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Techno-economic analysis of novel working fluid pairs for the Kalina cycle

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Abstract

The organic Rankine cycle (ORC) and the Kalina cycle (KC) are well established thermodynamic concepts for decentralized power generation based on waste heat at low and medium temperature level. In a previous exergetic analysis, it has been shown that second law efficiency of KC can be increased by applying alcohol/alcohol mixtures as working fluid instead of ammonia/water. The aim of this work is to provide a detailed evaluation of operational parameters of a novel ethanol/hexanol mixture as a working fluid for the KC. Therefore, process simulations in ASPEN PLUS V8.0 are conducted. As a benchmark the KC with standard working fluid ammonia/water and the ORC are examined. Next to thermodynamic aspects, a techno-economic evaluation of the KC and the ORC is conducted. For 200 °C, 300 °C and 400 °C heat source temperature the pressure, power output, heat exchange capacity and the size parameter are analyzed. Compared to ammonia/water alcohol/alcohol mixtures offer an up to 1.5 times higher power output, an up to 66.6 % lower pressure and heat exchange capacity, but lead to 5.6 times higher size parameters. Compared to the KC, the subcritical ORC leads to an up to 3.4 % lower power output. The heat exchange capacity is at least 33.3 % and the size parameter up to 6.3 times lower. For the considered concepts, ammonia/water leads to the lowest specific cost with 619.4 €/kW. However, the cost estimation for the KC is related to several uncertainties. Therefore, the pure fluid ORC should be preferred in terms of techno-economic considerations.To sum up, the results show that the pure fluid ORC should be preferred in terms of techno-economic considerations.

Keywords: waste heat recovery; Kalina cycle; alcohol mixtures; Organic Rankine cycle

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1. Introduction

The organic Rankine cycle (ORC) and the Kalina cycle (KC) are potential power systems for heat source temperatures below 500 °C. Exemplarily, geothermal, solar and waste heat recovery are potential applications [1–4]. With respect to an optimal match of the temperature profiles of the thermodynamic cycle and the heat source, zeotropic mixtures and supercritical cycles seem to be promising optimization approaches for the ORC [5–7]. For the KC it is shown that the ammonia/water mixture leads to high pressures for high temperature applications [8,9]. Therefore, the KC is limited for waste heat recovery. In this context, alternative working fluid pairs based on alcohol/water and alcohol/alcohol could provide a satisfying efficiency and pressure level [10]. Eller et al. [11] presented that second law efficiency of KC can be increased by applying alcohol/alcohol mixtures as working fluid instead of ammonia/water. The efficiency increase is in the range of 16% and 75%. Mixtures of ethanol and methanol with hexanol and heptanol are identified as the most efficient fluid pairs.

Based on this results a detailed evaluation of operational parameters and technical criterias of novel alcohol/alcohol mixtures as working fluid for the KC is provided in this work. This evaluation is based on process simulations in ASPEN PLUS V8.0. The results are compared to the KC with standard working fluid ammonia/water and to the ORC. The operational parameters analysed in this study are the pressure level, the electrical gross and net power output. In addition, the heat exchange capacity and the size parameter of the turbine are determined. Next to thermodynamic aspects, a techno-economic evaluation of the KC and the ORC is presented. In particular, grassroots cost are estimated for selected boundary conditions and working fluids.

2. Methodology

2.1. Process simulation

In this work simulations are performed by the software ASPEN PLUS V8.0 [12]. The cycle configuration of the ORC implemented in the simulation software includes an internal recuperator (Figure 1a). For the KC, in this study the configuration according to the “Kalina Cycle System 34” (KCS-34), is considered (Figure 1b) without separation step at condensation [2].

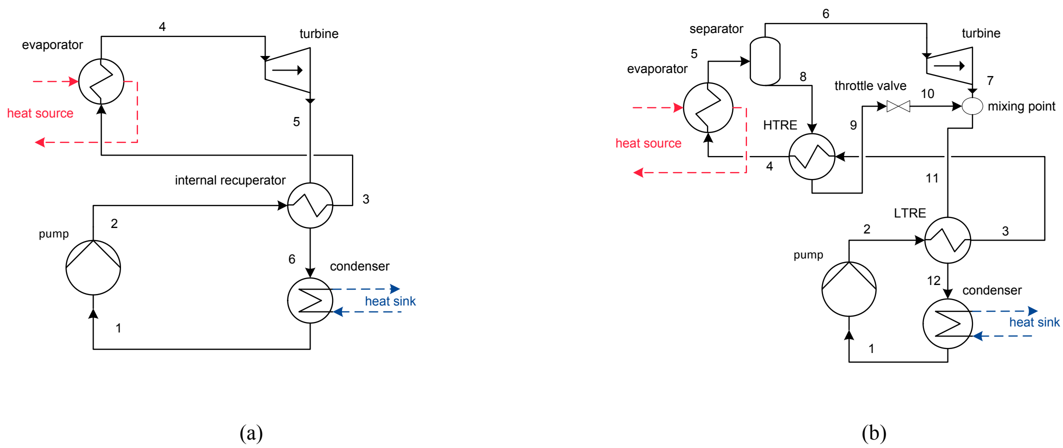

Figure 1: Process scheme of the ORC (a) and KCS-34 (b).

In contrast to the ORC, the working fluid mixture of the KCS-34 is evaporated partially (state 4 to 5 in Figure 1b) and before entering the turbine, vapor and liquid are separated (state 5 to 6 and 8 in Figure 1b). For this reason, mixture components with high differences of the boiling temperature are suitable. In terms of optimized system performance, the partial evaporation of KCS-34 offers one more degree of freedom, the vapor quality at the evaporator outlet. Here, the vapor quality at evaporator outlet is set to 0.9 [11]. Additional boundary conditions assumed for simulation are