Experiment of Pumpless Organic Rankine-type Cycle For Low-temperature Waste Heat Recovery

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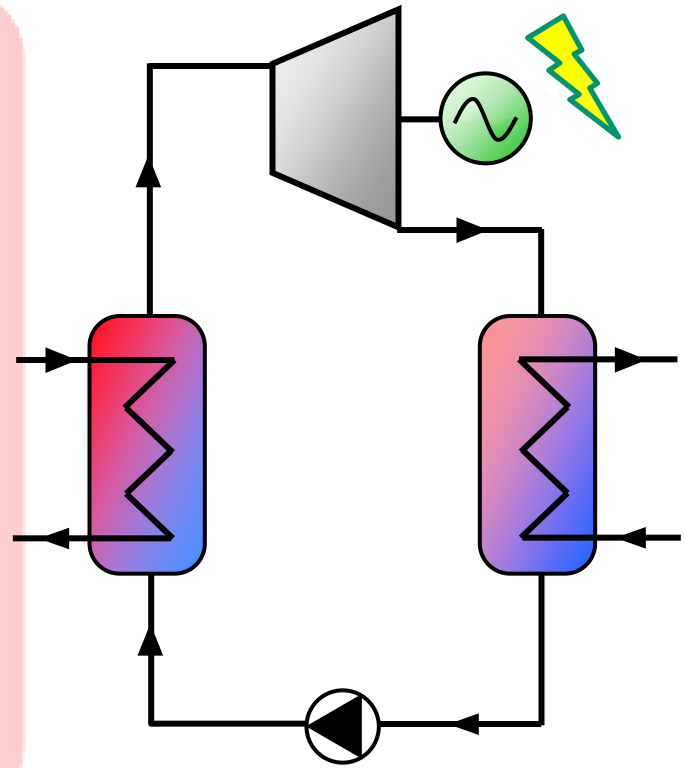
Background

Distributed & low-temp.
heat sources



ORC is one of excellent cycles for
power generation from low-temp. heat

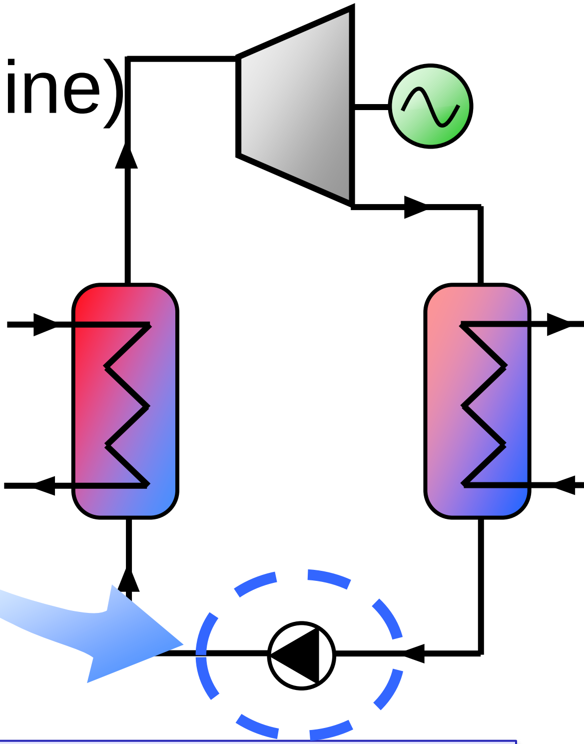
Background & Objective

Power ≈ 1kW

Heat source temp. ≈ 100°C

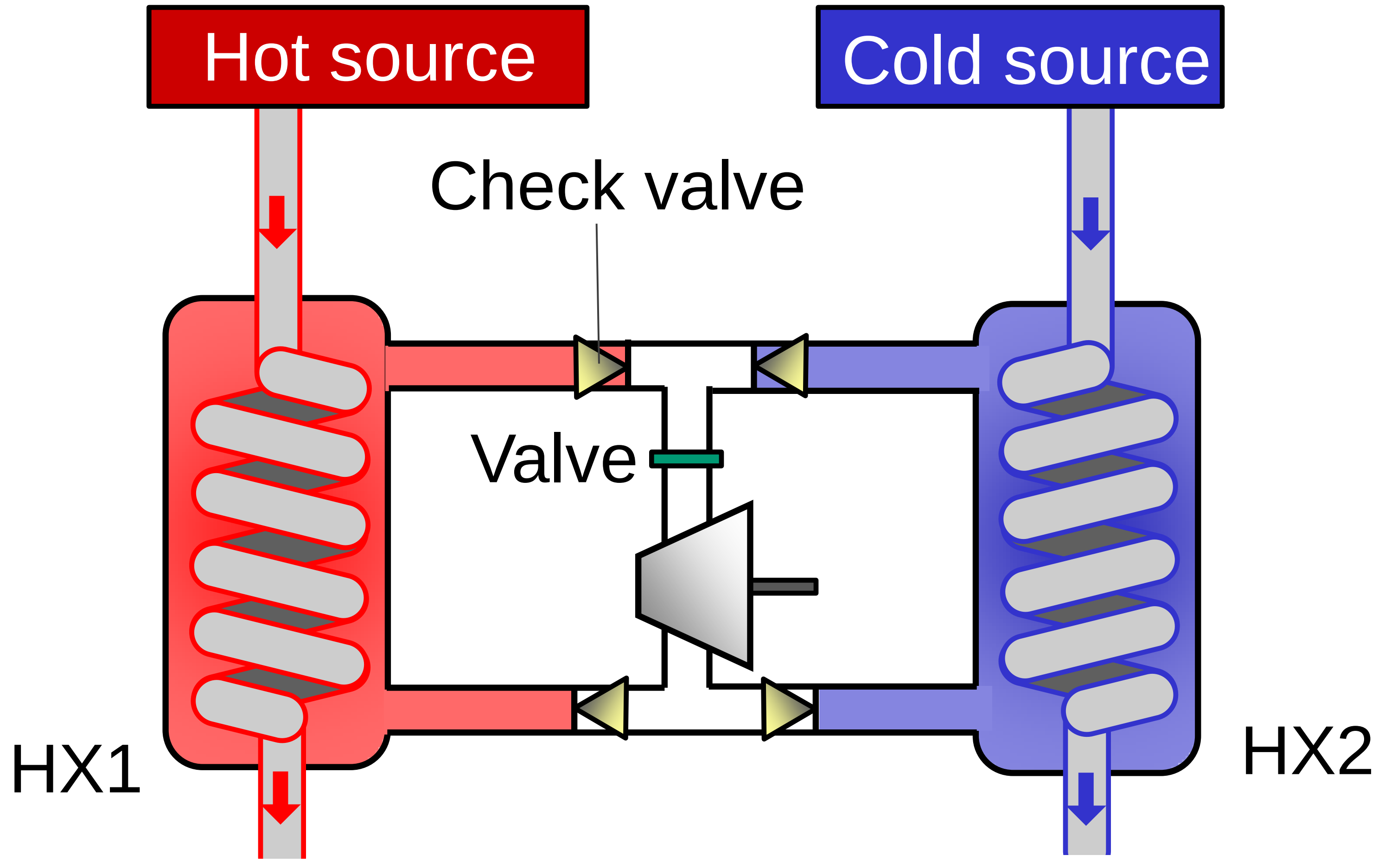
Non-steady heat source (e.g. Car engine)

- Pump selection
- Off-design pump efficiency
  → Net efficiency drop
- Positive suction head of pump
  → Not compact system layout



