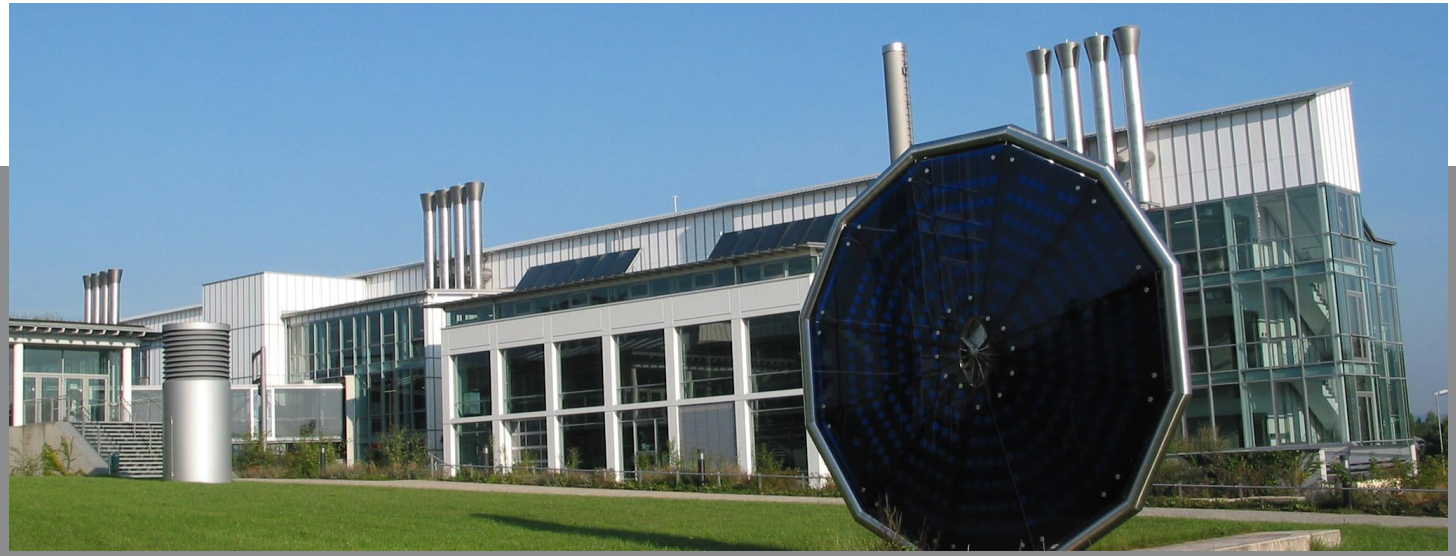

Simultaneous investigation of boiling heat transfer and power output in ORC

4th International Seminar on ORC Power Systems, 13-15 Sep. 2017, Milano

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UNIVERSITÄT BAYREUTH

LEHRSTUHL FÜR TECHNISCHE THERMODYNAMIK UND TRANSPORTPROZESSE
PROF. DR.-ING. D. BRÜGGEMANN

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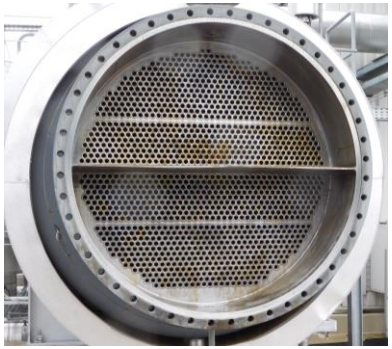
Working fluids

ORC geothermal binary power plants

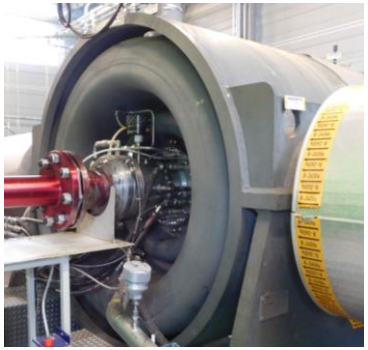
Shell-and-tube evaporator



HC: ⊖ Flammability

HFC: ⊖ GWP

ORC turbine



α_{nb}

Working fluids

P_{el}

Replacements? → **Simultaneous experimental investigation of nucleate boiling heat transfer and power output**

