EVALUATION OF AN ORC-BASED MICRO-CHP SYSTEM INVOLVING A HERMETIC SCROLL EXPANDER

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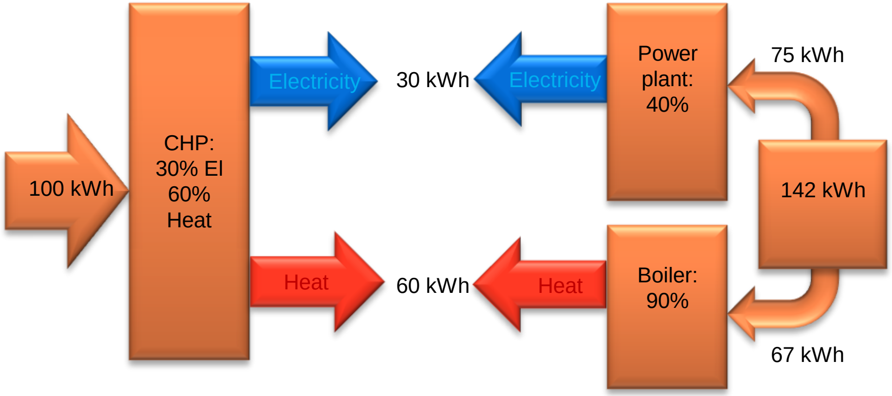
Micro Combined heat and power

✓ CHP: Produced electricity and useful heat



$$PES = \frac{142 - 100}{142} = 30\%$$

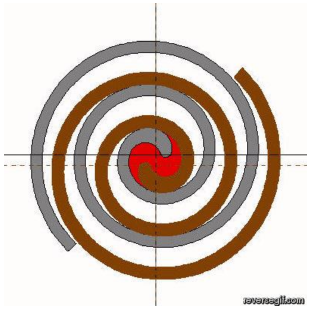
✓ Micro CHP: <50kW Electric

Technologies

	ICE	Micro-Turbine	Stirling	ORC	Fuel cell
Electrical power	5kWe-20MWe	15kWe-300kWe	1kWe-1.5MWe	1kWe-10MWe	1kWe-1MWe
Electrical efficency	**25-45%**	15-30%	10-20%	~10%	**30-70%**
Global efficiency	65-92%	65-90%	65-95%	~90%	90%
Fuel	Gasoline, Diesel, Gas,…	Gas, Biogas,…	**Flexible**	**Flexible**	Hydrogen or Hydrogen-rich gas
State	**Widespread**	Uncommon	Development, early market	Development, early market	Proven technology
Manufacturer exemple	Senertec	Capstone	Sunmachine	Otag	Hexis

Scroll expander

✓ Volumetric engine:



✓ Not avalable yet: Conversion of a compressor

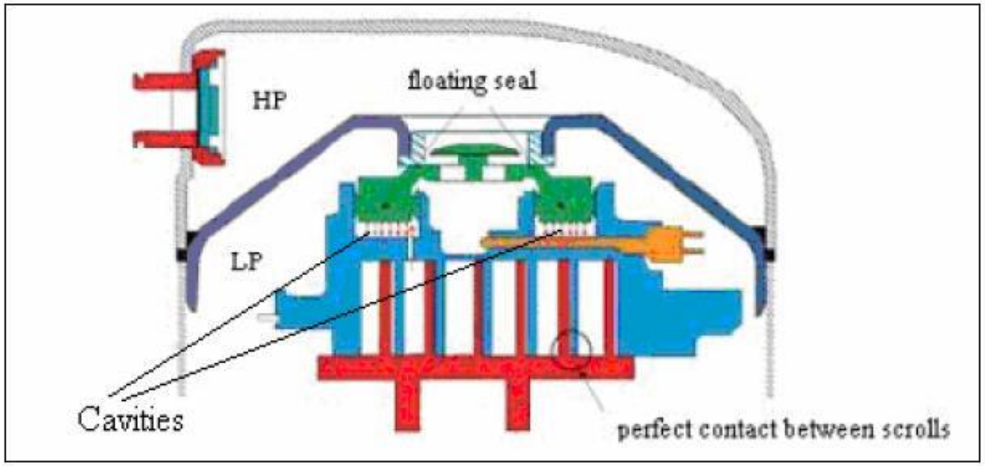
✓ Advantages :

- No check valve
- Reduced number of moving part
- Low rotational speed
- Handle high pressure ratio

