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Evaluation of suitable working fluids for single ORC by the concept of power maximization

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Aims and Definitions

Aims

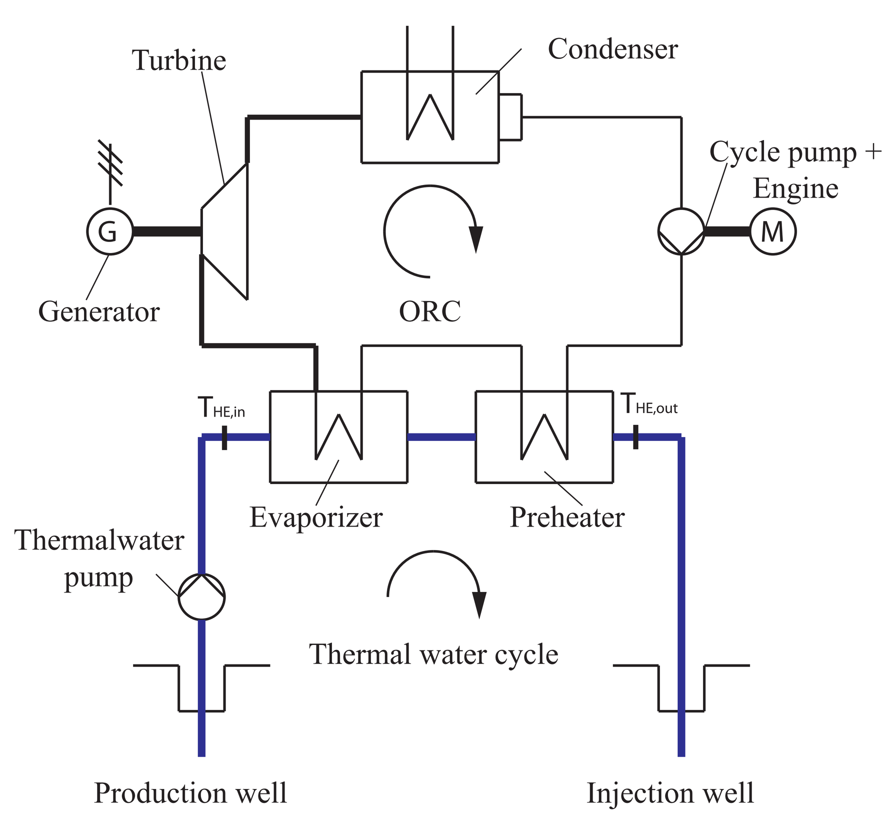
- Find a basis for efficiency to compare and evaluate different working fluids
- Show the usability of the concept of power maximization for different ORC-Fluids
- Analyze the heat transfer process between brine and working fluid

Calculation

- Only the simple power cycle is studied
- Variation of process pressure within the limits of definition

Software

EBSILON®Professional 9.0 (Evonik Industries) *including* REFPROP database 8.0 (NIST)



Boundary Conditions

Process

- Turbine efficiency: 85% (radial)
- Condensing temperature: 30°C
- Vapour fraction after turbine: min. 90%
- Start of boiling at inlet of evaporizer
- Saturated vapour at turbine inlet
- No superheating
- No overcritical conditions (<97% of T_{crit})
- Min. temperature difference (Pinch): 10K

Location

- Brine temperature: 150°C
- Brine mass flow: 100kg/s
- Salt concentration: 100g/kg_{Brine}
- Reinjection temperature: no restrictions