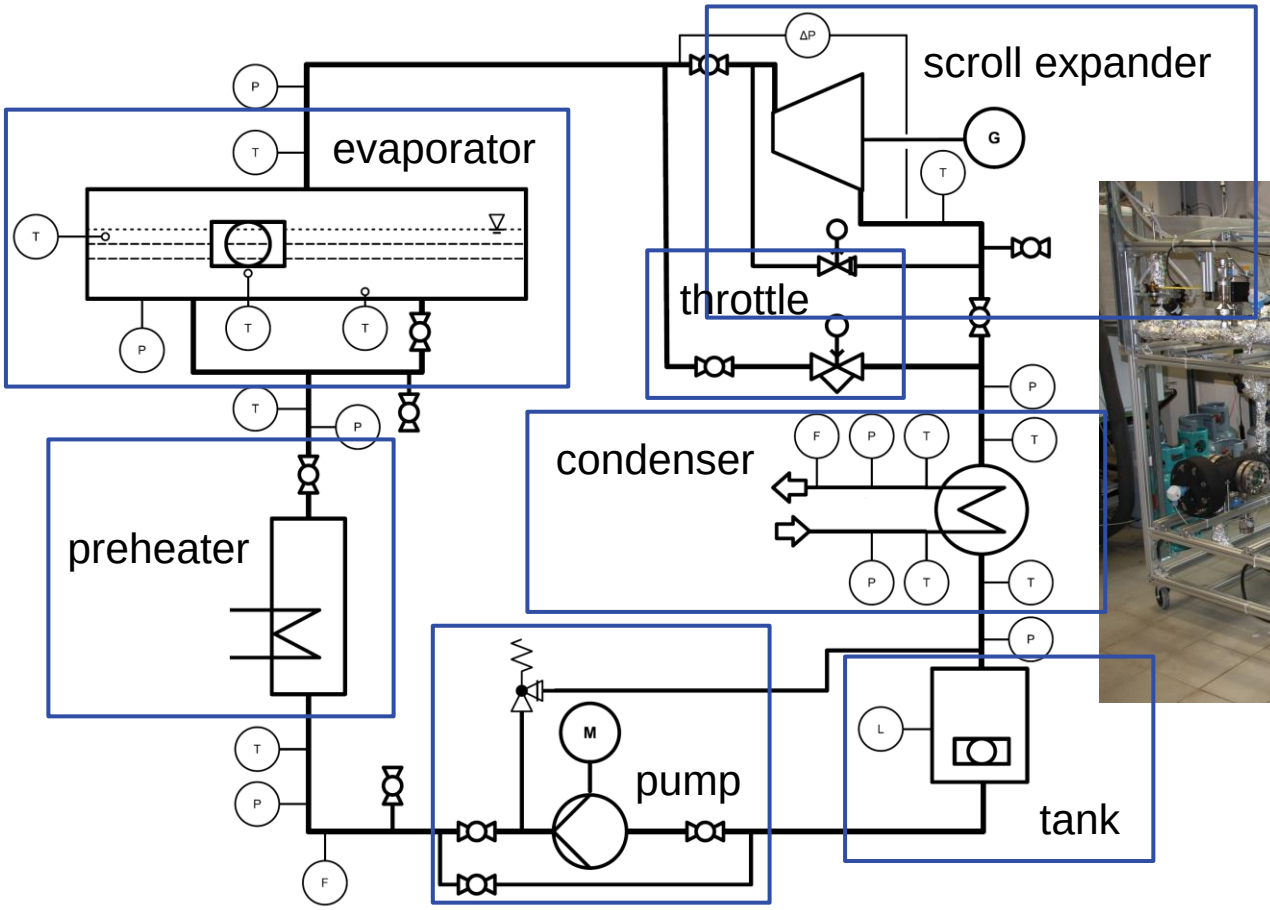
Working fluids

Low GWP replacement

	R245fa	R1233zd(E)
• Refrigerant group	HFC	HCFO
• GWP	1030	5
• Safety classification	B1	A1
• Sat. pressure (T_{sat} = 100 °C)	12.6 bar	10.4 bar
• Vapour density (T_{sat} = 100 °C)	72.8 kg/m³	56.3 kg/m³