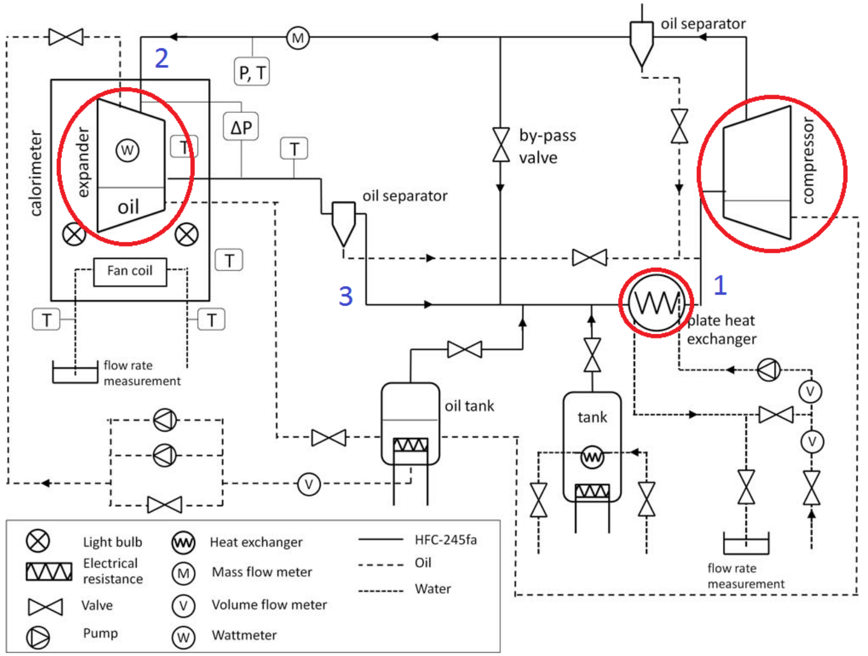
Modification of the compressor

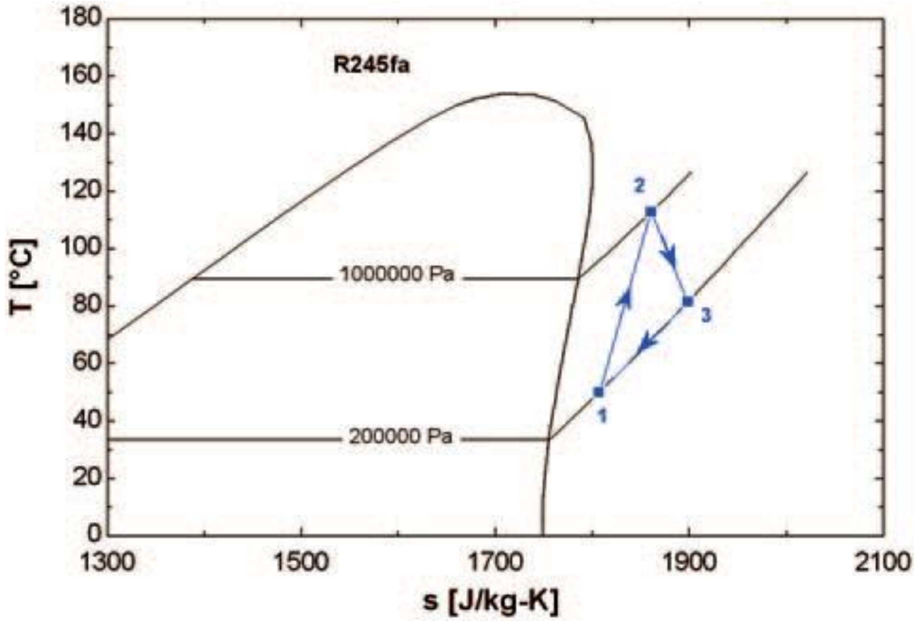
✓ Discharge and reed valve

✓ Floating seal



“Gas cycle” test rig

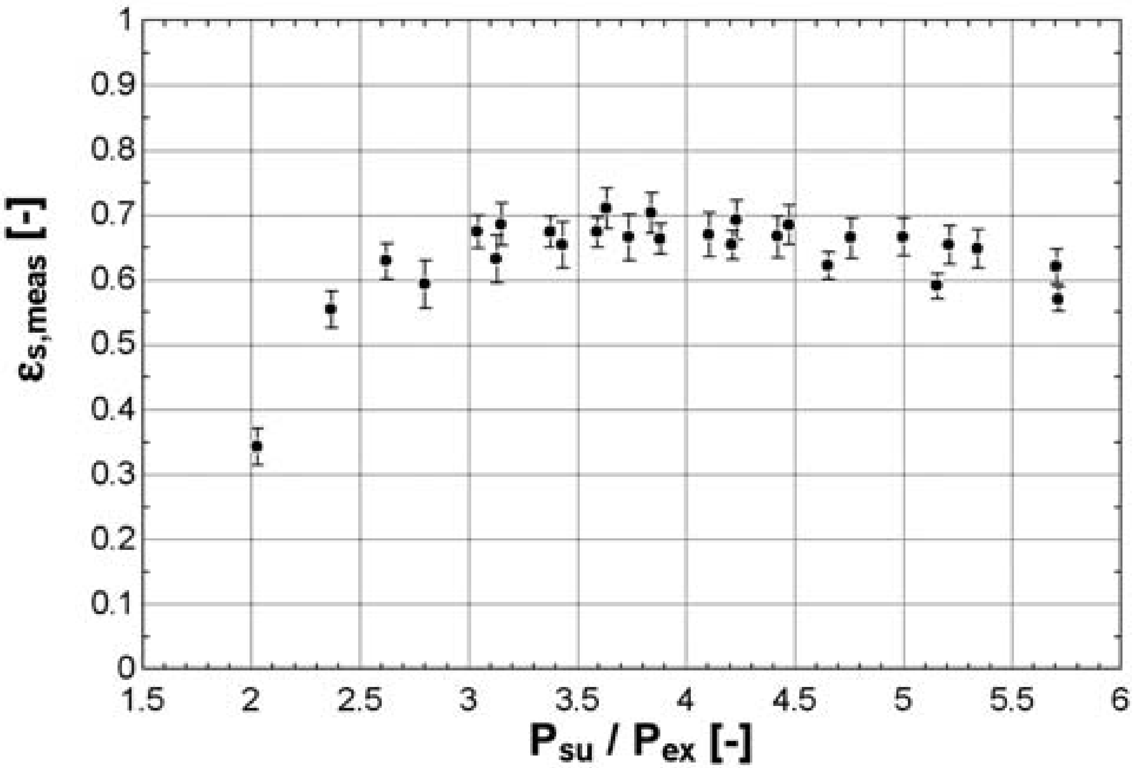




Results analysis

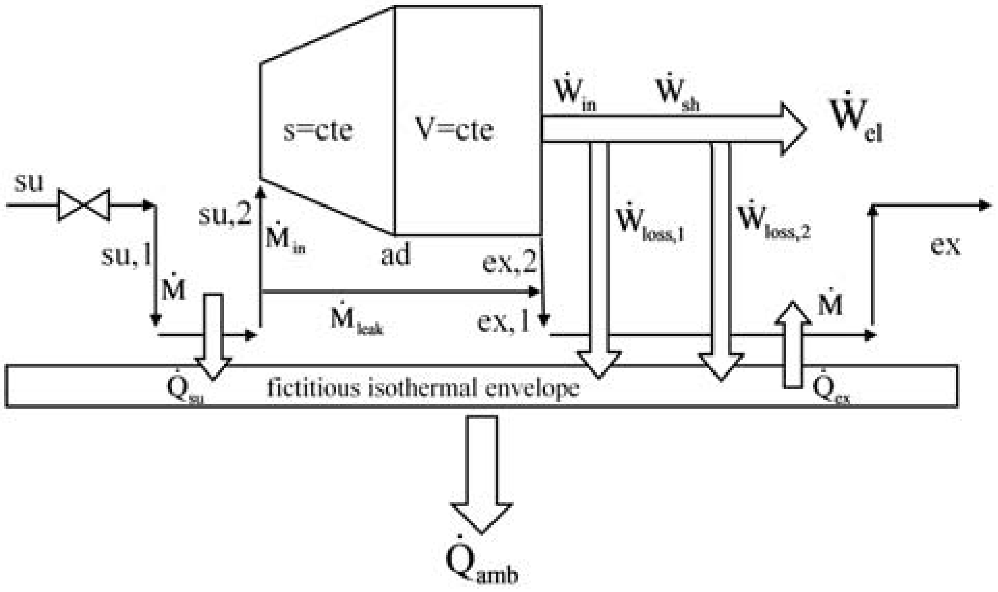
✓Maximum electrical isentropic efficiency: 71%

$$\epsilon_{s,meas} = \frac{\dot{W}_{el,meas}}{\dot{M}_{meas}.(h_{su} - h_{ex,s})}$$



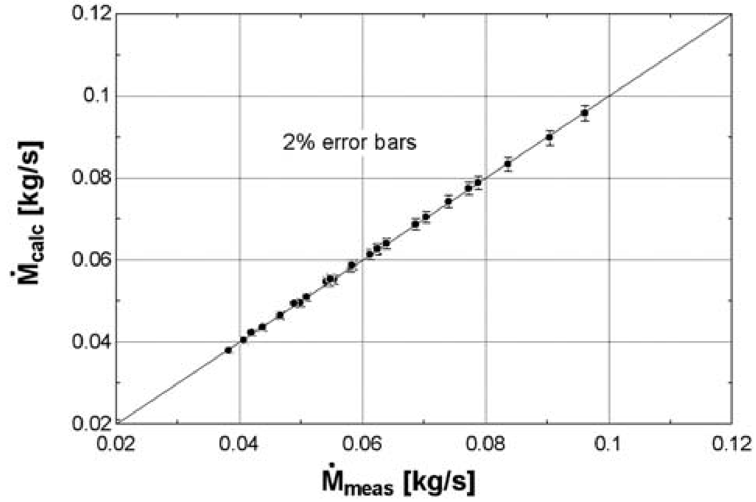
Expander model

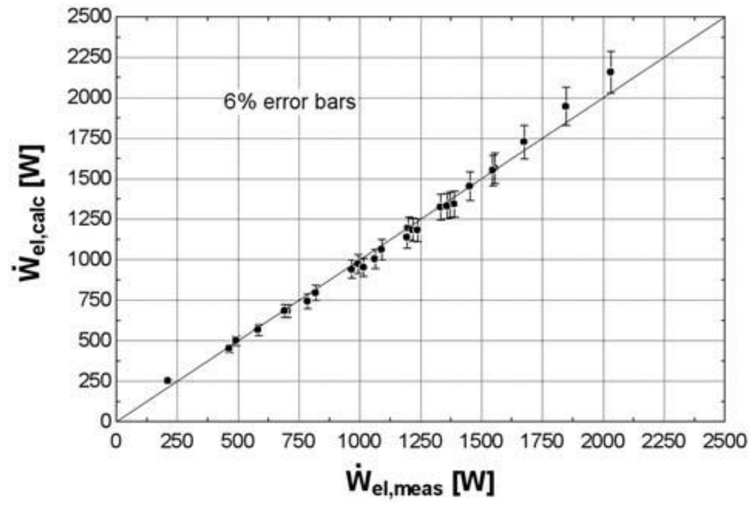
- ✓ Supply pressure drop
- ✓ Supply cooling down
- ✓ Isentropic expansion
- ✓ Isochoric expansion
- ✓ Internal leakage
- ✓ Exhaust heat exchange
- ✓ Mechanical losses
- ✓ Electromechanical losses
- ✓ Ambient losses
- ✓ Isothermal fictitious wall

