Experimental Study of a 1 kW Organic Rankine Cycle (ORC) System under Varying Operating Conditions

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A detailed study on a 1 kW Organic Rankine Cycle (ORC) power generation system tested under six operating conditions using R134a, R227ea, and R245fa. This research investigates the effects of working fluid type, heat source temperature, and filling quantity on system efficiency, net power, and exergy losses, revealing key findings for improving micro-scale waste heat recovery performance.

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Experimental study on steady-state operation of organic Rankine cycle system under different operating conditions

Overview
This study examines the steady-state operation of a 1 kW-class Organic Rankine Cycle (ORC) power generation system. The research focuses on how different operating parameters — including working fluid type, fluid filling quantity, and heat source temperature — influence system behavior, power output, and energy efficiency. The experiments demonstrate that even small-scale ORC systems can maintain stable operation and deliver consistent power generation across a range of environmental and thermal conditions.

Purpose and Objectives
• To investigate the performance of a 1 kW-class ORC system under different working fluids and filling quantities.
• To analyze how heat source temperature affects generator output, cycle efficiency, and exergy efficiency.
• To evaluate environmental performance by comparing fluids with varying global warming potentials (GWPs).
• To develop insights that guide the optimization of small-scale ORC systems for waste heat recovery applications.

Experimental Setup
• The ORC system consists of a closed loop including an evaporator, scroll expander, condenser, and working fluid pump.
• Heat is provided by thermal oil heated with an 80 kW electrical rod heater.
• A cooling tower regulates the condenser temperature and ensures stable operation.
• The working fluids tested were R134a, R245fa, and R227ea — all zero ozone depletion potential (ODP) refrigerants.
• The scroll expander was modified from an automotive air-conditioning compressor, directly coupled to a single-phase asynchronous generator.
• Cooling and heat source flow rates, temperatures, and pressures were precisely monitored to evaluate performance.

Operating Conditions
• Six operating conditions (C1–C6) were tested, with heat source temperatures ranging from 100°C to 120°C.
• Working fluid filling quantity was varied from 5 to 10 kilograms.
• The working pump operated at a constant frequency of 16 Hz.
• Cooling water temperature was actively controlled to minimize experimental fluctuations.

Key Experimental Findings
• The ORC system achieved stable operation across all six test conditions.
• Cooling water temperature (CWT) had a major influence on system behavior and component performance.
• Generator output power fluctuated more than other parameters due to dynamic interactions between expander speed and differential pressure.
• The system achieved a maximum power output of 1.019 kW and maximum net work of 2.041 kW under the C5 condition.
• The maximum generator power conversion efficiency was 64.65 percent under condition C1.
• The maximum cycle efficiency reached 9.65 percent, and the maximum exergy efficiency reached 27.35 percent under the C3 condition.
• R245fa produced higher power output due to its higher density, but also showed greater exergy loss in the condenser.
• R227ea demonstrated higher efficiency in utilizing low-temperature heat sources compared to R134a and R245fa.

Thermodynamic and Exergy Insights
• Total exergy loss increased with both heat source temperature and working fluid quantity.
• The evaporator accounted for the largest share of total system exergy loss, followed by the expander.
• Increasing the fluid charge improved heat absorption and expander work but slightly reduced isentropic efficiency at higher flow rates.
• Higher filling quantities enhanced overall power generation but also increased system thermal losses.