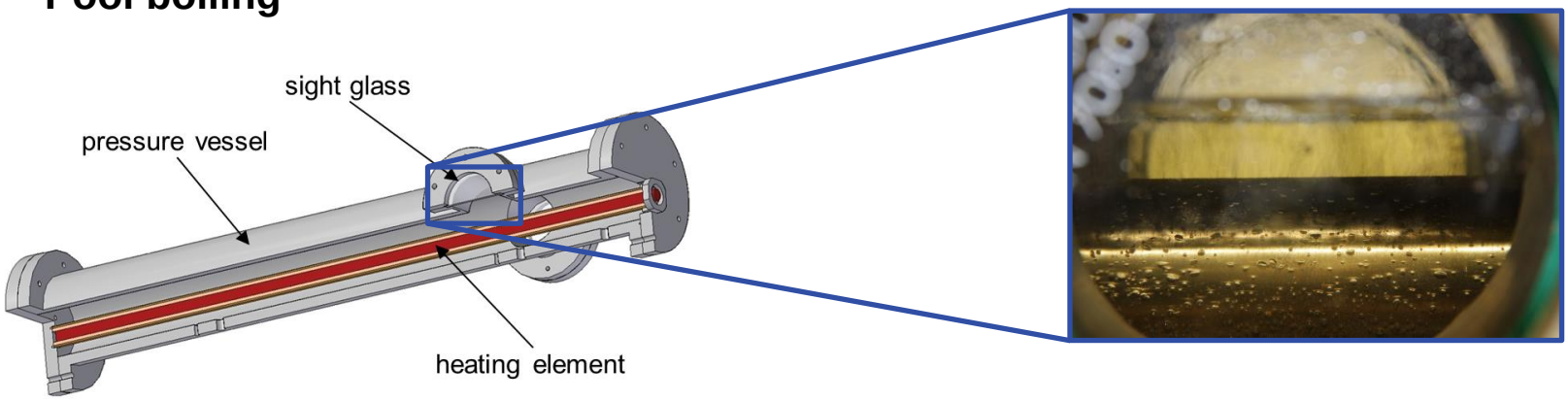
ORC test rig

Flowsheet

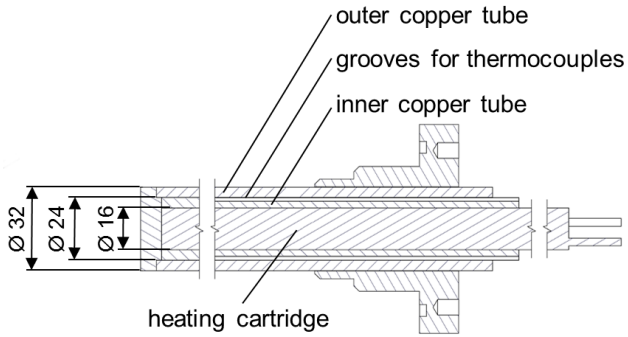


ORC test rig
Evaporator

Pool boiling



Heating element



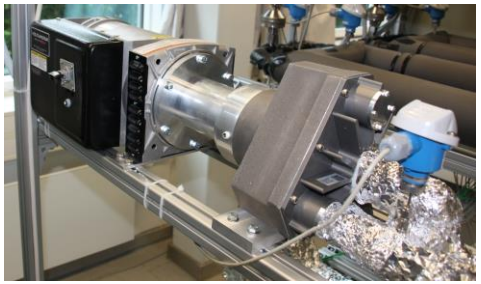
Calculation of nucleate pool boiling HTC

$$\alpha_{\mathrm{nb}} = \frac{q}{T_{\mathrm{w}} - T_{\mathrm{sat}}}$$

$$T_{\mathrm{w}} = T_{\mathrm{i}} - \frac{q D_{\mathrm{o}} \ln(D_{\mathrm{o}}/D_{\mathrm{i}})}{2\lambda_{\mathrm{t}}}$$

ORC test rig

Scroll expander and generator

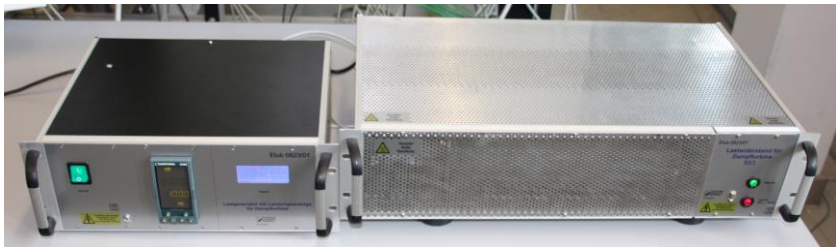


Scroll expander

- Manufacturer: Air Squared
- Nominal power: 1 kW
- Max. speed: 3600 1/min
- Volume ratio: 3.5

Generator

- Manufacturer: Voltmaster
- Type: Self-excited AC
- Nominal power: 2.4 kW
- Nominal speed: 3000 1/min