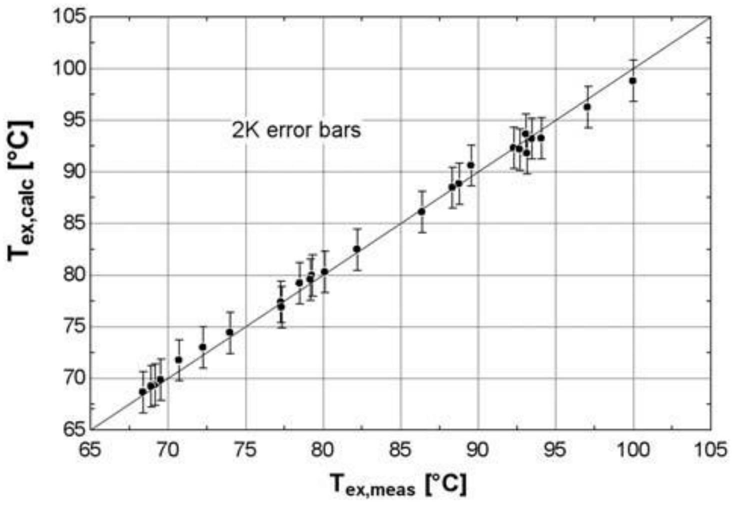


Validation of the model

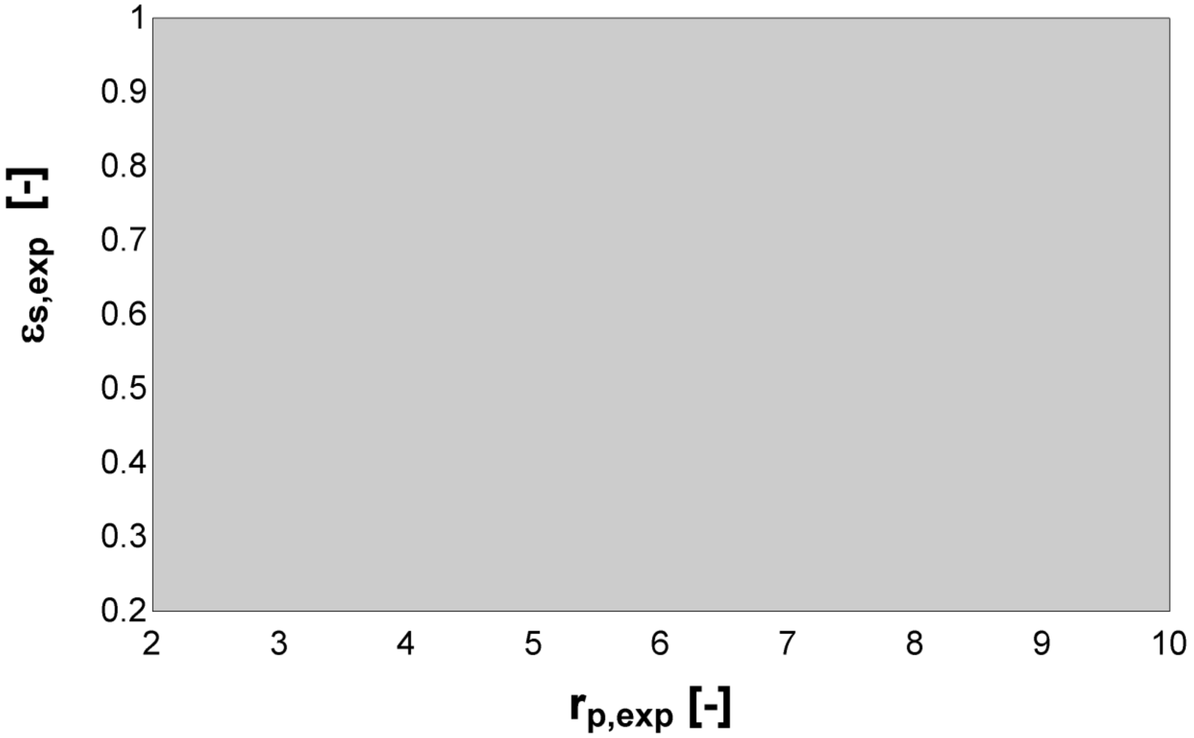
✓ Error max:
- Flow rate: 2%
- Power: 6%
- Exhaust T°: 2K







Simulation of losses



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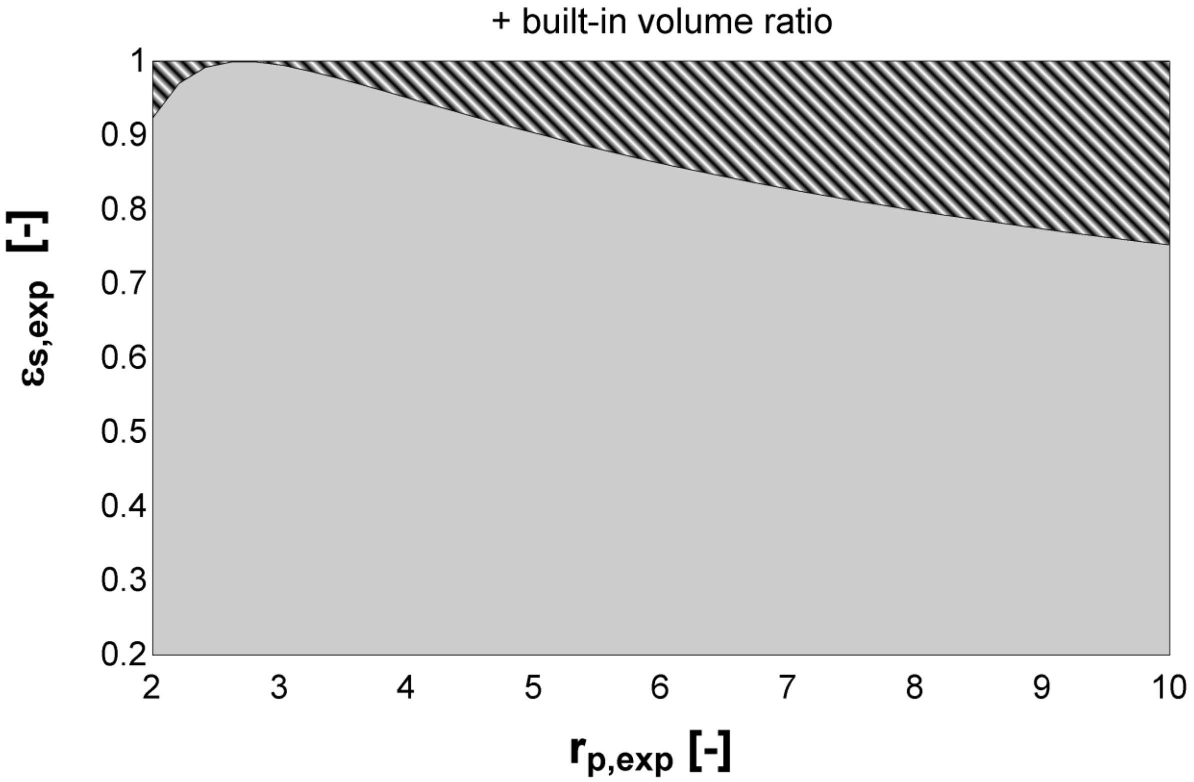

