Popular science summary of the PhD thesis

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Title of the PhD thesis	Two-phase expansion in turbo-expanders for organic Rankine cycle power systems
PhD school/Department	DTU Construct / TES

Science summary

Increasing the efficiency of energy production systems from renewable energy sources and reducing the energy consumption of industrial processes is crucial to limit the global emissions of greenhouse gases. In this context, organic Rankine cycles are a key technology, as they enable the efficient and cost-effective recovery and conversion of low-grade heat in electrical power from various energy sources, including geothermal sources and industrial waste heat.

The partial evaporation organic Rankine cycle represents an alternative cycle architecture to conventional organic Rankine cycles, which can significantly increase the overall power system efficiency by improving the heat transfer between the heat source and the working fluid that realizes the thermodynamic cycle. However, the feasibility of partial evaporation organic Rankine cycle systems is highly dependent on the possibility of realizing the two-phase expansion in efficient and robust machines.

This Ph.D. thesis investigates the two-phase, or flashing, expansion of organic fluids in turbo-expanders for partial evaporation organic Rankine cycle applications at three different levels, which reflect the main objectives of this work. The first objective consists of the evaluation of the techno-economic feasibility of partial evaporation organic Rankine cycles and the determination of the optimal operating conditions of the expander. The second objective is the identification and development of accurate models for the prediction of the flashing phenomenon, which characterizes the operation of turbo-expanders for partial evaporation cycles. The last objective is the realization of a tool for the preliminary design of axial turbines operating in flashing conditions and the evaluation of their performance.

The first part of this work presents the results from the optimization of partial evaporation organic Rankine cycles for low-temperature geothermal power systems based on thermodynamic and economic criteria. The partial evaporation organic Rankine cycle is found to be able to provide a substantial increase in net power output of the system with respect to conventional organic Rankine cycles for a fixed heat source, at the cost of an increase in system costs. Nevertheless, partial evaporation cycles are found to be economically more profitable when the return of the investment along the lifetime of the system is considered.

In the second part of the thesis, a one-dimensional model for the prediction of flashing flows with thermal non-equilibrium effects is presented. For this purpose, the adoption of the simple geometry of a converging-diverging nozzle allows focusing exclusively on the thermodynamic description of the flow. The excellent agreement observed when comparing the obtained numerical results with experimental data on R134a suggests that the proposed model can be applied to other fluids with reasonable confidence.

The last part of the thesis is dedicated to the description of the two-phase flashing expansion in axial cascades and of a novel mean-line model developed to predict their effect on the performance of axial turbines. The model is here applied to a case study based on the optimal operating conditions derived in the first part of the work from the cycle analysis. The results show that the performance of the machine is significantly affected by the two-phase operation only if the deposition of liquid droplets on the blades occurs at high rates and that the choice of an adequate geometry highly contributes to limiting two-phase losses.

The work presented in this thesis demonstrates the potential of partial evaporation organic Rankine cycles and the possibility of realizing the two-phase expansion in turbomachines with a limited penalization in their efficiency. The outcome of this thesis represents a basis for the future development of the partial evaporation organic Rankine cycle technology and for its application to large size power systems.

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