Variable electronic load

- Type: Phase angle control
- Nominal power: 1.5 kW
- Frequency range: 45 … 55 Hz

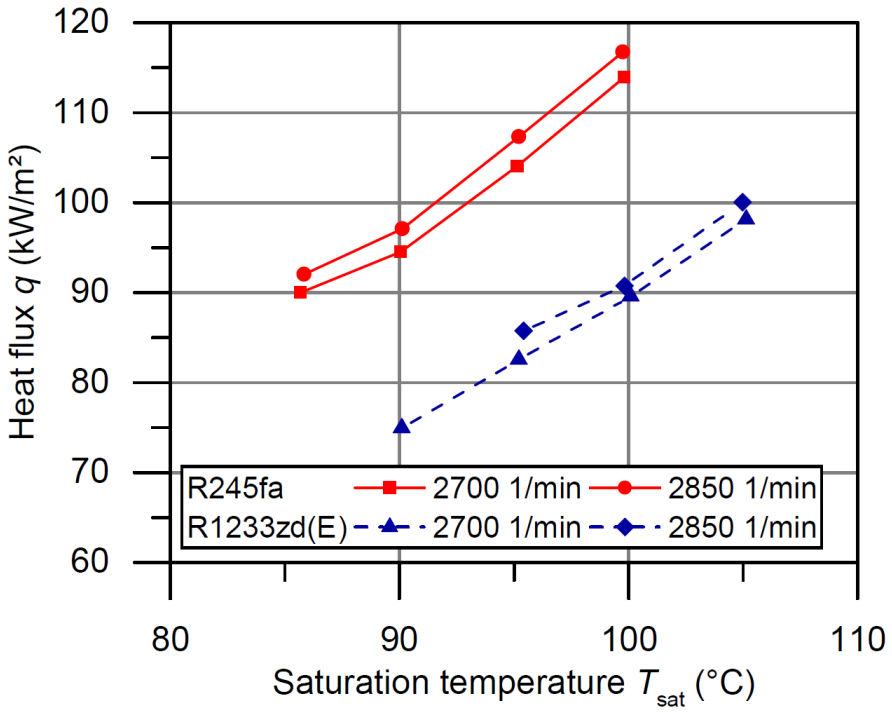
ORC test rig

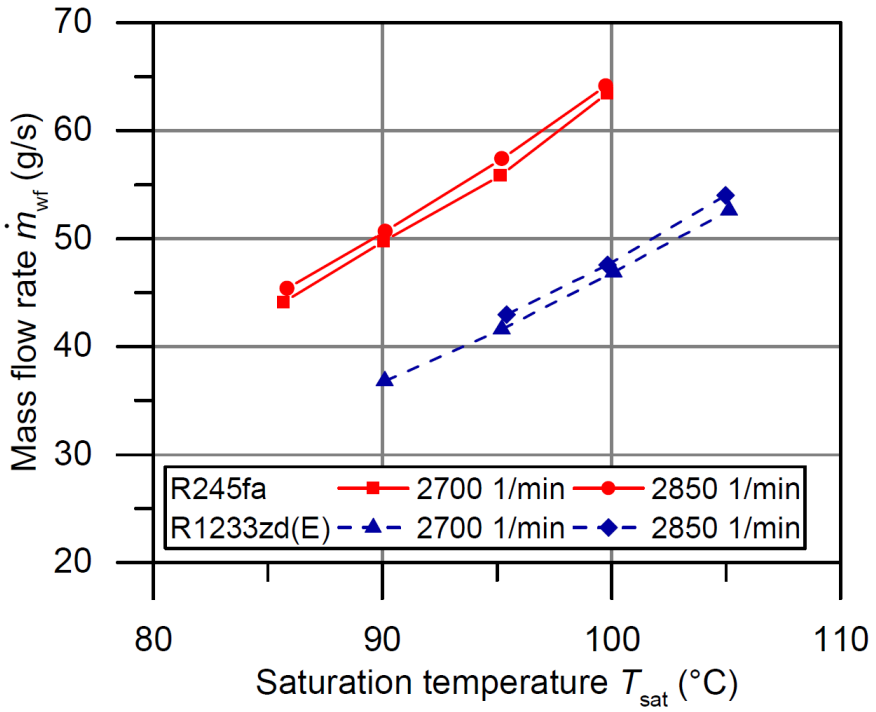
Operating parameters

	$\dot{Q}_{evap}$ (kW)	n_{scroll} (1/min)	T_{sat} (°C)
Equal saturation temperatures → Optimization of applications with limited heat source temperatures	variable	2700 2850	85 90 … 105
Equal rotational speeds → Comparison at equal heat fluxes and similar mass flow rates	8.7	2700 2850 3000	variable
Scroll expander at idle operation → Evaluation of thermal and generator losses	7.8 8.7 9.6	variable	variable