Efficiency considerations

Referring to the total heat potential of the brine

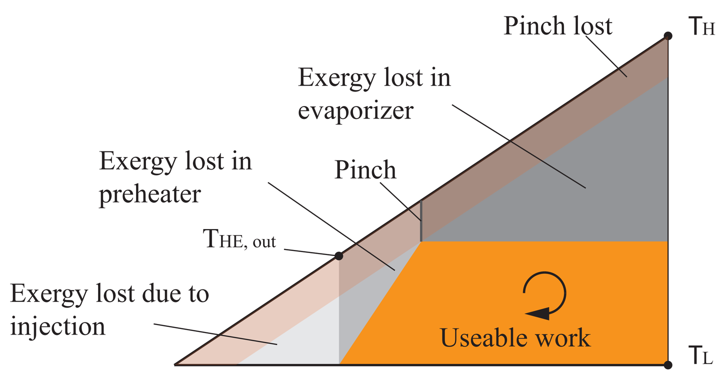
$$(1)\ \eta_{total} = \frac{P_{Gen} - P_{Pump}}{\dot{m}_{Brine} \cdot c_{p,Brine} \cdot (T_{HE,in} - T_{Cond})} = \frac{P_{Net}}{\dot{H}_{total}}$$

Referring to the added heat from the brine into the cycle

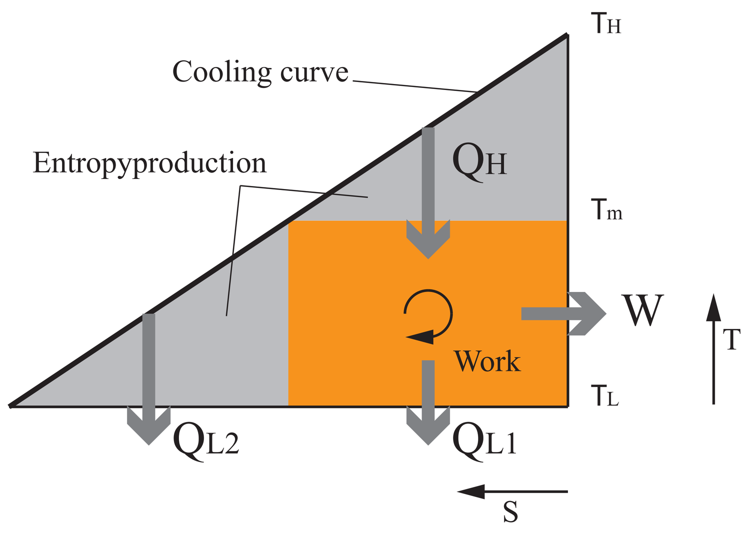
$$(2)\ \eta_{add} = \frac{P_{Gen} - P_{Pump}}{\dot{m}_{Brine} \cdot c_{p,Brine} \cdot (T_{HE,in} - T_{HE,out})} = \frac{P_{Net}}{\dot{H}_{add,Brine}}$$

Concept of Power Maximization[1]

The heat transfer process is characterized by **several sources of exergetic losses**. Especially the evaporation process and the loss at reinjection is compareable large.



- Maximum work is equal to the entropy production if a Carnot cycle transfers energy from a cooling medium (brine) into work.
- Two areas of entropy production: in the evaporation process and due to reinjection.



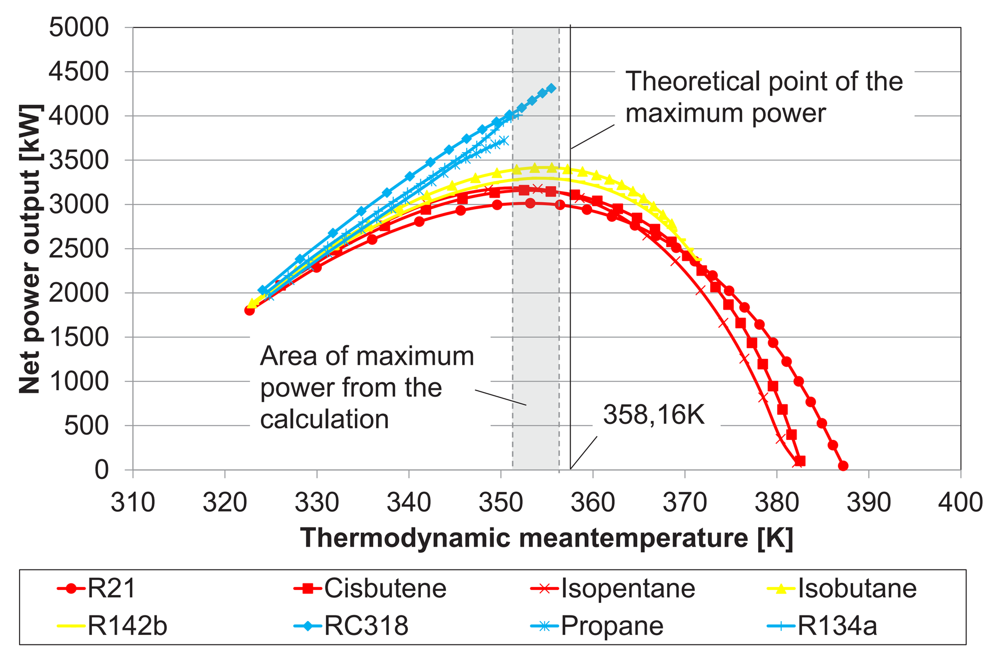
Maximum power depends on the highest temperatur of the energy source (brine) and the condensing temperature:

$$T_m = \sqrt{T_H \cdot T_L}$$

According to Carnot, the efficiency is:

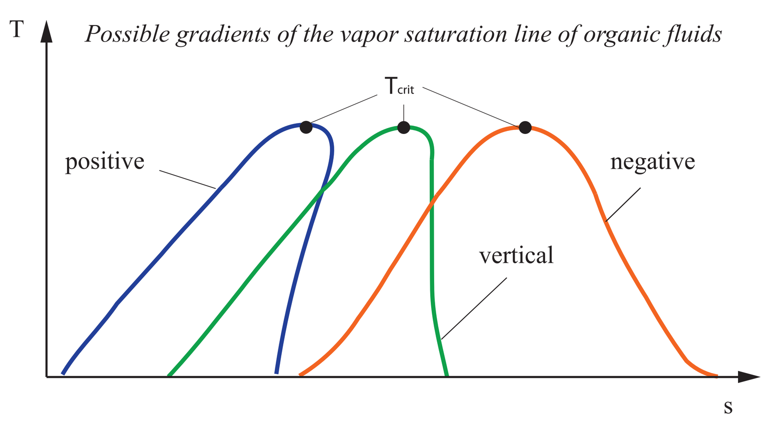
$$\eta_{Pmax} = 1 - \sqrt{\frac{T_L}{T_m}}$$

- Maximum power of all analyzed fluids is close to the theoretical point (the small difference comes possibly due to the pinch of 10K used in the calculation):



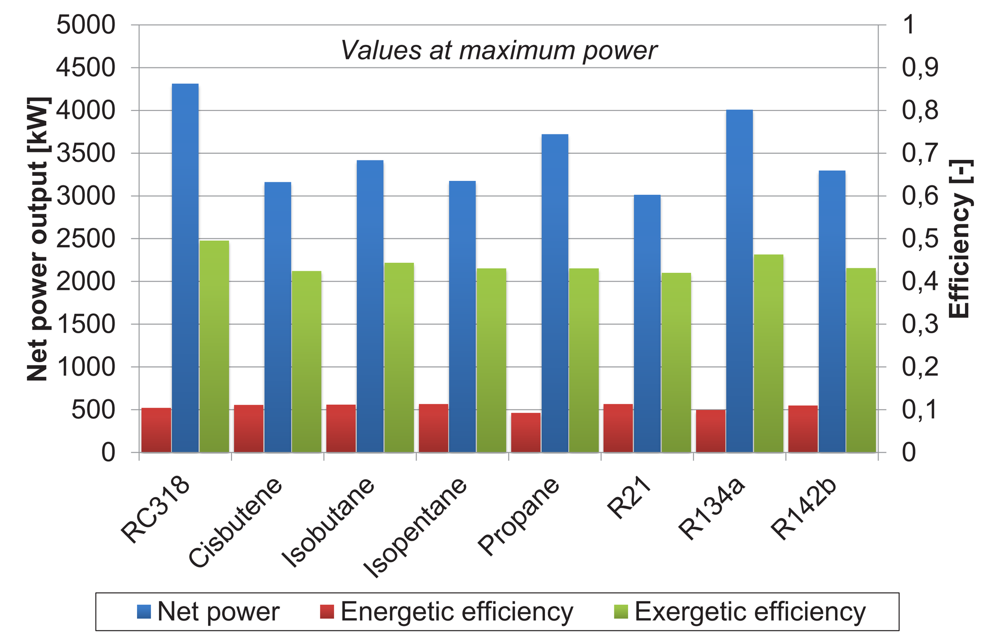
[1]Bejan, A.: Entropy Generation Minimization - The Method of Thermodynamic Optimization of Finite-Size Systems and Finite-Time Processes. ORC Press, 1996.