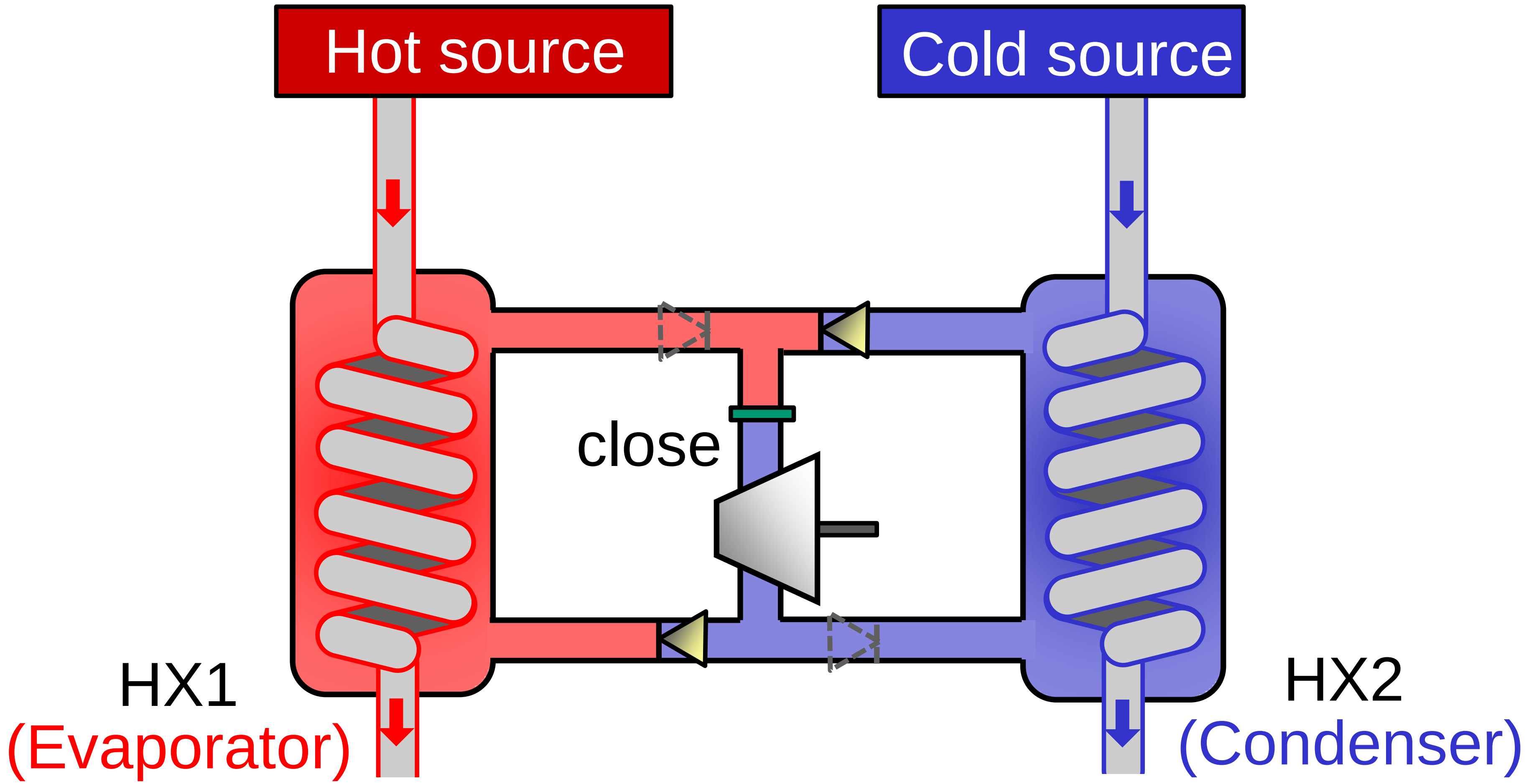
Downgrade ORC to "Pumpless" cycle for exploring cost-effective alternative