Heat Transfer and Power Output

Equal saturation temperatures

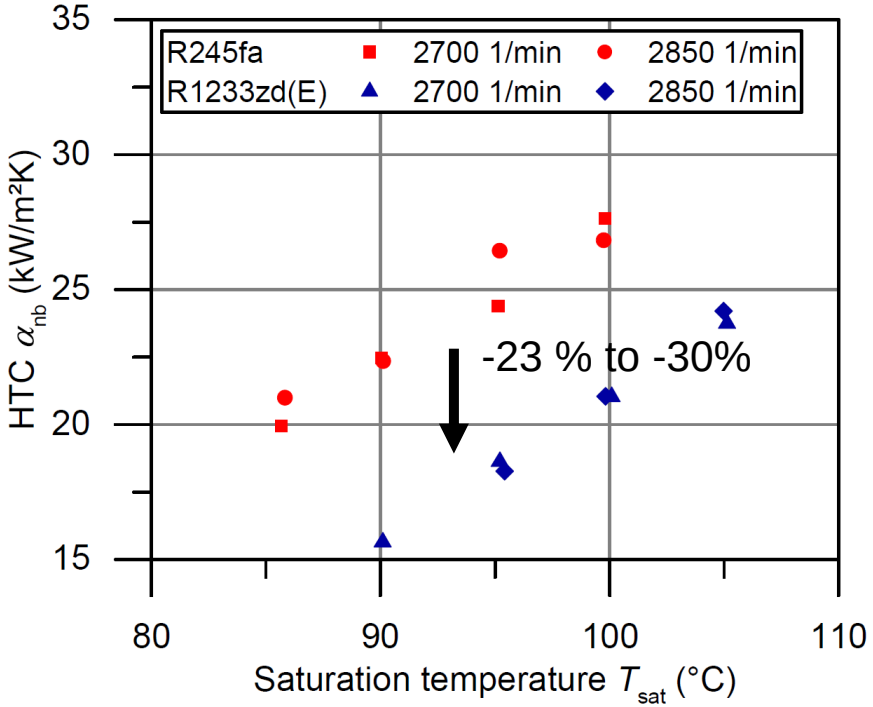


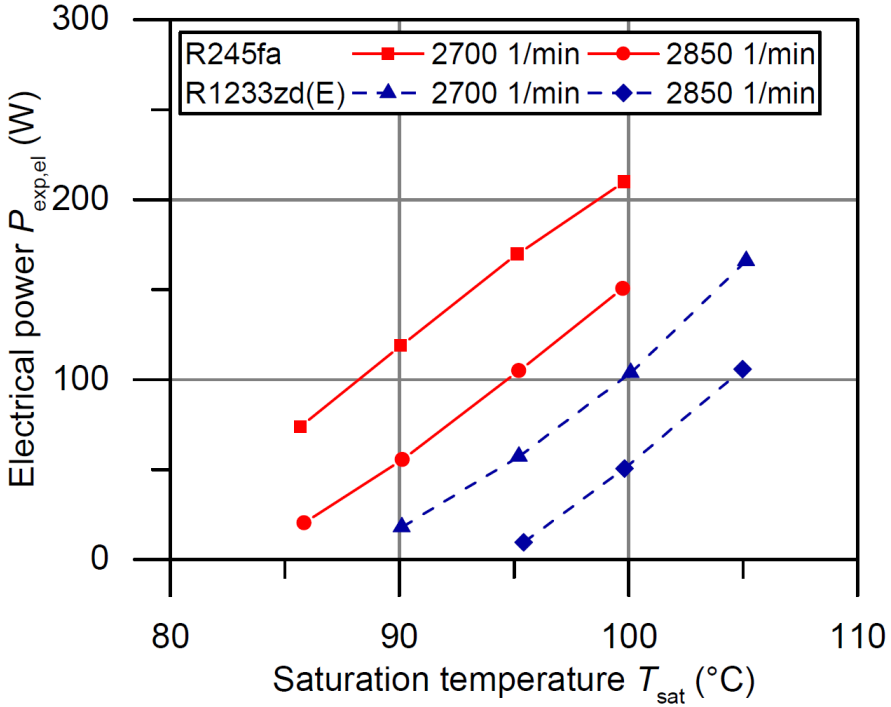


- R1233zd(E): Heat flux and mass flow rate lower
- Influence of rotational speed low