Results of the Calculation

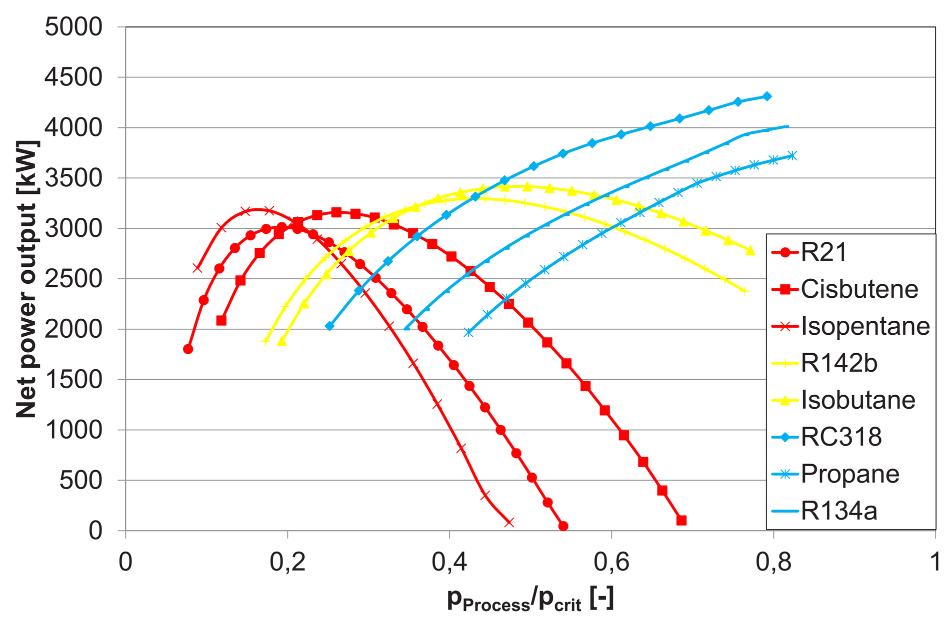


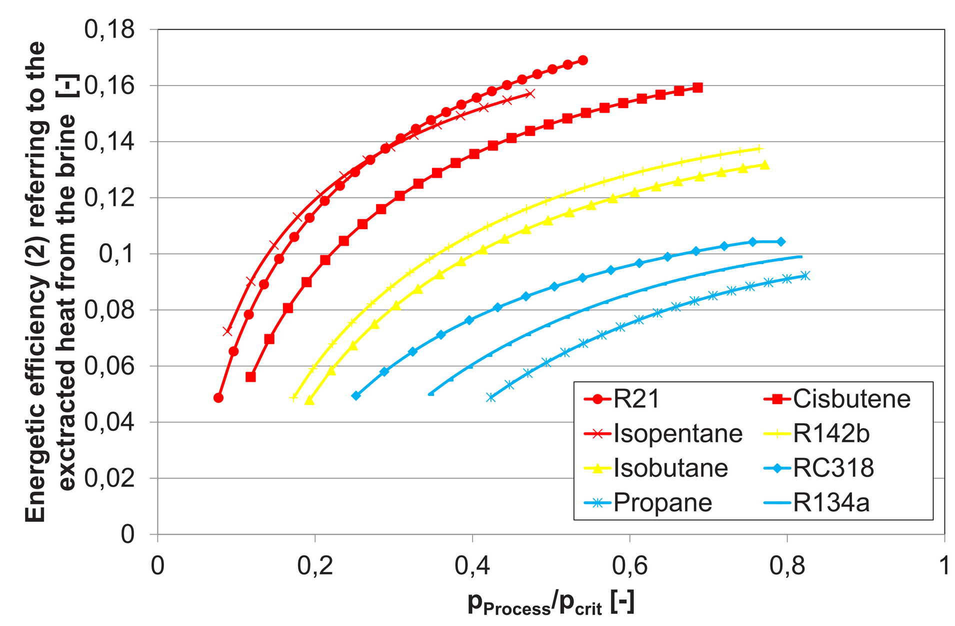
Type	A	B	C
	T_{crit} >> 413K	T_{crit} ≈ 413K	T_{crit} << 413K
negative	R21	Ammonia	R134a
vertical	Cisbutene	R142b	Propane
positive	Isopentane	Isobutane	RC318