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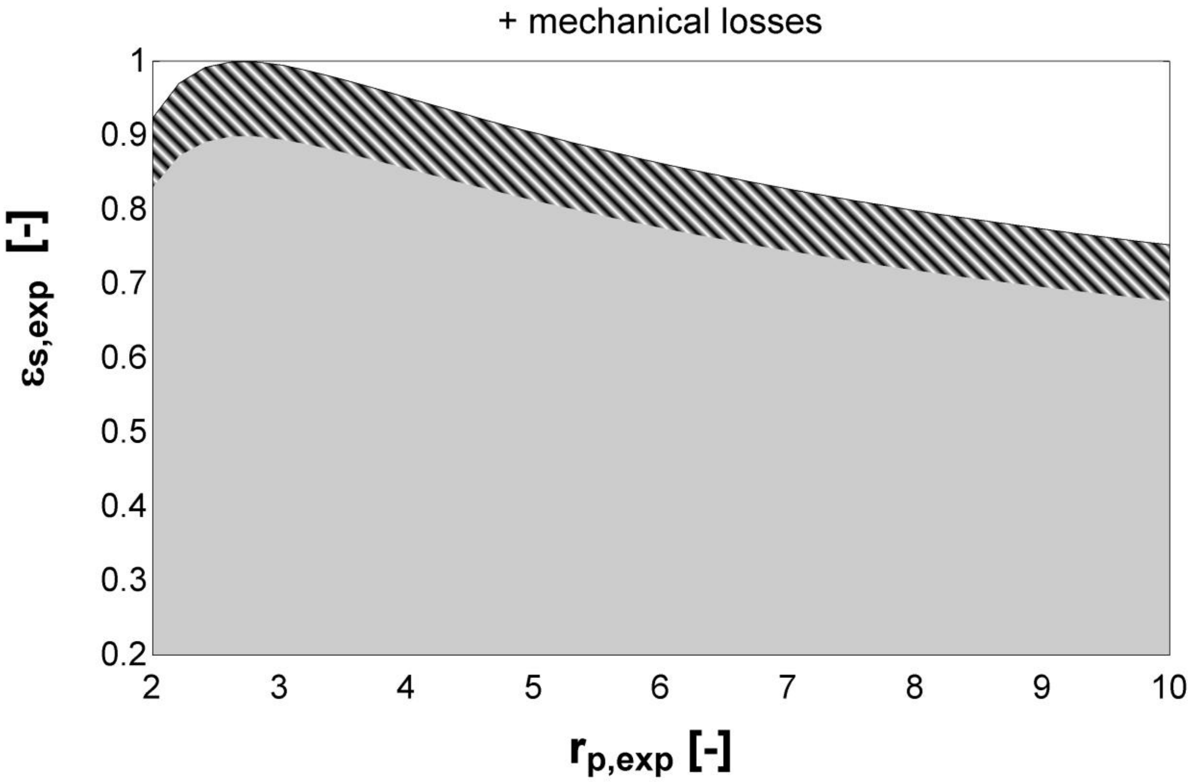

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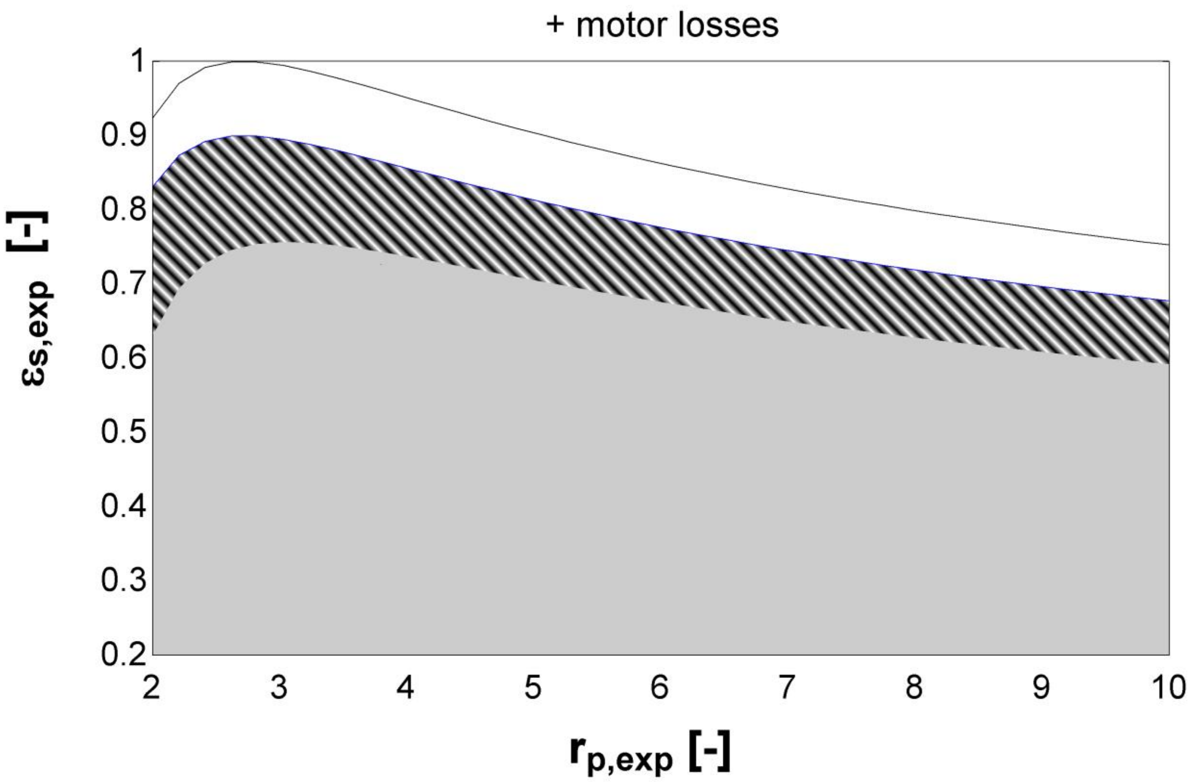

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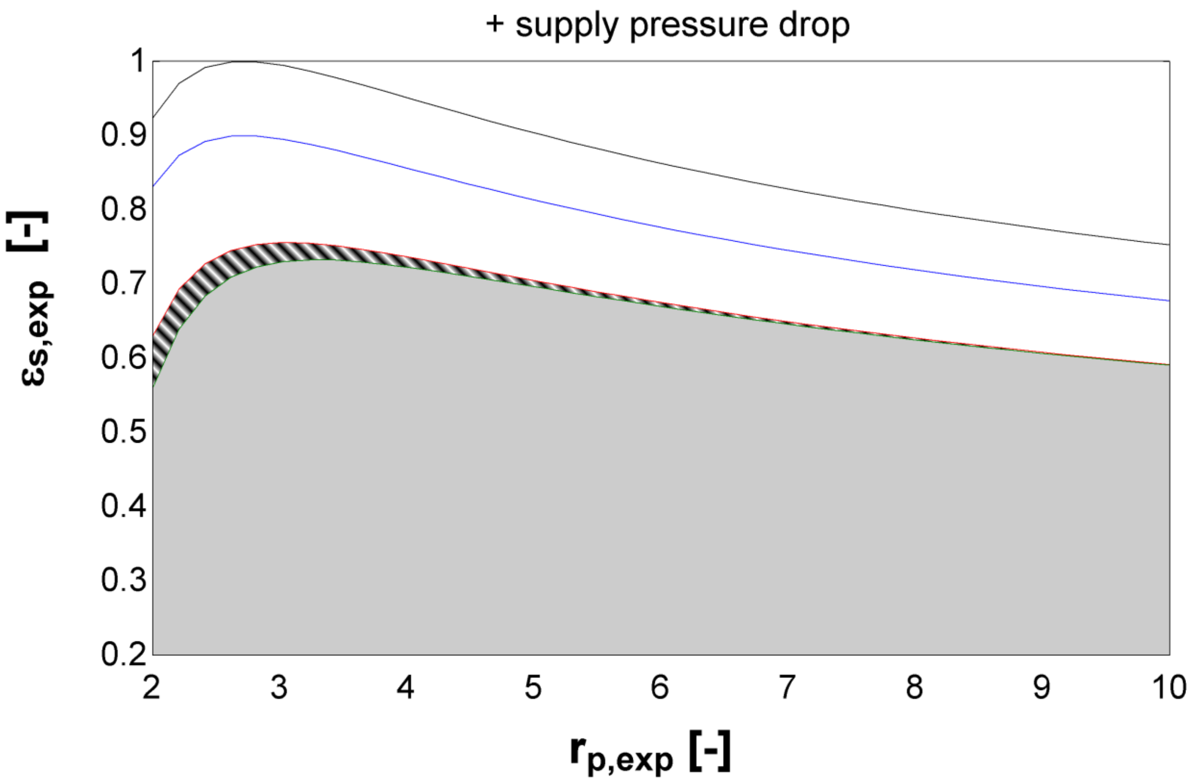