Heat Transfer and Power Output

Equal saturation temperatures



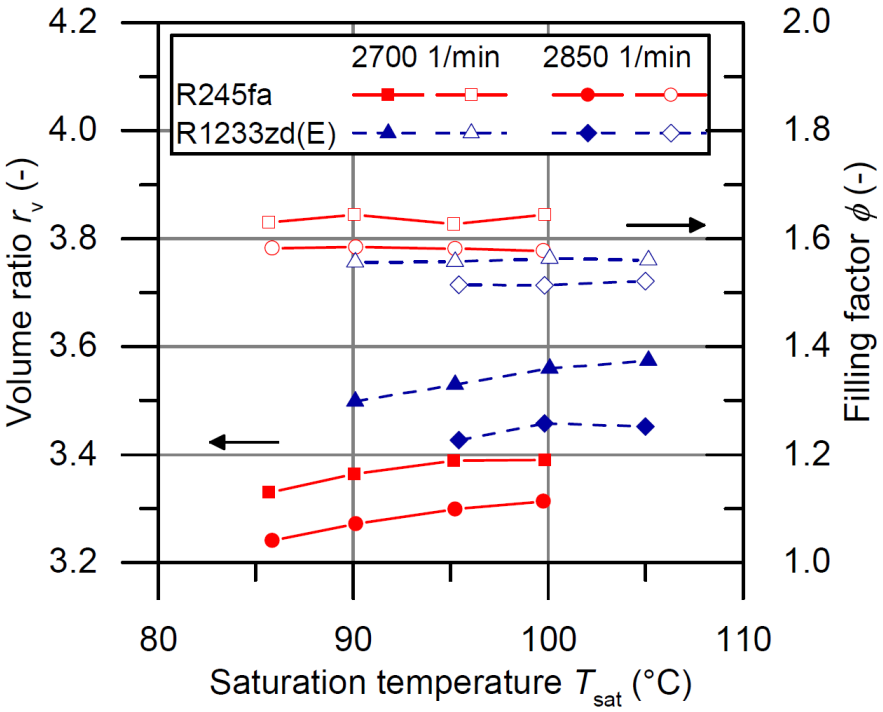


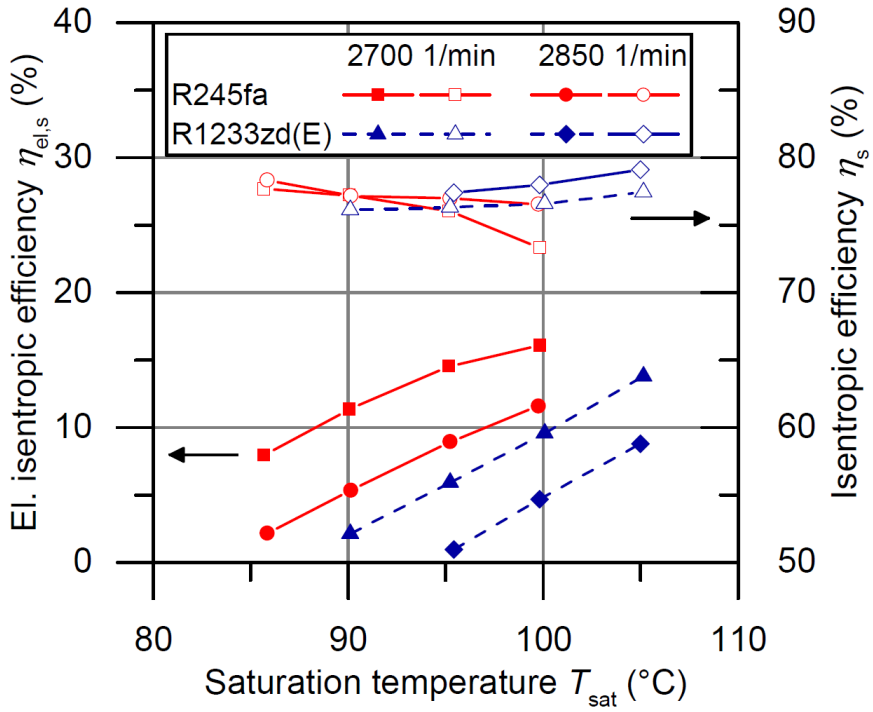
→ R1233zd(E): Lower HTC due to lower pressure and heat flux