Pumpless Rankine-type cycle



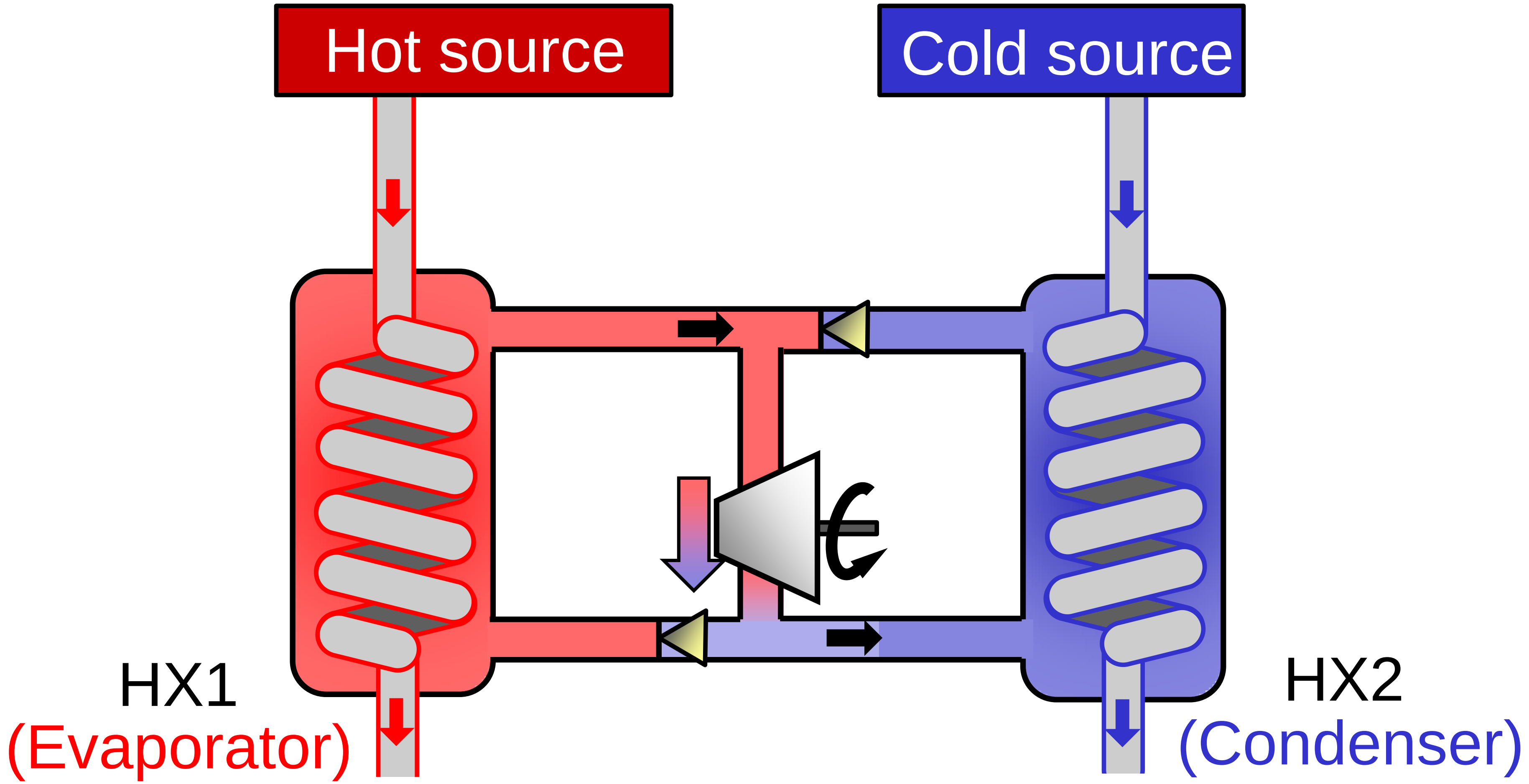
Working principle

① Close valve



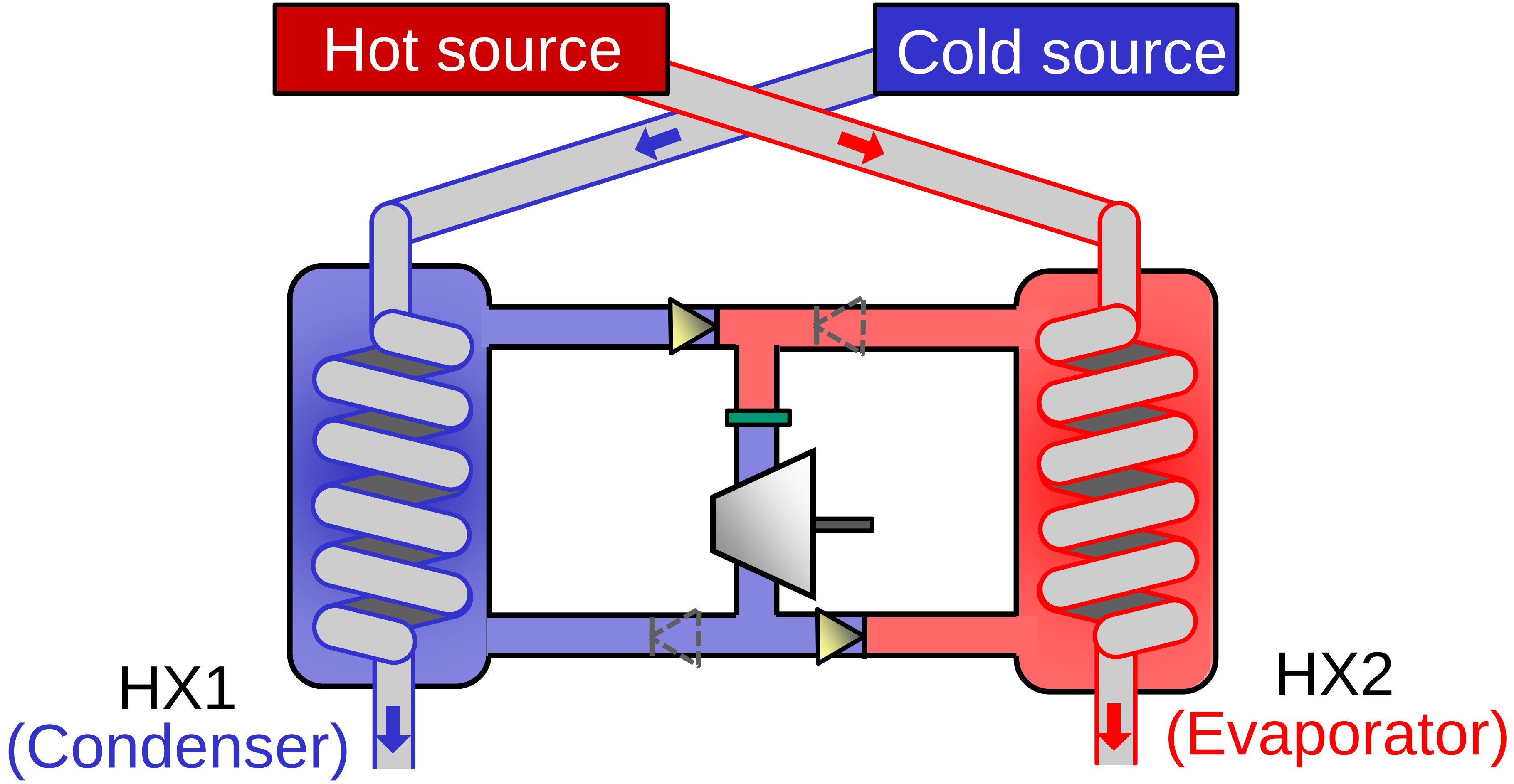
Working principle

② Open valve



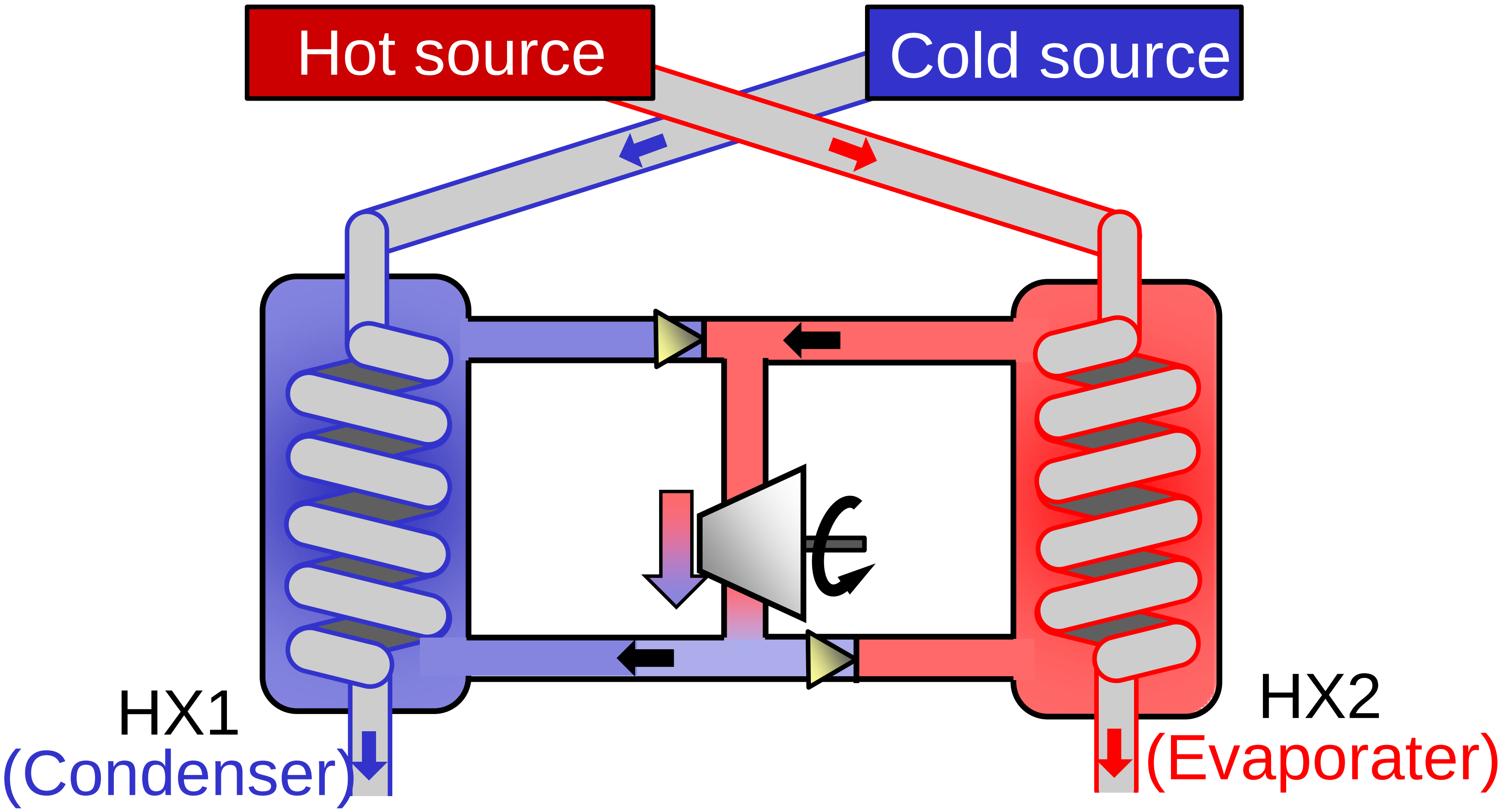
Working principle

③ Close valve & change heat source flow

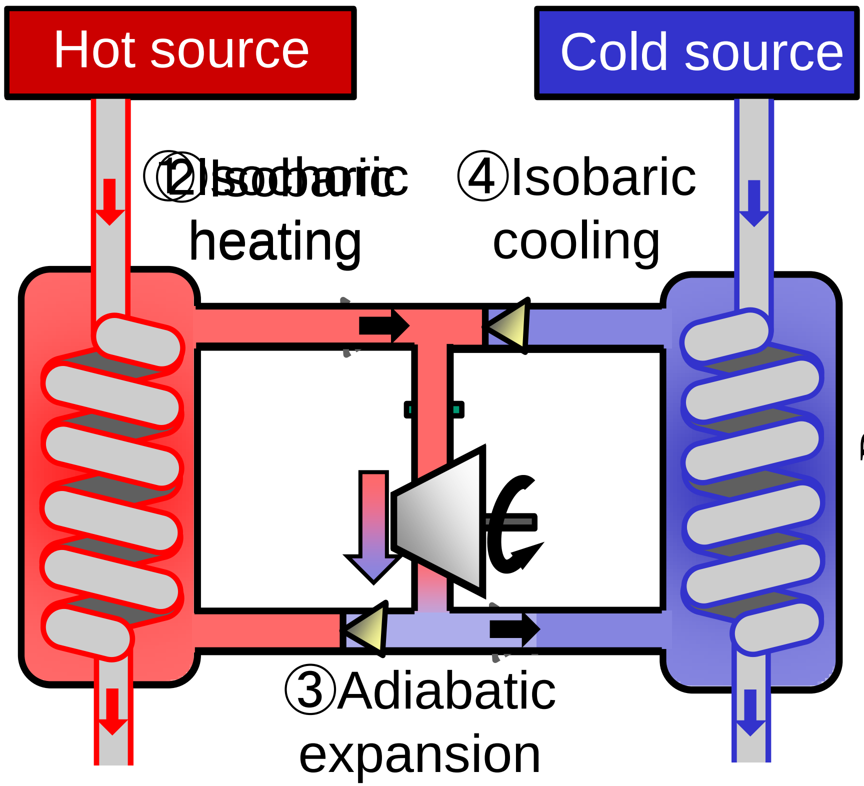


