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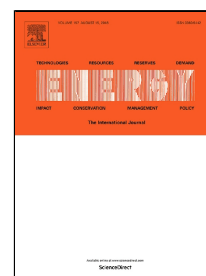
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Comparison between ORC and CO₂ Power Systems for the exploitation of Low-Medium Temperature Heat Sources

Marco Astolfi^a, Dario Alfani^a, Silvia Lasala^b, Ennio Macchi^a

^aPolitecnico di Milano, Dipartimento di Energia, Via Lambruschini 4, 20156 Milano, Italy

^bUniversité de Lorraine, Laboratoire Réactions et Génie des Procédés, 1 rue Grandville, 54000 Nancy, France

Abstract

Low-medium temperature heat sources in the range 5 - 50 MW_{th} are made available by many industrial fields but they may also be of interest for biomass, geothermal and solar energy applications. ORC has been proposed in the last 20 years as a reliable solution for the exploitation of these energy sources since the alternative represented by steam cycles leads to an inefficient conversion of such small available thermal powers. However, the use of organic fluids involves a number of safety and environmental issues, either related to fluid flammability (for hydrocarbons) or to their high Global Warming Potential (for halogenated fluids), and of limitations to the achievable cycle maximum temperature, due to fluids thermal decomposition. To overcome these limitations, in recent years CO₂-based transcritical and supercritical cycles have been proposed as a viable option for this kind of applications. The present work aims to present a comparison between four CO₂ cycle configurations and four ORC layouts using a working fluid selected from 47 candidates. The final result is a set of performance maps that allow for an easy selection of the best solution for applications exploiting low-medium temperature heat sources.

1. Introduction

Among closed-cycle power plants the steam Rankine cycle plays a dominant role in large-scale stationary power generation. This power plant is widely used worldwide in different configurations depending on the heat source, the maximum attainable temperature and the thermal power availability. Ultra-Super Critical (USC) and future AUSC (advanced USC) are the most efficient solution and are commonly adopted for large scale (up to 1 GW) fossil fuel based applications [1,2]. Indeed, high performances are achieved by the use of steam at very high pressure (300 bar) and temperature (620 °C), which involves the use of expensive materials and justify the convenient application of these cycles to high-temperature and large-scale applications. To recover lower temperature heat sources represented for example by hot gases discharged by gas turbines (450 °C - 600 °C), subcritical superheated steam cycles without feed-water preheating represent a common solution. Improved results can be achieved adopting two or three evaporation levels plus vapor reheating as for combined cycles at the state-of-the art [3]. Subcritical steam plants are also used in large scale CSP (Concentrating Solar Power) applications based on either parabolic trough [4] or solar tower system [5,6,7]. Those adopt an opportune high temperature oil (390 °C) or molten salt (565 °C) [8] as Heat Transfer Fluid (HTF) in the solar field and in the storage system. Finally, saturated steam cycles with maximum temperature around 300 °C are commonly used in nuclear plants in both BWR and PWR (Boiling and Pressurized Water Reactors) configurations [9]. All the steam cycle applications mentioned above concern the exploitation of medium-high power grades (50 MW – 1.5 GW).

By contrast, the low efficiency of steam Rankine cycles eventually used to exploit relatively small available thermal powers (from few hundreds of kW up to tens of MW) and/or low-medium heat source temperatures (namely between 80 - 400 °C) actually prevents the use of water as working fluid [10]. This kind of applications concern small biomass plants, small and low-temperature solar systems, small-scale industrial waste heat recovery (WHR) and geothermal plants. The exploitation of low temperature heat sources by means of steam cycles would entail, in fact; the use of subcritical cycles with very low evaporation temperature and a large enough superheating grade to guarantee a sufficiently high vapour quality at turbine discharge, leading to a strong penalization of cycle thermodynamic performance. Also, steam cycles with low thermal input would involve the miniaturization of the turbine still having very high enthalpy drops with a consequent reduction of the expansion isentropic efficiency and the increased component specific cost [11]. The use of a working fluid alternative to water, characterised by more appropriate thermodynamic properties, actually allows to avoid the occurrence of the aforementioned issues and to achieve higher plant efficiency. This technology generally based on the use of organic compounds (hydrocarbons, halogenated hydrocarbons, siloxanes) is named Organic Rankine Cycle (ORC) and currently represents the most reliable option available on the market for the exploitation of low-medium temperature heat sources in a large range of plant power outputs (from few kW to tens of MW). Compared to water, in fact, organic fluids enable the reduction of the evaporation pressure, the increase of the condensation one, leading to a lower number of stages and reduced costs of the turbine and, likely, to higher cycle efficiency. In the last 20 years, the

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