for use in regenerative ORCs at temperatures up to 630 K was performed, which is a limitation imposed on many organic working fluids due to chemical decomposition associated with properties lost. They found 700 potential working fluids meeting a set of criteria oriented towards

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doi:10.1016/j.applthermaleng.2012.02.039