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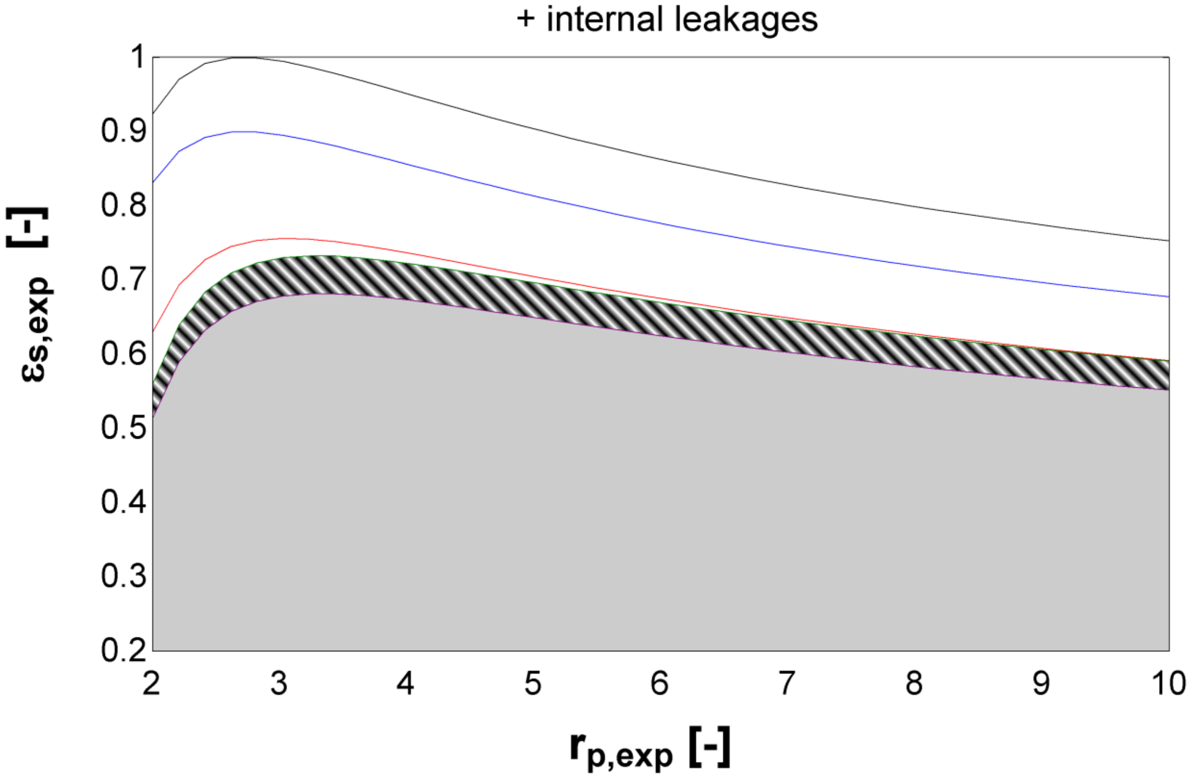

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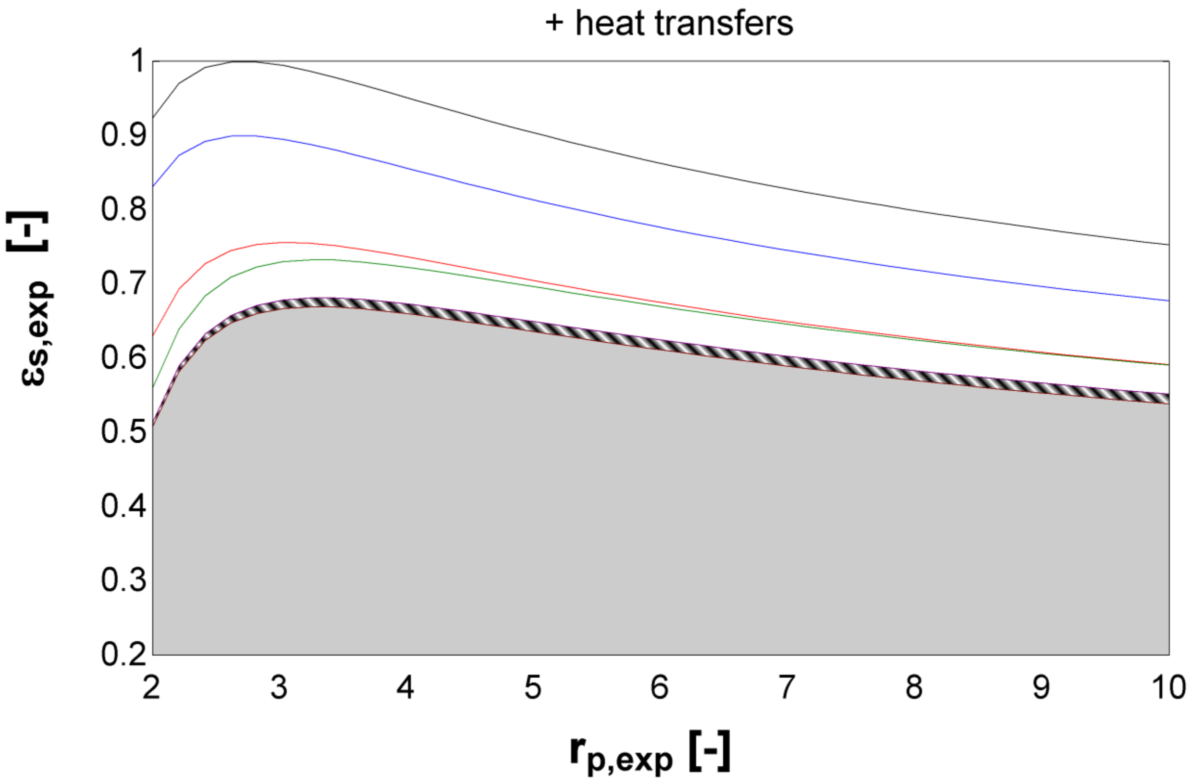
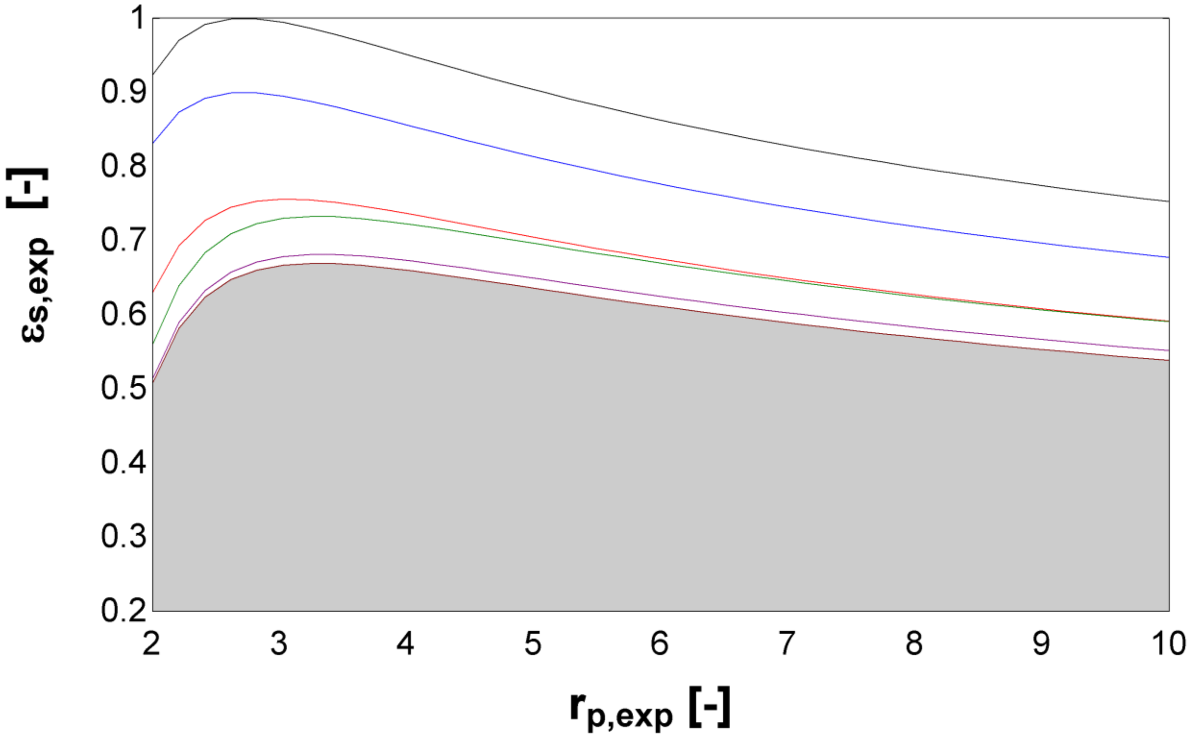