→ R1233zd(E): Lower power due to lower thermal input power and mass flow rate

Heat Transfer and Power Output

Equal saturation temperatures



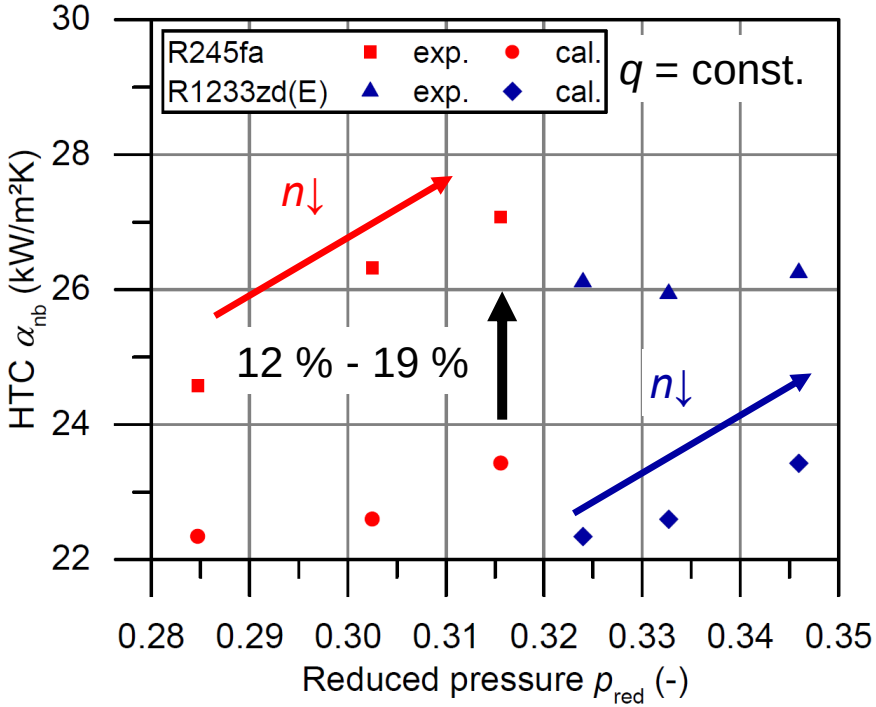


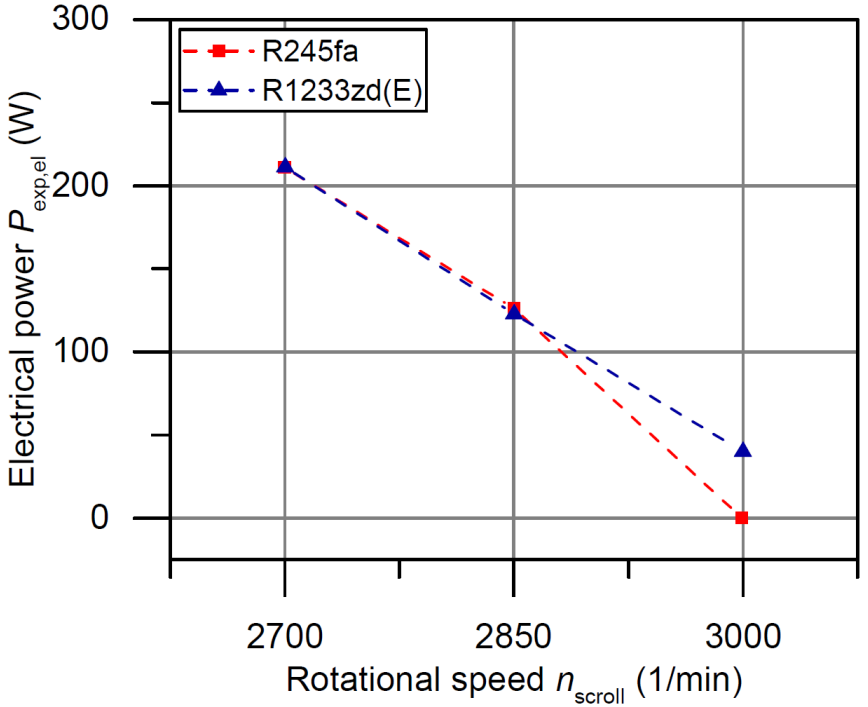
R1233zd(E): Lower filling factor causes lower volume flow rate and higher volume ratio

