Postprint: Simultaneous Multi-Objective Optimization of Structure and Operating Parameters for ORC Heat Exchangers

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Abstract

With the increasingly severe global energy shortage and environmental problems, fully utilizing renewable energy and low-grade waste heat resources from industries to improve energy utilization efficiency represents an important approach to mitigating energy and environmental issues. Organic Rankine Cycle (ORC) is one of the most promising low-grade thermal power generation technologies. This paper establishes a multi-objective optimization model for heat exchange equipment that simultaneously optimizes structural parameters and system operating parameters for ORC systems, using R245fa as the working fluid and plate heat exchangers, with the objective functions of maximizing exergy efficiency and minimizing specific investment cost. First, the influence of individual variables (evaporation pressure, condensation pressure, superheat, evaporator plate spacing, condenser plate spacing) on system performance is analyzed. Then, nine parameters are selected as decision variables: system operating parameters (evaporation pressure, condensation pressure, superheat) and heat exchanger structural parameters (plate length, plate width, and plate spacing of the evaporator and condenser). Genetic algorithm is employed to perform multi-objective simultaneous optimization of ORC heat exchange equipment structure and operating parameters, obtaining the Pareto optimal frontier of the multi-objective optimization along with the corresponding optimal system operating parameters and optimal heat exchanger structural parameter combinations.

Full Text

Multi-Objective Optimization of Organic Rankine Cycle for Low-Grade Waste Heat Recovery

System Modeling and Thermodynamic Analysis

The Organic Rankine Cycle (ORC) system is modeled based on fundamental thermodynamic principles. The key performance equations are:

Heat transfer in the condenser:

$$Q_{con} = m(h_2 - h_4)$$

Turbine work output:

$$W_{tur} = m(h_1 - h_2)$$

Pump work input:

$$W_{pump} = m(h_5 - h_4)$$

The total system cost comprises heat exchanger, pump, and turbine components:

$$C_{com} = C_{HE} + C_{pump} + C_{tur}$$

Where the individual cost correlations are:

$$C_{HE} = 10,000 + 324A^{0.91}$$

$$C_{pump} = 422W_{pump}^{0.71} \times 1.41 + 1.41$$

$$C_{tur} = 6000W_{tur}^{0.7} \times (1 - 0.8)$$

The optimization considers two conflicting objectives: maximizing exergy efficiency and minimizing specific investment cost (SIC). The system uses R245fa as the working fluid, with evaporation pressures ranging from 0.8 to 1.5 MPa and condensation pressures from 0.1 to 0.5 MPa.

Parametric Performance Analysis

Influence of Evaporation Pressure As shown in [Figure 2: see original paper], increasing evaporation pressure initially improves cycle efficiency but eventually leads to diminishing returns. The optimal pressure range balances thermodynamic performance with equipment costs, with peak efficiency occurring around 1.2 MPa under the given constraints.

Influence of Condensation Pressure [Figure 3: see original paper] demonstrates that lower condensation pressures generally improve cycle performance by increasing the pressure ratio across the turbine. However, practical limits exist due to cooling medium temperatures and pump cavitation concerns.

Influence of Superheat Degree The superheat degree affects system performance as illustrated in [Figure 4: see original paper]. Moderate superheating of 5-15°C proves optimal, as excessive superheating increases heat exchanger costs without proportional efficiency gains.

Influence of Heat Exchanger Geometry Plate spacing parameters for both evaporator and condenser significantly impact performance. [Figure 5: see original paper] and [Figure 6: see original paper] show that narrower plate spacing enhances heat transfer but increases pressure drop and manufacturing complexity. The optimal plate spacing represents a compromise between thermal effectiveness and cost.

Multi-Objective Optimization Methodology

A genetic algorithm (GaMultiObj) is employed for Pareto optimization. The decision variables and their bounds are specified in , including evaporation pressure, condensation pressure, superheat temperature, and plate heat exchanger geometric parameters (width, length, and plate spacing for both evaporator and condenser).

The genetic algorithm parameters are configured as shown in , with a population size of 100, maximum generations of 200, crossover probability of 0.8, and mutation probability of 0.2.

Optimization Results

The Pareto frontier reveals the trade-off between efficiency and cost, as depicted in [Figure 7: see original paper]. Key optimization results are summarized in :

- **Maximum exergy efficiency**: 43.79% (SIC = 5463.6 $/kW)
- **Minimum specific investment cost**: 5588.7 $/kW (efficiency = 42.95%)
- **Pareto optimal solution**: 42.95% efficiency at 5588.7 $/kW

The optimization identifies that the best compromise solution achieves 42.95% exergy efficiency with a specific investment cost of 5588.7 $/kW, representing only a 0.26% efficiency reduction compared to the maximum efficiency case while providing significant cost savings.

Conclusion

The multi-objective optimization framework successfully balances thermodynamic performance and economic viability for ORC systems recovering low-grade waste heat. The parametric studies reveal that evaporation pressure, condensation pressure, and heat exchanger geometry are critical design parameters requiring careful optimization. The genetic algorithm approach efficiently generates Pareto optimal solutions, enabling designers to select the most suitable configuration based on specific project priorities.

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Note: Figure translations are in progress. See original paper for figures.