Simulation of losses



- ✓ Most significant: Intern volume ratio and electromechanical

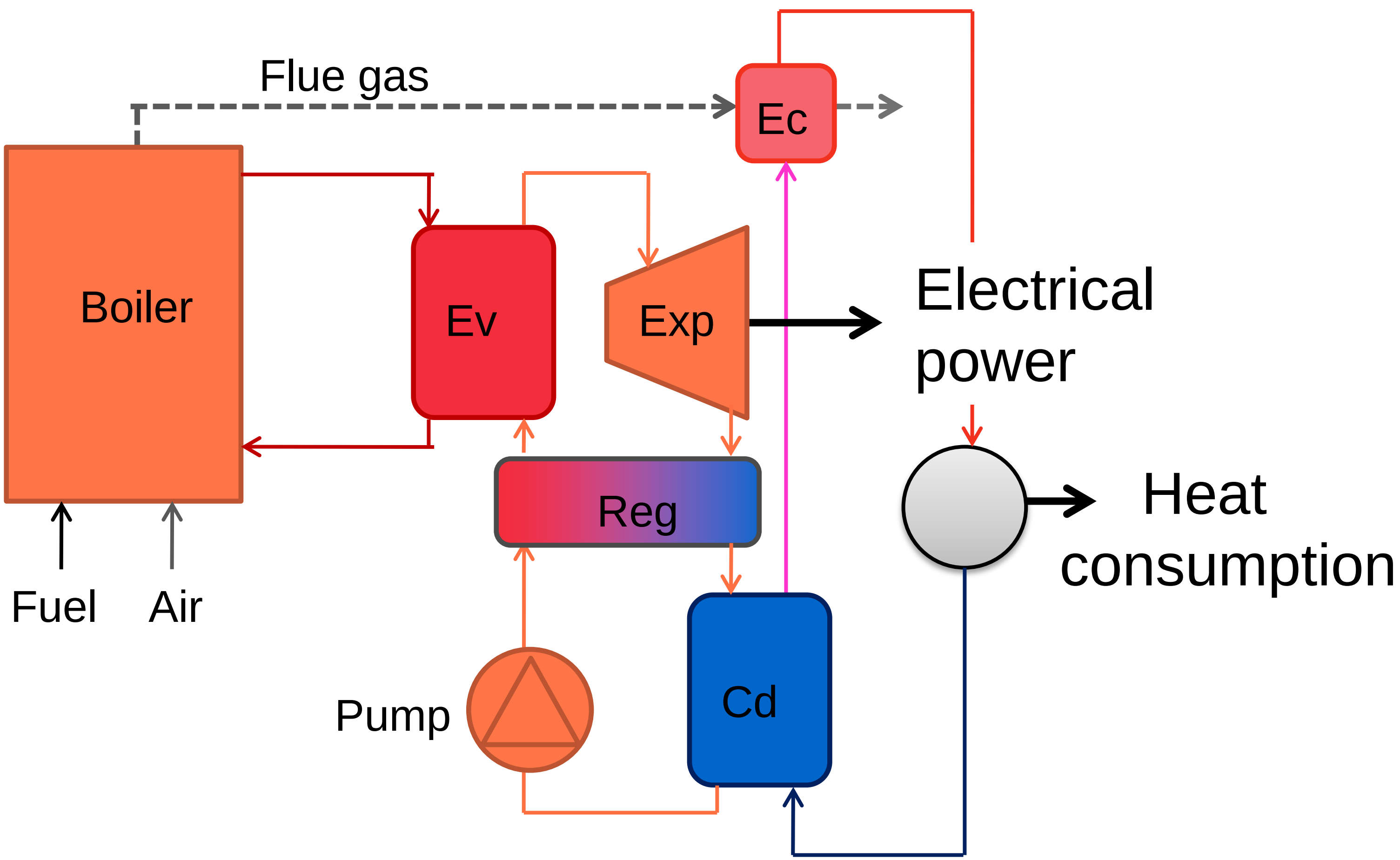
Dimensionless expander model

- ✓ Previous model: Dimensional parameters
- ✓ Dimensionless model: Polynomial law for isentropic efficiency and for filling factor

$$\epsilon = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} a_{ij} . \left(ln(r_p) \right)^i . (\ln (P_{su}))^j = f(r_p, P_{su})$$

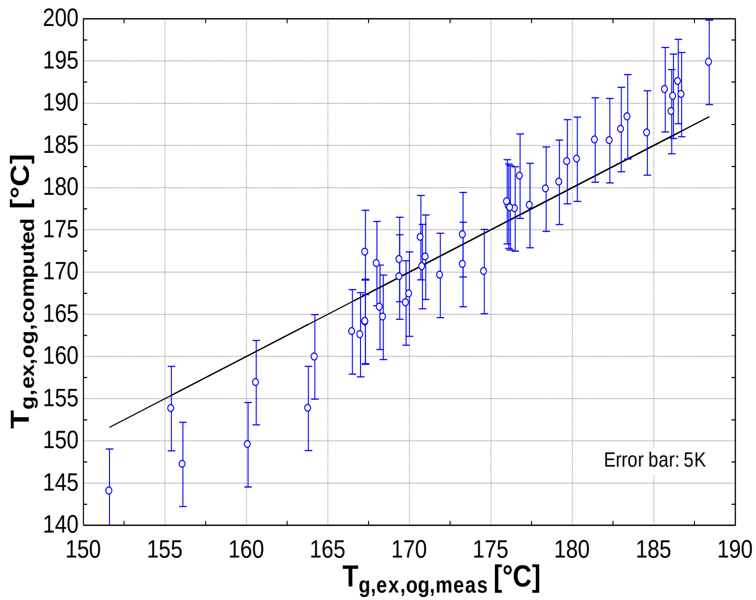
- ✓ Assumption: independent of the size

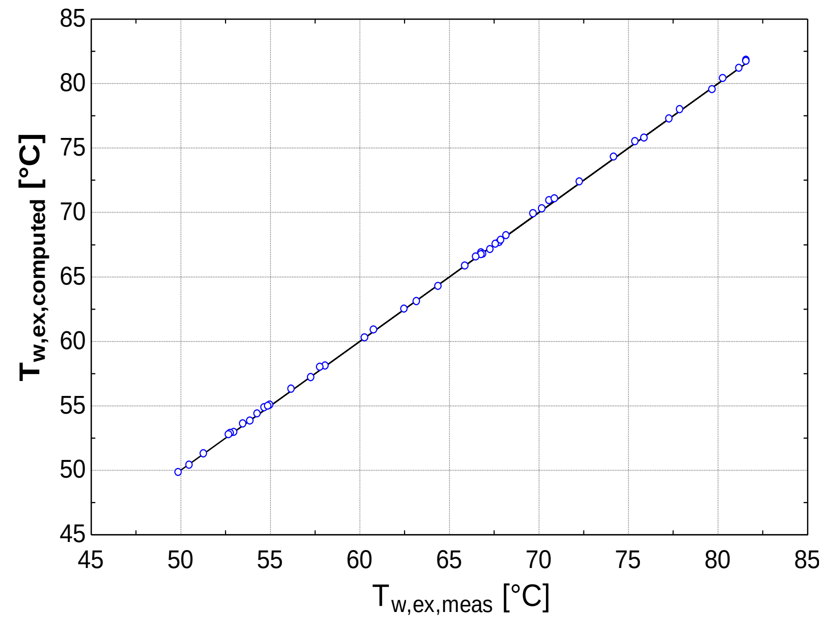
ORC-based mCHP



Boiler Model

- ✓ Adiabatic combustion chamber
- ✓ Heat exchanger gas/HTF
- ✓ Heat exchanger HTF/ambience