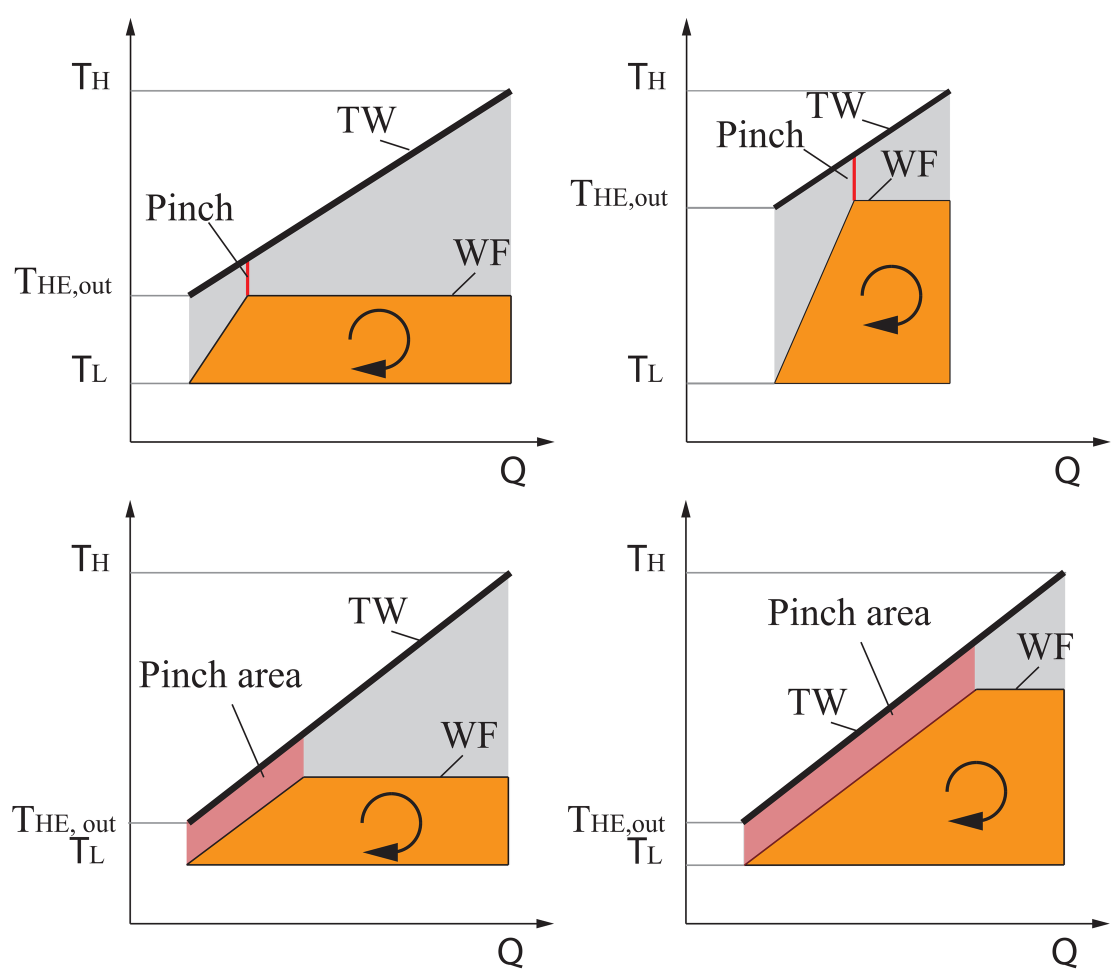
- Working fluids were chosen by their critical temperature relative to the maximum brine temperature (considering the pinch of 10K) and the gradient of its vapour saturation line