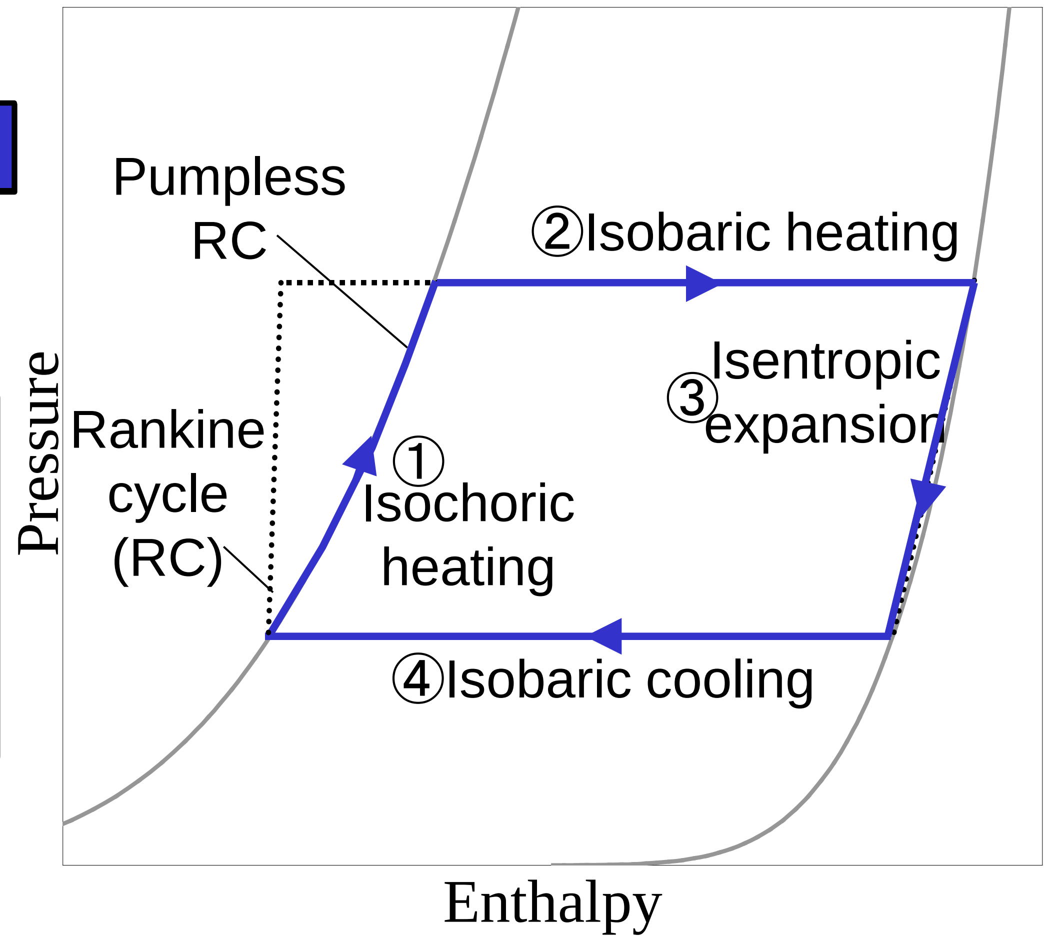
Working principle

④ Open valve again



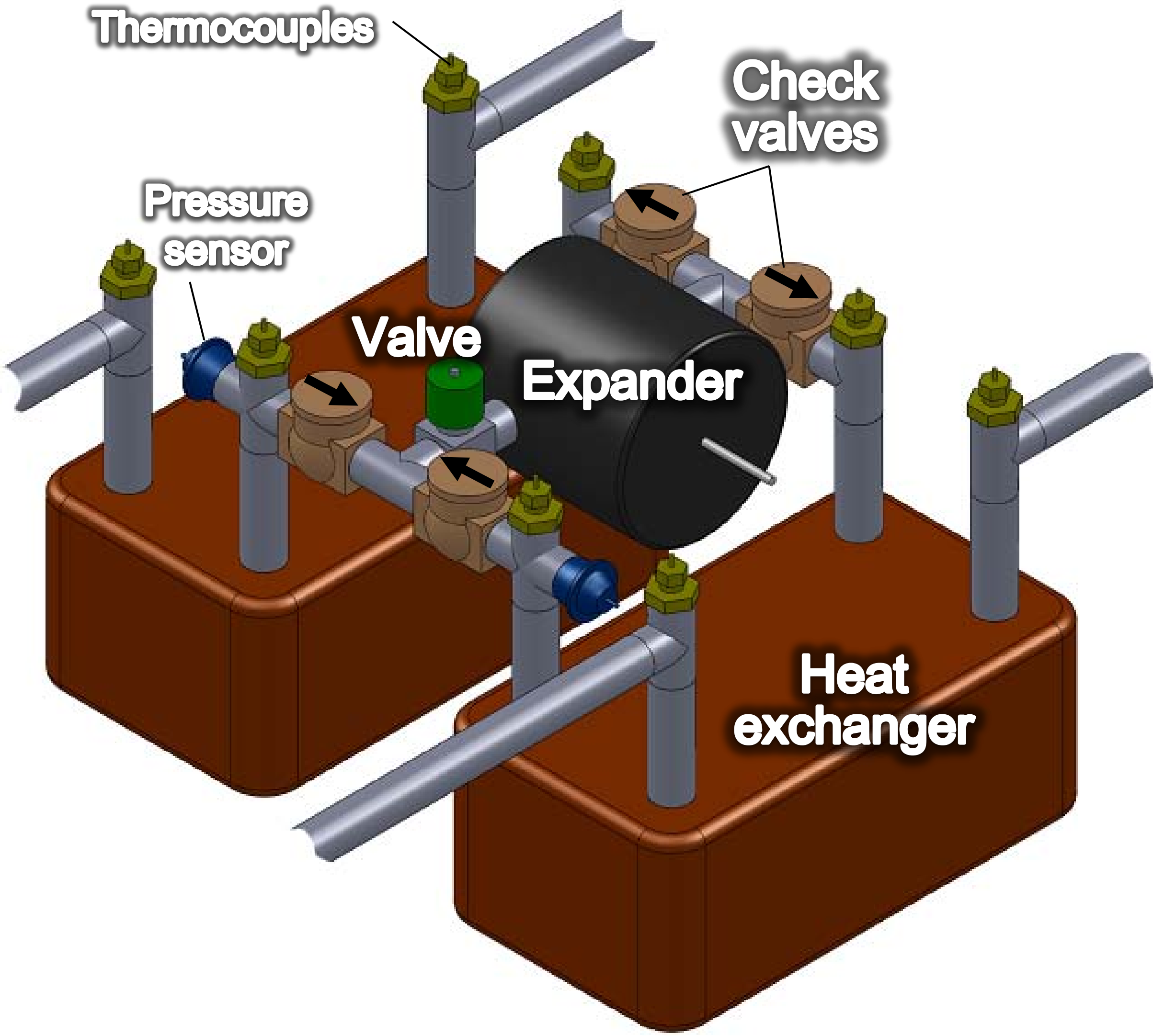
$P - h$ diagram


Hot source
Cold source
②Isobaric heating
④Isobaric cooling
③Adiabatic expansion


Pumpless RC
②Isobaric heating
Isentropic ③expansion
Rankine cycle (RC)
①Isochoric heating
④Isobaric cooling
Pressure
Enthalpy

