

Composition-adjustable fluid mixtures for enhanced performance of reversible Heat Pump - ORC systems

Maximilian Weitzer, Hannah Cortnum, Nora Elhaus, Jürgen Karl

Carnot batteries for flexible and efficient energy storage

Carnot batteries are an emerging energy storage technology based on thermodynamic cycles. The working principle includes a high-temperature heat pump that utilizes surplus electrical energy to charge a thermal energy storage (Fig. 1). The thermal integration of low-grade waste heat, e.g. from industrial processes, is beneficial for boosting the heat pump's coefficient of performance. During discharging, an Organic Rankine Cycle (ORC) converts the thermal energy back into electrical energy. In the intended storage temperature range between 100°C and 200°C, simple hot water storages enable a simply scalable and low-cost storage capacity.

Moreover, reversible heat pump-ORC systems facilitate flexible and efficient processes for several application, e.g.:

- Electrical energy storage (Carnot battery)
- Sector coupling (power-to-heat / heat-to-power)
- Combination with process heat/steam generation
- Building energy systems (heat, cooling, electricity)
- Geothermal and waste heat energy utilization

Our HP-ORC pilot plant

At the Chair of Energy Process Engineering, a first-of-its-kind heat pump-ORC system has been realized (Fig. 2). The pilot plant allows for fully reversible utilization of the components (e.g. heat exchangers and fluid energy machines). The system (15 kW_{el} charging / 9 kW_{el} discharging) is equipped with two 4,000-liter hot water storages (270 kWh_{th}).



Fig. 2: Reversible heat pump-ORC pilot plant with two hot water storages in FAU's lab.

The main performance indicator for Carnot batteries is the power-to-power efficiency η_{PTP}

$$\eta_{PTP} = COP \cdot \eta_{storage} \cdot \eta_{ORC}$$

Thermal integration of waste heat into the heat pump allows the power-to-power efficiency to be boosted to values greater than 60%, facilitating scalable and competitive energy storage (Fig. 1).

Besides cost-efficient storage scalability, the main advantages of heat pump-ORC processes are geographical independence (in contrast to pumped hydro storage), technological maturity of the individual components, and synergetic temperature levels for sector coupling and process heat applications.

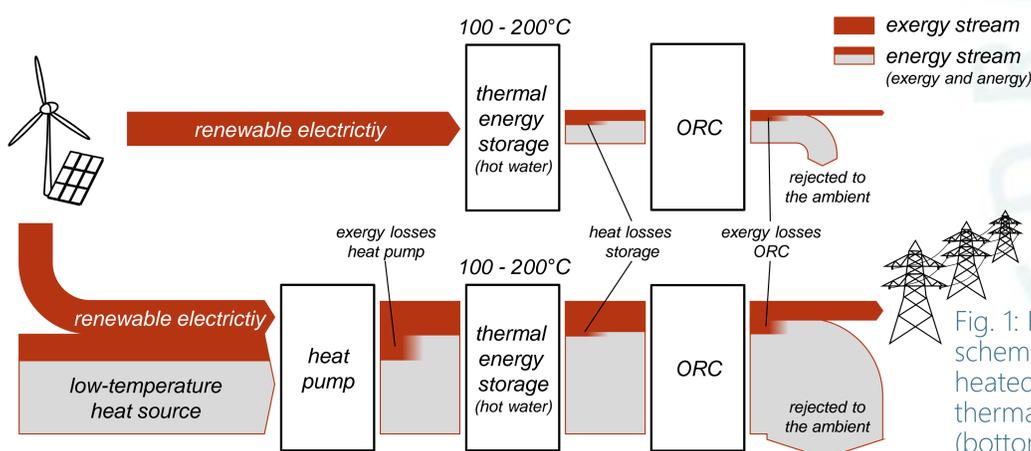


Fig. 1: Energy/exergy flow scheme of an electrically heated (top) versus a thermally integrated (bottom) Carnot battery.

Experimental results

Two different fluid pairs were experimentally investigated: one low-glide mixture (R-1336mzz(Z) and R-1366mzz(E)) and one high-glide mixture (R-1233zd(E) and CO₂). Both fluid pairs demonstrated realistic efficiency gains of up to 20% in both modes, heat pump and ORC (Fig. 3). The optimal composition strongly depends on the operating mode and temperature levels.

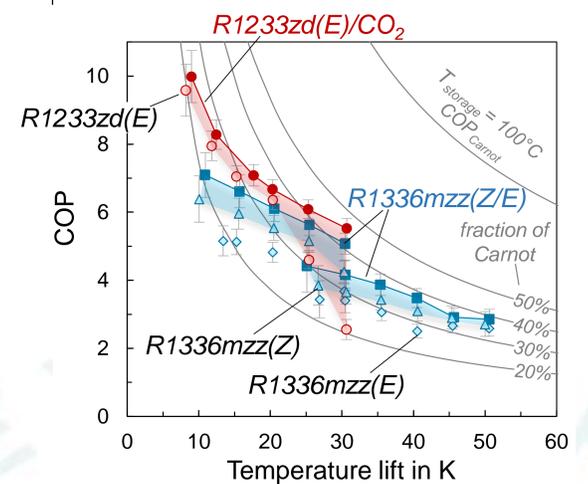


Fig. 3: Experimental results with fluid mixtures.

Composition-adjustable mixtures

Concluding from the experimental results, composition-adjustable fluid mixtures would be ideal to maximize the benefits of mixtures under varying operating conditions. Hence, a concept for a reversible HP-ORC system with passive composition adjustment was developed.

In scenario simulations with reversible HP-ORC systems operating with electricity arbitrage in the German electricity grid, composition-adjustable fluid mixtures were able to increase the mean yearly power-to-power efficiency by up to 18% and profits by up to 26% compared to fixed mixtures.

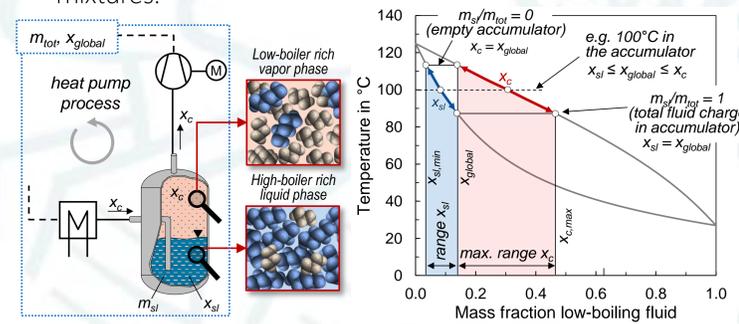


Fig. 4: Composition-adjustment for heat pumps.