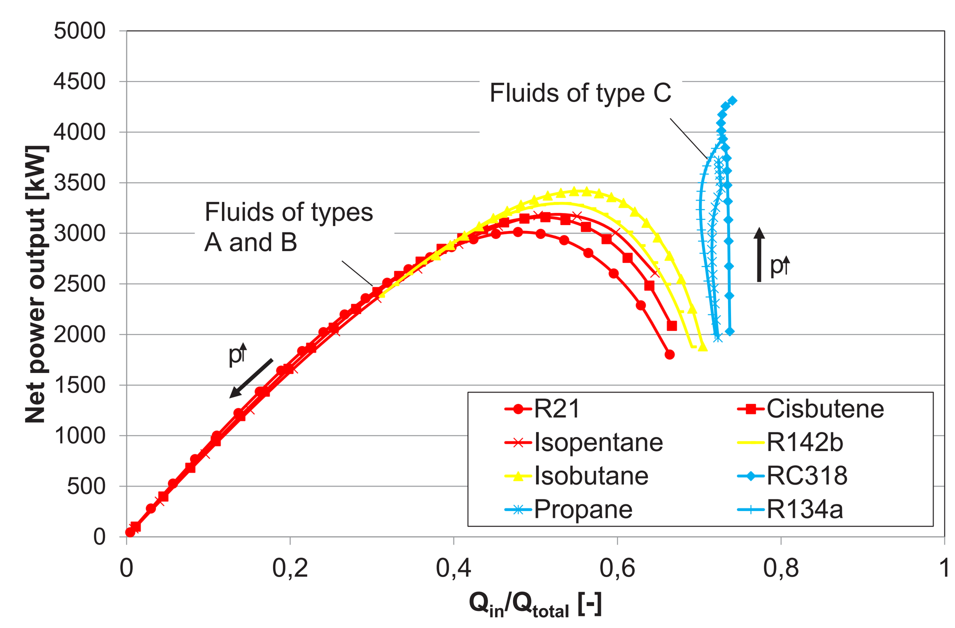
- The parametric study over the process pressure shows that the location of maximum power and maximum efficiency are not necessarily equal for efficiency equation (2), depending on the fluid's critical temperature







Heat transfer diagram for fluids of type A and B (upper diagram) and for fluids of type C (lower diagram).
Legend: TW=Thermal water (brine), WF=Working fluid (ORC)



- The heat transfer is limited by the pinch for fluids with high critical temperatures relative to the maximum brine temperature
- For fluids with lower critical temperaturs as the maximum brine temperature the pinch can be find in a wide area while the preheating process, resulting in an unlimited heat transfer

Conclusion

- The thermodynamic comparison basis of an ORC strongly depends on the used working fluid
- Because of the **non-uniform connection of highest efficiency and net power output** (eq. (2)), and the shown dependencies of the heat input, the basis of comparison between cycles should be an **efficiency referring to the total heat potential** of the brine and the condensing temperature (eq. (1))
- The heat transfer is limited by the pinch, except a fluid with low critical temperature is used. More heat can be added to the cycle with the result of higher power outputs
- The concept of power maximization is usefull to identify the **point of highest power output independently of the working fluid**

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