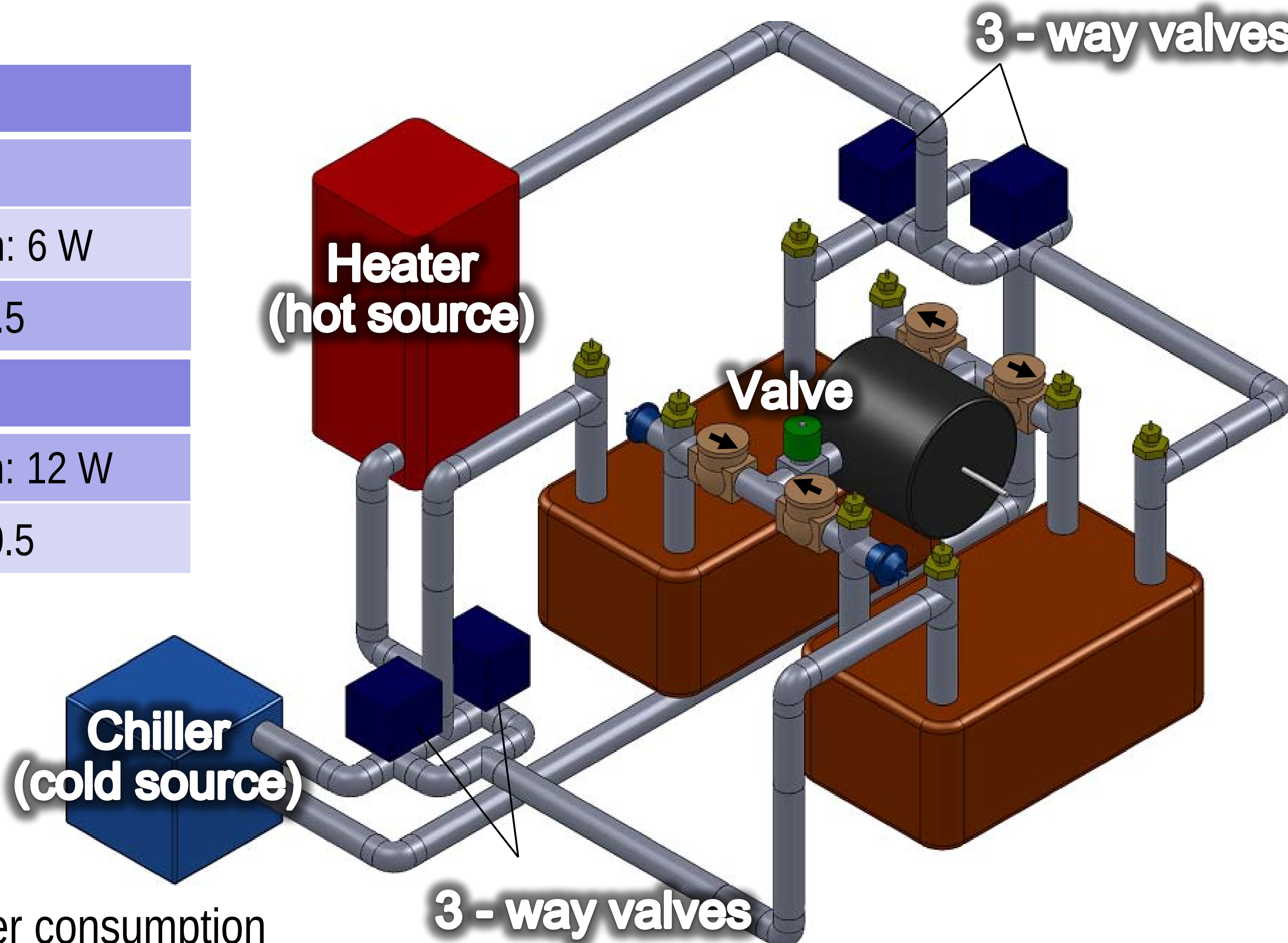
Experimental setup

Expander
Displacement-type
Trochoidal (gerotor) expander
Heat exchanger
Brazed plate heat exchanger
Volume: 1.2 L
Heat transfer area: 1.2 m^2
Working fluid
HFC245fa
Boiling temperature: 14.9℃



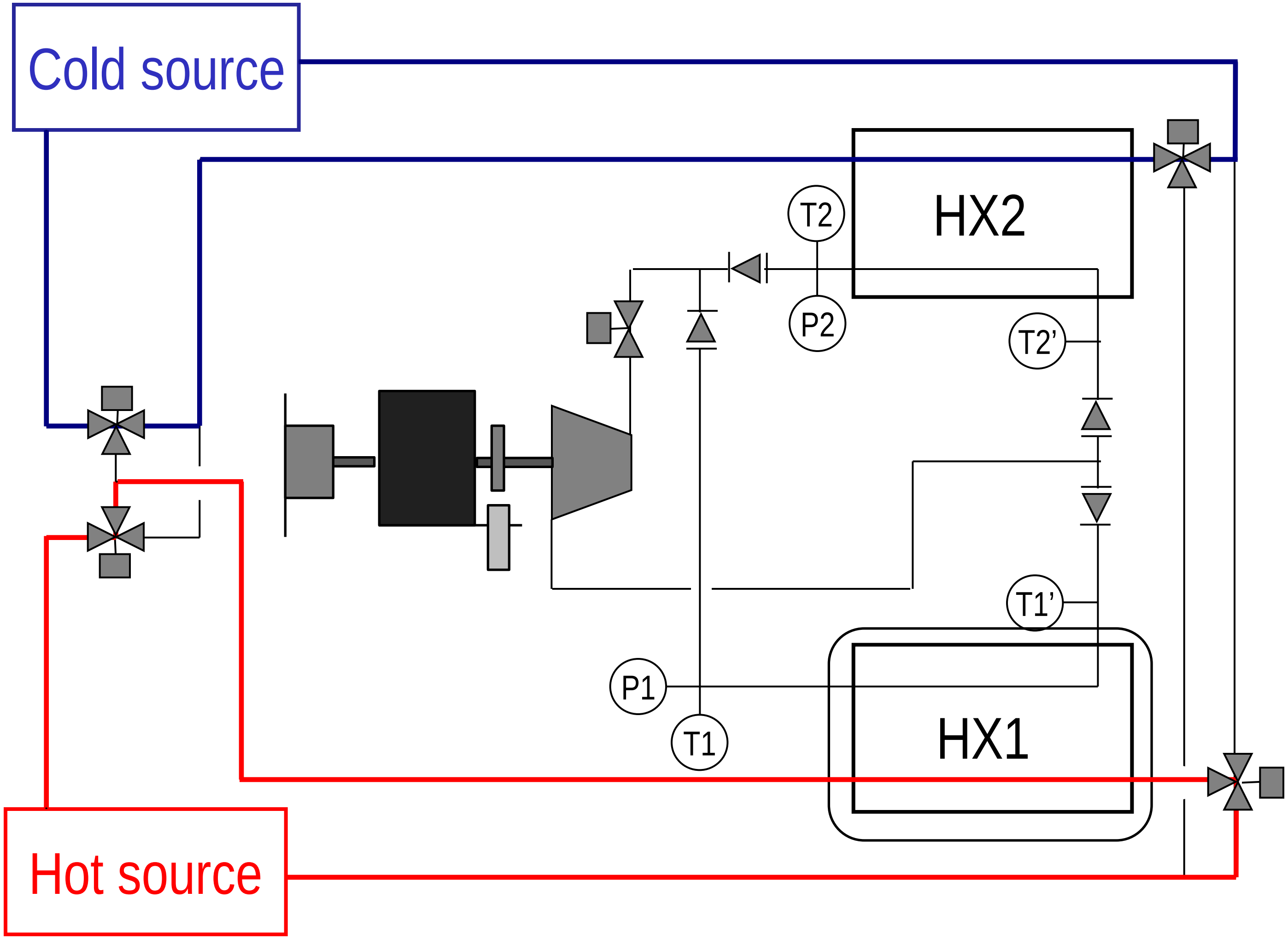
Experimental setup

Solenoid valve
Bi-direction type
Electricity consumption: 6 W
Flow coefficient: C_v =1.5
3-way solenoid valve
Electricity consumption: 12 W
Flow coefficient: C_v = 0.5