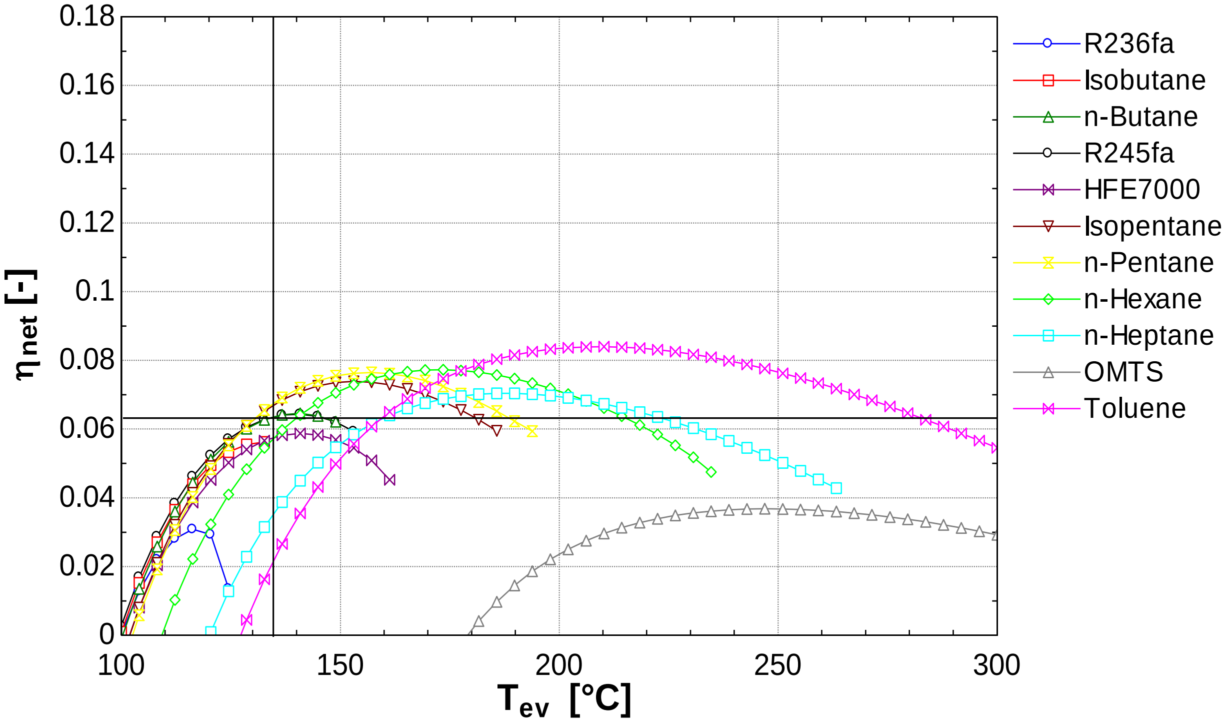


ORC model

- ✓ Components
  - Heat exchangers: ε-NTU method
  - Pump: Isentropic efficiency
  - Expander: Dimensionless model
- ✓ ORC model: Interconnection of the different components

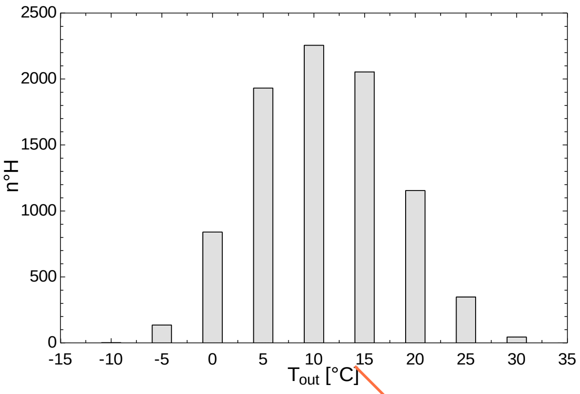
Fluid selection

- ✓ Maximum inlet temperature of the expander: 135 °C
- ✓ Best fluid: R245fa

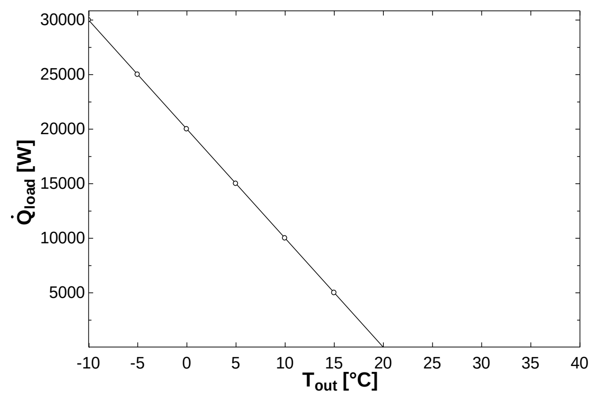


Seasonal simulation

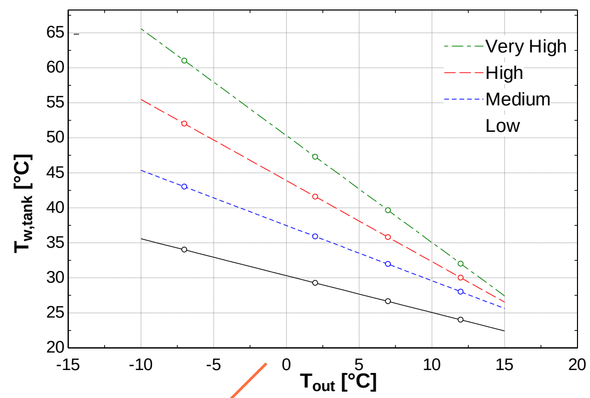
Average climate EN14825



Heat demand

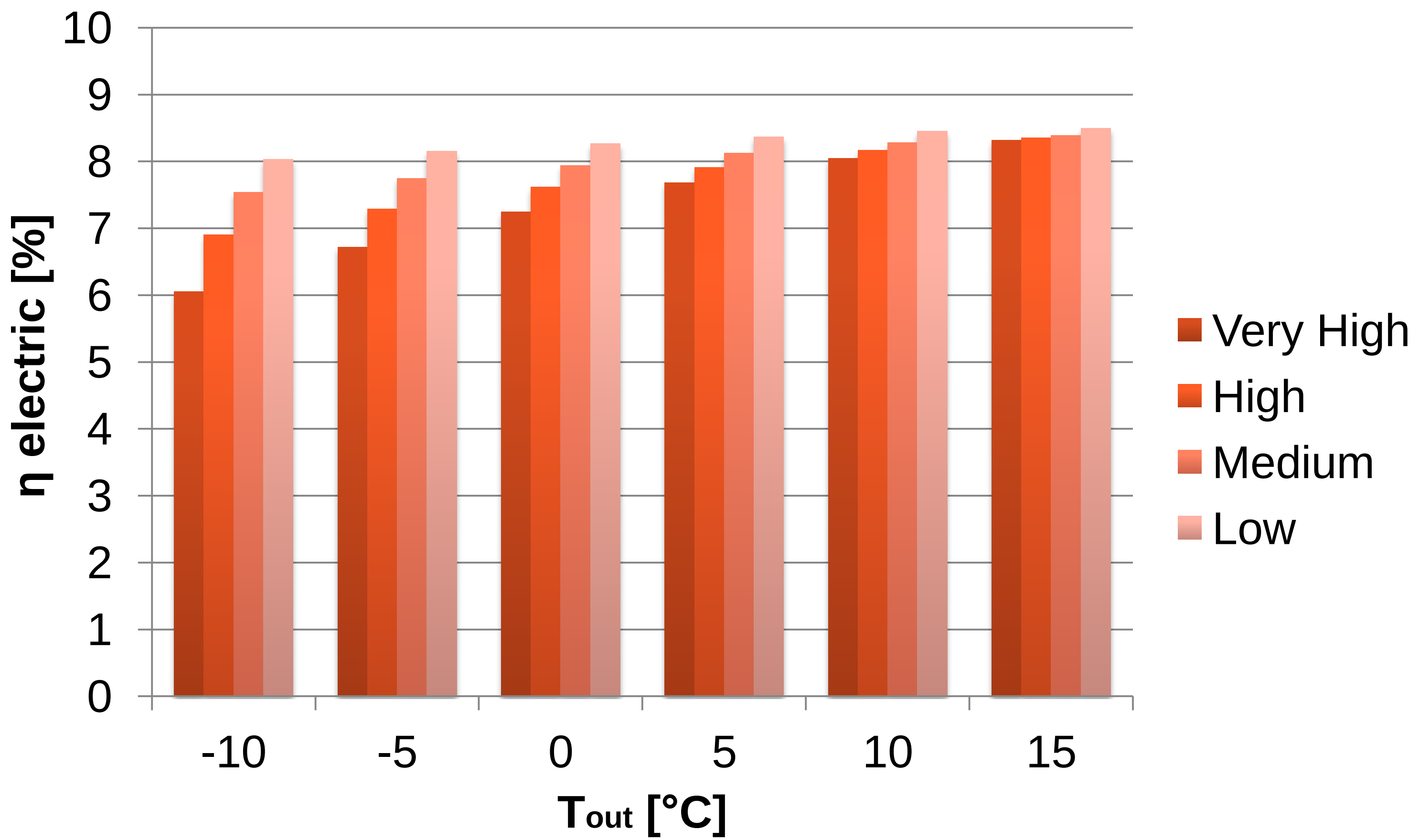


Temperature setting law EN14825



ORC based
m-CHP Model

Results: Electrical efficiency



Results: Annual efficiencies

- ✓ Annual electrical efficiencies:

