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COMPARISON BETWEEN SINGLE AND CASCADED ORGANIC RANKINE CYCLE SYSTEMS ACCOUNTING FOR THE EFFECTS OF EXPANSION VOLUME RATIO ON EXPANDER PERFORMANCE

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Compared to single-stage organic Rankine cycle (ORC) systems, cascaded ORC systems, in which a high-temperature topping cycle and low-temperature bottoming cycle are coupled together, could have advantages in terms of removing the potential for sub-atmospheric condensation conditions and improving expander performance as the expansion process is effectively divided across two stages. Moreover, reducing the expansion volume ratio could facilitate the use of volumetric expanders, such as twin-screw expanders, which, in turn, could facilitate two-phase expansion to be utilised in one, or both, of the cycles. The aim of this paper is to compare single-stage and cascaded ORC systems, accounting for the effect of the expander volume ratio on expander performance. To investigate this, thermodynamic models for single-stage and cascaded ORC systems are developed, which include variable efficiency expander models for both radial turbines and twin-screw expanders that can estimate the effect of the expansion volume ratio on the expander isentropic efficiency. Using this model, three different scenarios are compared for different temperature heat-source temperatures, namely: (i) single-stage ORC systems with vapour-phase expansion obtained using a turboexpander; (ii) single-stage ORC systems operating with a twin-screw expander, with the possibility for two-phase expansion; and (iii) cascaded cycles with either vapour- or two-phase expansion. The results from this comparison are used to identify applications where cascaded ORC systems could offer performance benefits.

Keywords: single-stage Rankine cycle, cascaded Rankine cycle, turboexpander, screw expander, isentropic efficiency.

References

1. Costall A. W., Gonzalez Hernandez A., Newton P. J., Martinez-Botas R. F. Design methodology for radial turbo expanders in mobile organic Rankine cycle applications // Applied Energy. 2015. Vol. 157 (C). P. 729–743. DOI: 10.1016/j.apenergy.2015.02.072. (In Engl.).

2. Read M. G., Smith I. K., Stosic N. Optimisation of power generation cycles using saturated liquidexpansion to maximise heat recovery // Journal of Process Mechanical Engineering: Proc. of the Institution of Mechanical Engineers, Part E. 2017. Vol. 231 (1). P. 57–69. DOI: 10.1177/0954408916679202. (In Engl.).

3. Smith I. K. Development of the Trilateral Flash Cycle System: Part 1: Fundamental Considerations // Journal of Power and Energy: Proc. of the Institution of Mechanical Engineers, Part A. 1993. Vol. 207 (3). P. 179–194. DOI: 10.1243/PIME_PROC_1993_207_032_02. (In Engl.).

4. Fischer J. Comparison of trilateral cycles and organic Rankine cycles // Energy. 2011. Vol. 36, Issue 10. P. 6208–6219. DOI: 10.1016/j.energy.2011.07.041. (In Engl.).

5. Kane M., Larrain D., Favrat D., Allani Y. Small hybrid solar power system // Energy. 2003. Vol. 28, Issue 14. P. 1427–1443. DOI: 10.1016/S0360-5442(03)00127-0. (In Engl.).

6. Kosmadakis G., Manolakos D., Kyritsis S., Papadakis G. Economic assessment of a two-stage solar organic Rankine cycle for reverse osmosis desalination // Renewable Energy. 2009. Vol. 34 (6). P. 1579–1586. DOI: 10.1016/j.renene.2008.11.007. (In Engl.).

7. White M. T., Read M. G., Sayma A. I. Optimisation of cascaded organic Rankine cycle systems for high-temperature waste-heat recovery // Proc. 31st Int. Conf. on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. 2018. (In Engl.).

8. White M. T., Sayma I. A. A generalized assessment of working fluids and radial turbines for nonrecuperated subcritical organic Rankin cycles // Energies. 2018. Vol. 11 (4). P. 800. DOI: 10.3390/en11040800. (In Engl.).

9. Perdichizzi A., Lozza G. Design criteria and efficiency prediction for radial inflow turbines // Proc. Gas Turbine Conference and Exhibition. 1987. 87-GT-231. (In Engl.).

10. Lio L. D., Manente G., Lazzaretto A. A mean-line model to predict the design efficiency of radial inflow turbines in organic Rankine cycle (ORC) systems // Applied Energy. 2017. Vol. 205 (C). P. 187–209. DOI: 10.1016/j.apenergy.2017.07.120. (In Engl.).

11. White M. T., Read M. G., Sayma A. I. Using a cubic equation of state to identify optimal working fluids for an ORC operating with two-phase expansion using a twin-screw expander // 17th International Refrigeration and Air Conditioning Conference. 2018. (In Engl.).

12. Read M. G., Smith I., Stosic N. Effect of Air Temperature Variation on the Performance of Wet Vapour Organic Rankine Cycle Systems // Geothermal Resources Council Transactions. 2014. Vol. 38. P. 705–712. (In Engl.).

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