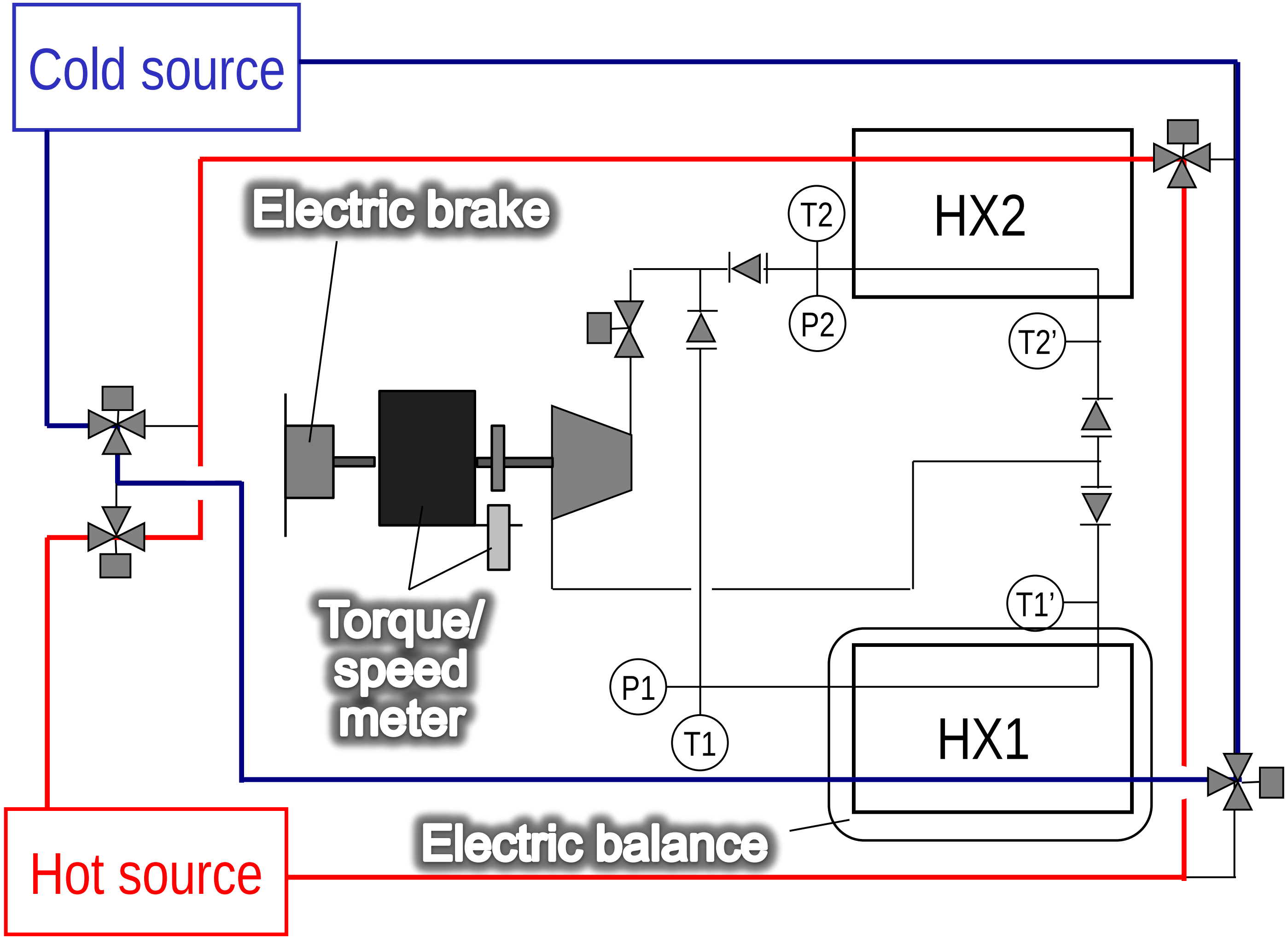


*Average total power consumption
of five valves: 28 W

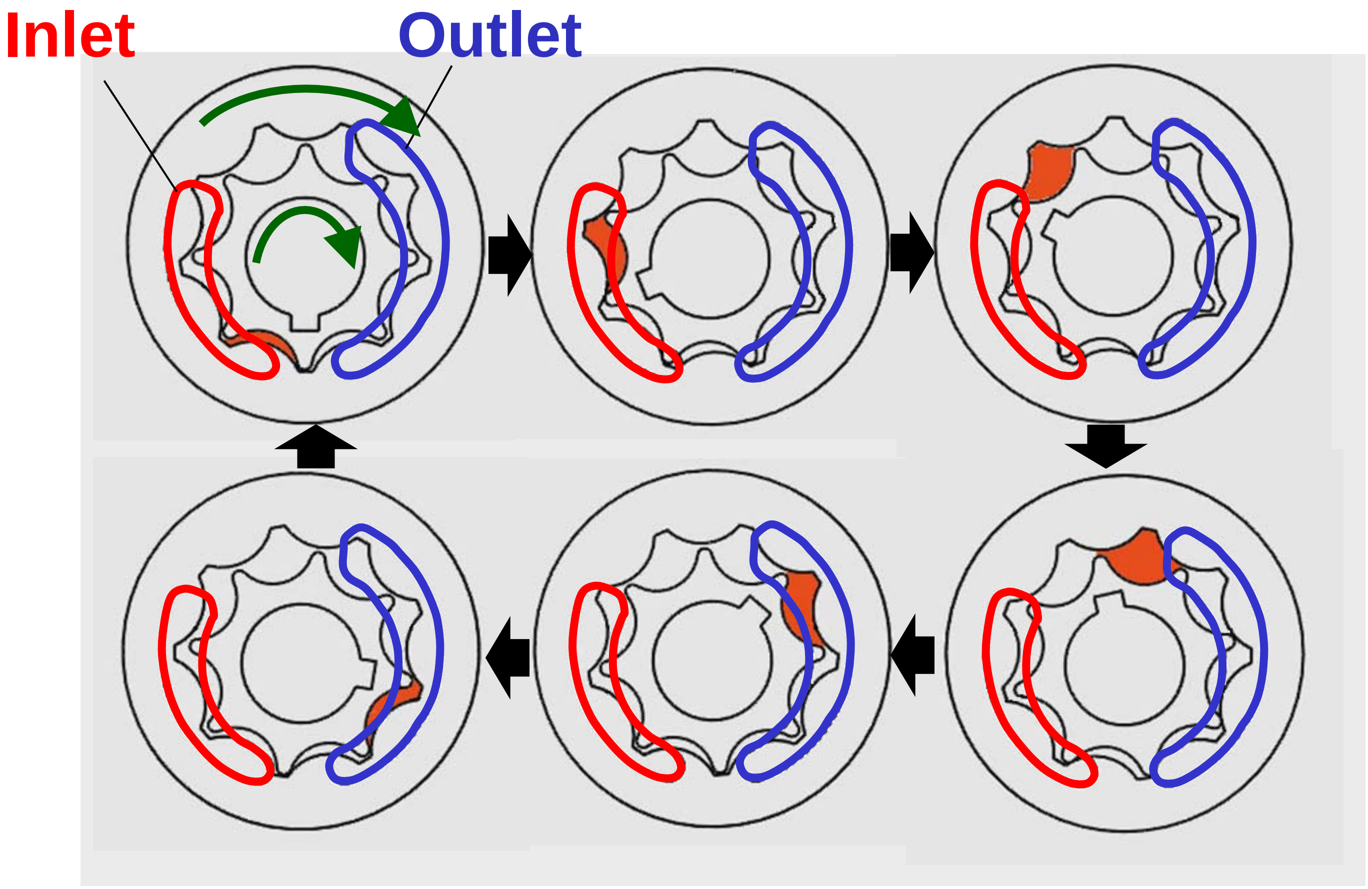
Switching valves method



Switching valves method

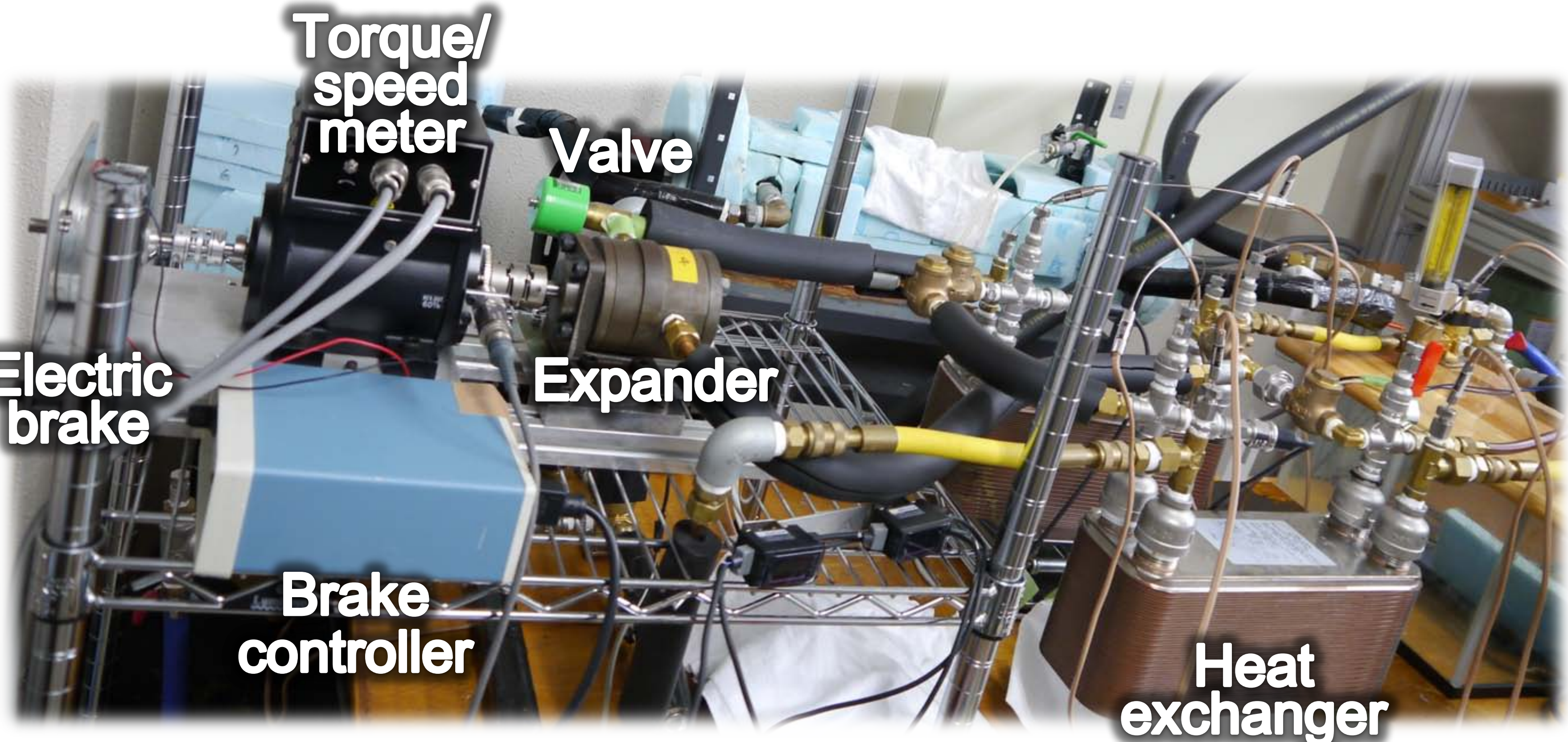


Trochoidal (Gerotor) expander



Built-in volume ratio = 2

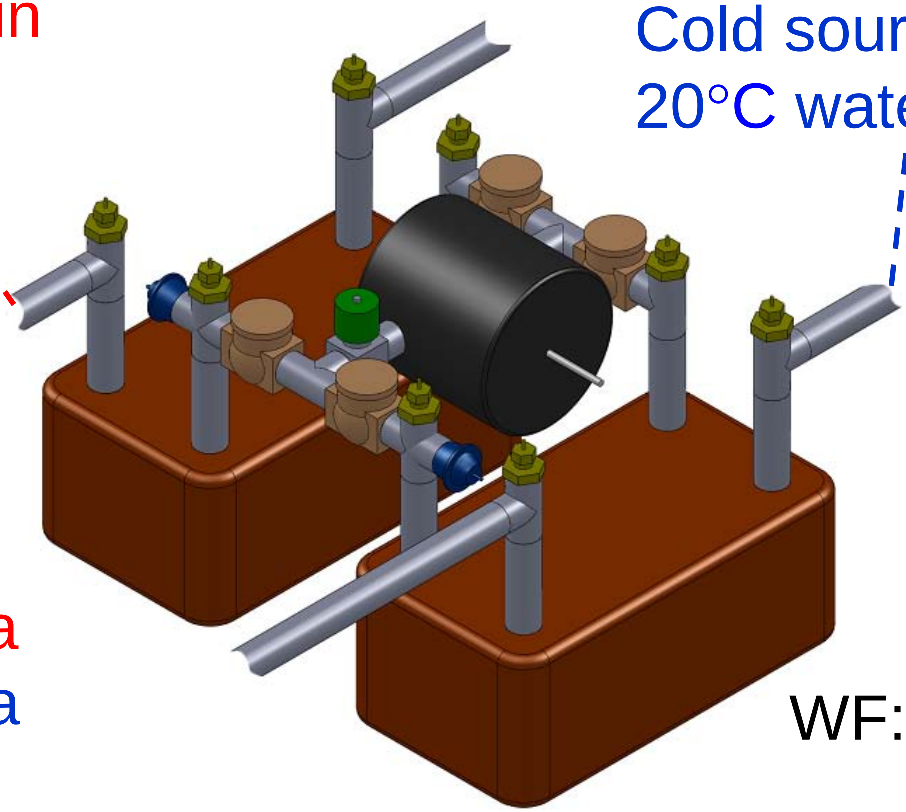
Photo of experimental system



Experimental conditions

Hot source:
90°C water, 2L/min

Cold source:
20°C water, 8L/min



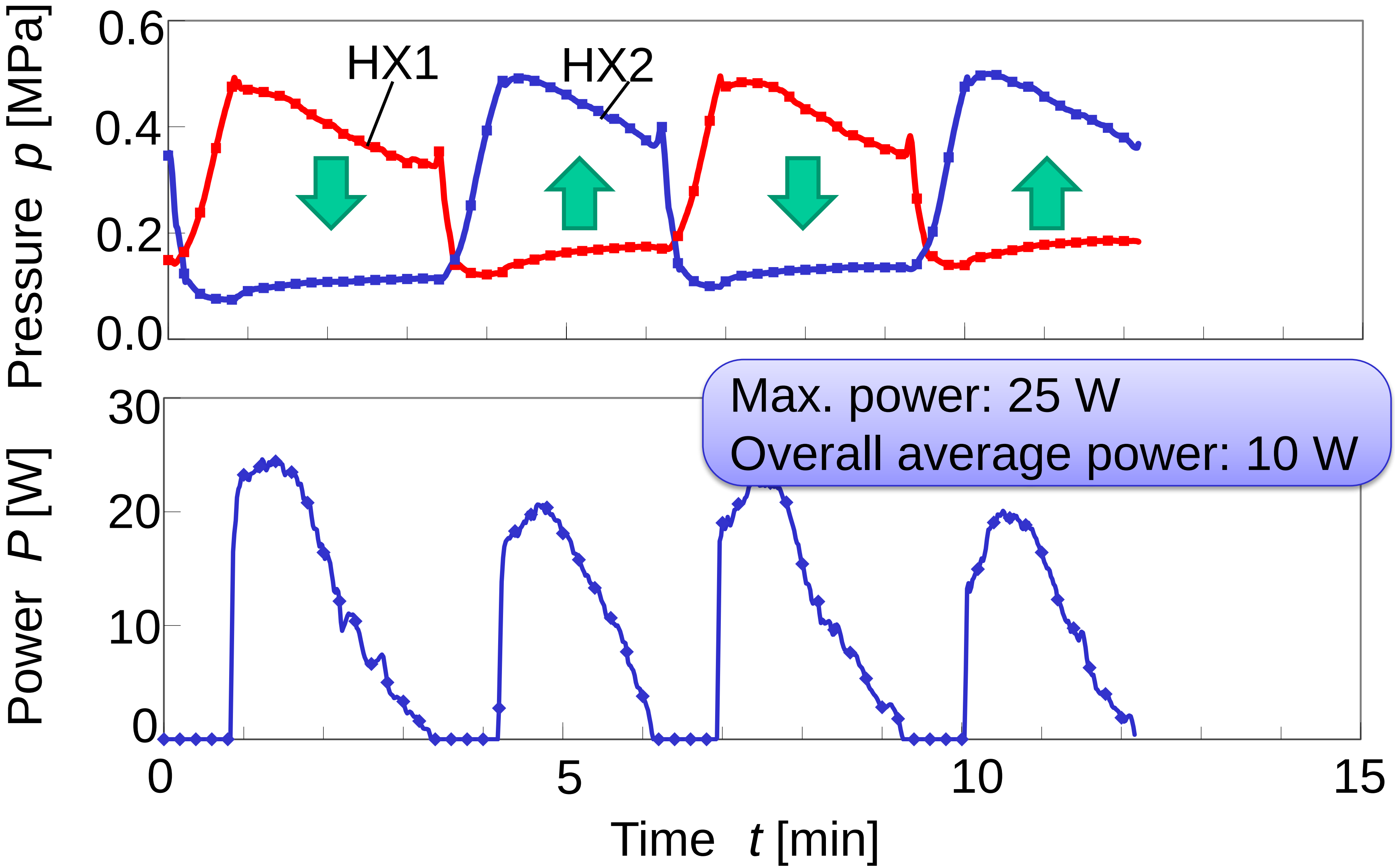
Valve-open pressure

Evaporator: 0.5MPa
Condenser: 0.1MPa

WF: 1kg

Result

