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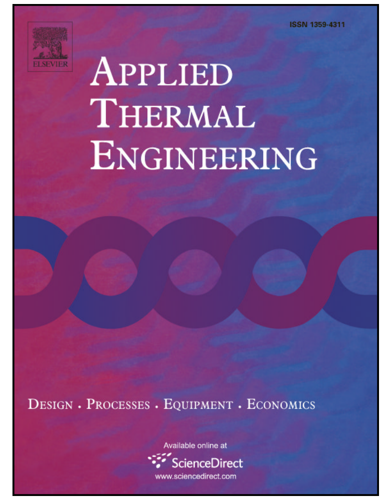

Research Paper

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Modeling and simulation of a shell-and-tube heat exchanger for Organic Rankine Cycle systems with double-segmental baffles by adapting the Bell-Delaware method

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key words: shell-and-tube heat exchanger, double-segmental baffles, Bell-Delaware method, ORC, R245fa, TIL

Abstract:

In respect of an efficient design of Organic Rankine Cycle (ORC) power plants, the heat exchange equipment plays an important role. Shell-and-tube heat exchangers are widely used in such energy conversion systems. The TEMA (Tubular Exchanger Manufacturers Association) E shell type with single-segmental baffles is a relatively simple and the most common design. For this configuration the shell-side heat transfer coefficient is in general determined by the Bell-Delaware method. However, in case of applications with low mean temperature differences like geothermal ORC systems, more advanced flow configurations are applied. In this work a TEMA NFN shell-and-tube heat exchanger with double-segmental baffles is analyzed for single-phase flow. For this design, the standard version of the Bell-Delaware method is not applicable. In this context, the Taborek version of the Bell-Delaware method is adapted to the specific heat exchanger design by adjusting the calculation methods for the main geometrical parameters like cross flow area, leakage areas and effective number of tubes in the overlapping region. The entire heat exchanger is simulated in DYMOLA 2015 FD01. Thereafter, the obtained temperature profiles are validated by real power plant data and deviate from operational data by up to -1.14 %. Subsequently, a novel correlation for an enhancement factor J_x is developed. Due to the application to other shell-and-tube heat exchangers with double-segmental baffles, high accuracy is achieved. In addition, a heat exchanger baffle section is simulated in ANSYS FLUENT 15.0 in order to validate locally the novel adaption of the Taborek version of the Bell-Delaware method (main approach) by CFD simulations. The obtained heat transfer coefficients show a sufficient agreement.

1 Introduction

The world electricity generation primarily bases on conventional fossil and nuclear energy sources. Due to limited resources and environmental problems, renewable energy generation systems like geothermal power plants grow in importance, showing base load capability and a considerable technical potential [1,2]. Binary power plants like Organic Rankine Cycle (ORC) systems are suitable for geothermal fluid temperatures below 180 °C [3]. In order to develop an innovative and efficient geothermal ORC system, various main aspects have to be considered: fluid selection [4–7], consideration of advanced configurations [8–11], environmental issues [12,13] and techno-economic feasibility [14–17]. Furthermore, the optimization of power plant components based on reliable design models and methods is crucial in the context of an energetically and economically efficient system. Regarding an appropriate design and dimensioning of heat exchangers, an accurate prediction of the heat transfer coefficients (HTCs) by suitable correlations or CFD simulations is evident. Furthermore, a reliable prediction of heat exchangers also affects the selection of suitable pumps and the development of control strategies.

For the design of heat exchangers in ORC systems, several aspects like the phase state of the working fluid, the material selection, the type of construction or optimization of geometrical parameters have to be taken into account. In this context, Gomez Alaez et al [18] investigate plastic heat exchangers for low-temperature applications of the ORC. In comparison to stainless steel, the authors determine a reduction of levelized costs of electricity by 6.6 %. Karellas et al. [19] examine the influence of the supercritical state of the ORC working fluid on the plate heat exchanger design parameters. They obtained a reduction of the mean overall heat transfer coefficient with increasing process pressure. Regarding geothermal applications, different types of heat exchangers are considered. Hsieh et al. [20] provide experimental data for a co-axial multi-tube heat exchanger used as evaporator for an ORC system with the working fluid R245fa. In addition, the application of a plate heat exchanger and a shell-and-tube heat exchanger (STHE) is compared for a low-temperature ORC by Walraven et al. [21,22]. In this context, they show that STHE are more suitable for a subcritical cycle using R245fa, isobutane and RC318 as working fluids. Furthermore, Walraven et al. [23] optimize the configuration for STHE in order to maximize the exergetic efficiency of the ORC system. The authors identified that the 30°- and the 60°-tube layout are the most suitable configurations for single phase flow. Yang et al. [24] proposed a modified

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