Low electrical isentropic efficiency indicates poor generator efficiency

Heat Transfer and Power Output

Equal rotational speeds



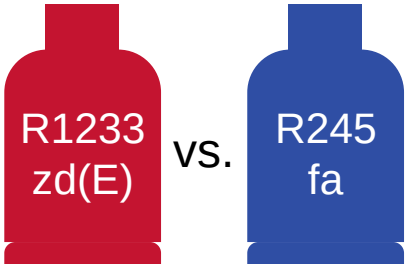


→ R245fa ≈ R1233zd(E): Reduced pressure "compensates" effect of thermophysical properties

→ Decreasing electrical power due to lower thermal input power and higher internal consumption of generator

R1233zd(E) vs. R245fa

Summary



+ R1233zd(E)

- GWP ▼ 99.6 %
- Filling factor ▼ 5 %
- Volume ratio ▲ 6 %

+ R245fa

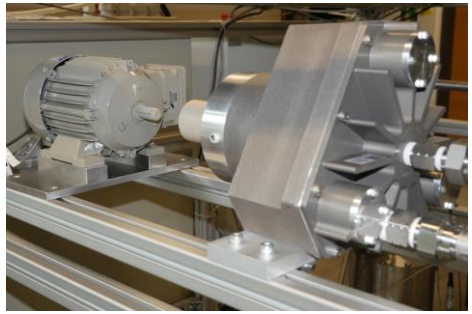
- HTC ▼ 30 %
- Power output ▼ 100 W

Isentropic efficiency ►

Further work and acknowledgments

Further work

- Comparison of measured HTC to common pool boiling correlations
- Scroll expander
  - High efficiency generator
  - Torque measurement
- Evaporator
  - Stainless steel tube
  - Bundle evaporator



Acknowledgments

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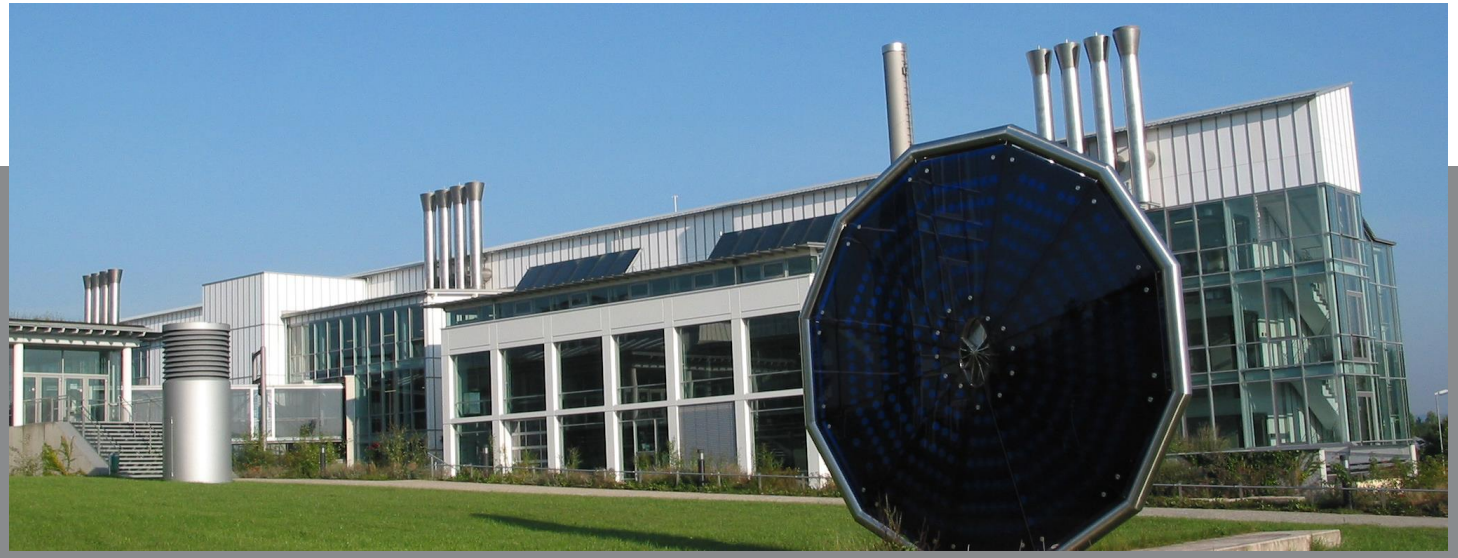

Thank you

www.zet.uni-bayreuth.de

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Heat Transfer and Power Output

Idle operation