Pressure & power VS Time



Expander isentropic efficiency

Actual power

$$P = T\omega$$

Average 10 W

$\div$

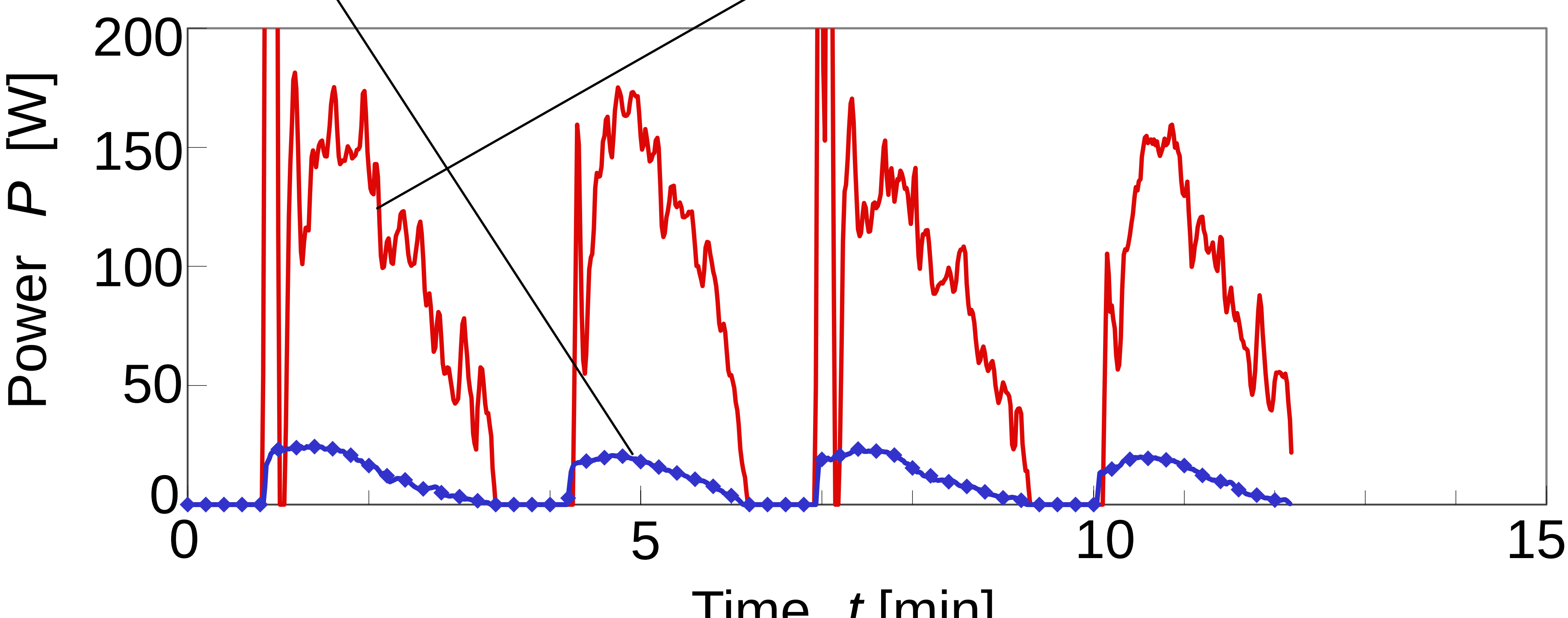
Isentropic power

$$P = \dot{m}(h_{in} - h_{out\_isentropic})$$

Average 89 W

(small due to friction loss. It can be improved)

$=$ 11%



Estimated efficiency

Excluding valves electricity!

External thermal efficiency

$$\eta_{\mathrm{ex}} = \frac{\text{overall average power } P_{\mathrm{Ave}}}{\text{the heat hot source released } Q_{\mathrm{ex}}} = 0.4\% \quad (\text{isentropic } 3.6\%)$$

Internal thermal efficiency

$$\eta_{\mathrm{in}} = \frac{P_{\mathrm{Ave}}}{\text{the heat working fluid received } Q_{\mathrm{in}}} = 1.1\% \quad (\text{isentropic } 10\%)$$

Heat exchanger efficiency

$$\eta_{\mathrm{HX}} = \frac{Q_{\mathrm{in}}}{Q_{\mathrm{ex}}} = \frac{0.9\mathrm{kW}}{2.5\mathrm{kW}} = 36\%$$

Heat loss for warming and cooling HX material
~ 1 kW

Conclusions

- Pumpless cycle worked with actual expander under 90°C/20°C (Max. power: 25W, Average: 10W)
- Advantages:
  - Free from pump problems!
- Disadvantages:
  - Low heat exchanger efficiency
  - Non-continuous power output

Thank you!