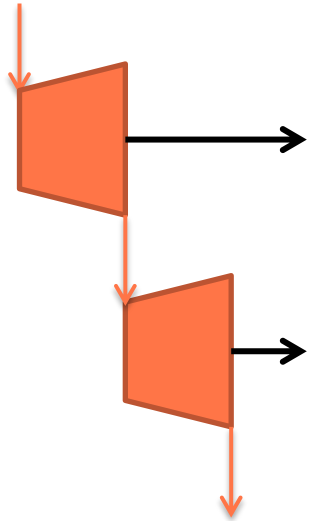
$$\eta_{el,g} = \frac{\sum(RunTime.\dot{W}_{net})}{(\sum RunTime).LHV_f.\dot{M}_f}.C_\eta$$

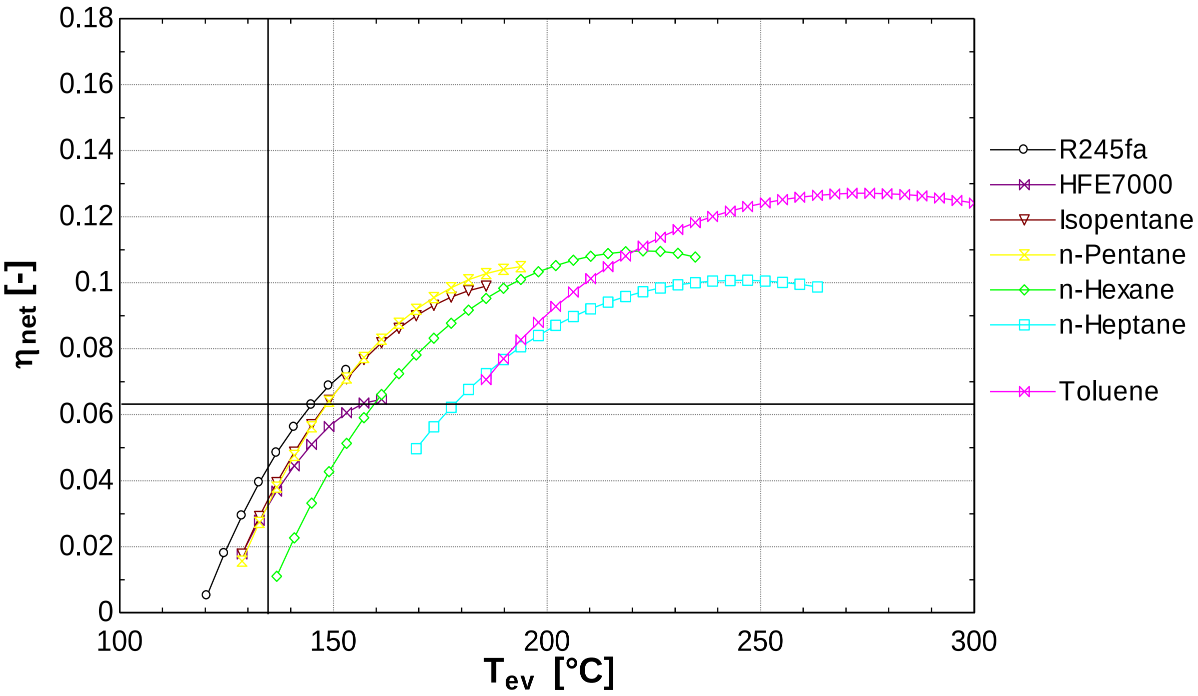
- ✓ On/Off coefficient: $C_\eta = 0.9$

	Low	Medium	High	Very high
Electric	7.5 %	7.2%	7%	6.7%
Thermal	80 %	80 %	80 %	80 %

Possible improvement

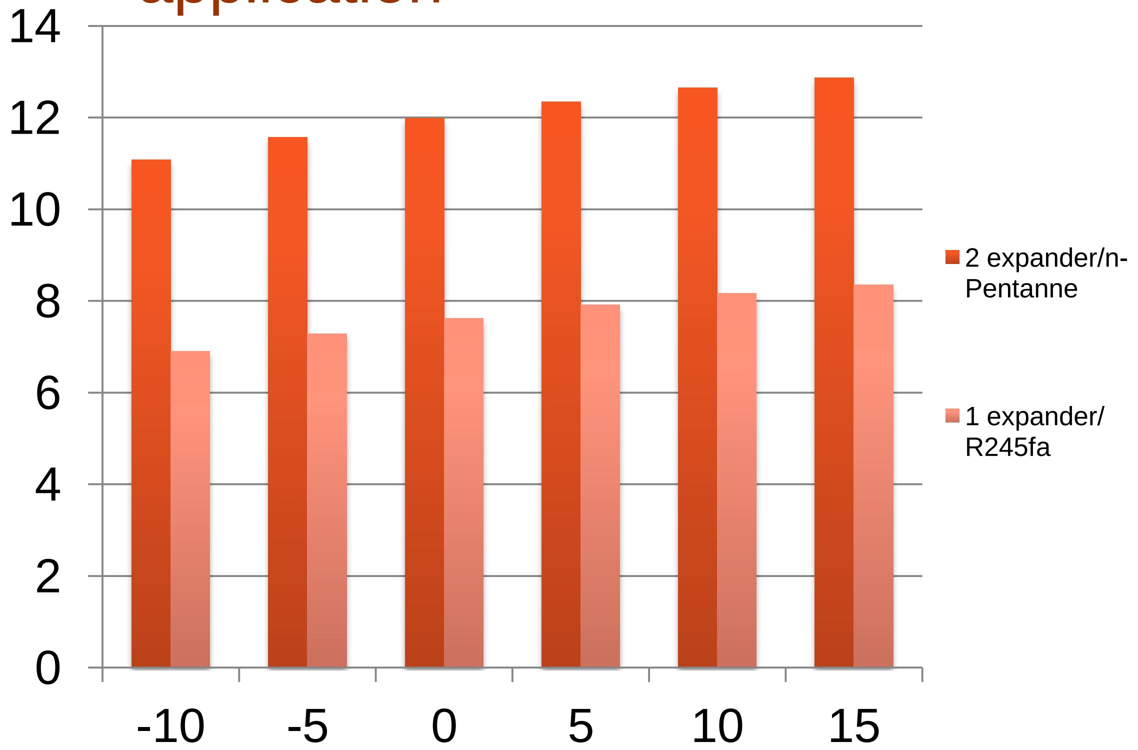
- ✓ 2 expander in series: increase global volume ratio
- ✓ Ok only with Tmax>135°C





Possible improvement

- ✓ Result with n-Pentane, Tev=190°C, High temperature application



	1 Ex	2 Ex
Electric	7 %	11 %
Thermal	80 %	72 %

Conclusion

✓ Investigation of an expander:

- Good achieved performance (71% efficiency)
- Well suited for low grade heat source ORC
- Validated semi empirical model

✓ ORC based mCHP

- Annual electrical efficiency of 7%
- Need a more suitable expander: higher maximum inlet temperature, higher built in volume ratio
- Can be competitive with other technologies

Thank you for your attention.