Optimization of waste heat utilization in oil field development employing a supercritical Organic Rankine Cycle (ORC) for electricity generation - with Chevron Technology Venture Emerging Energy

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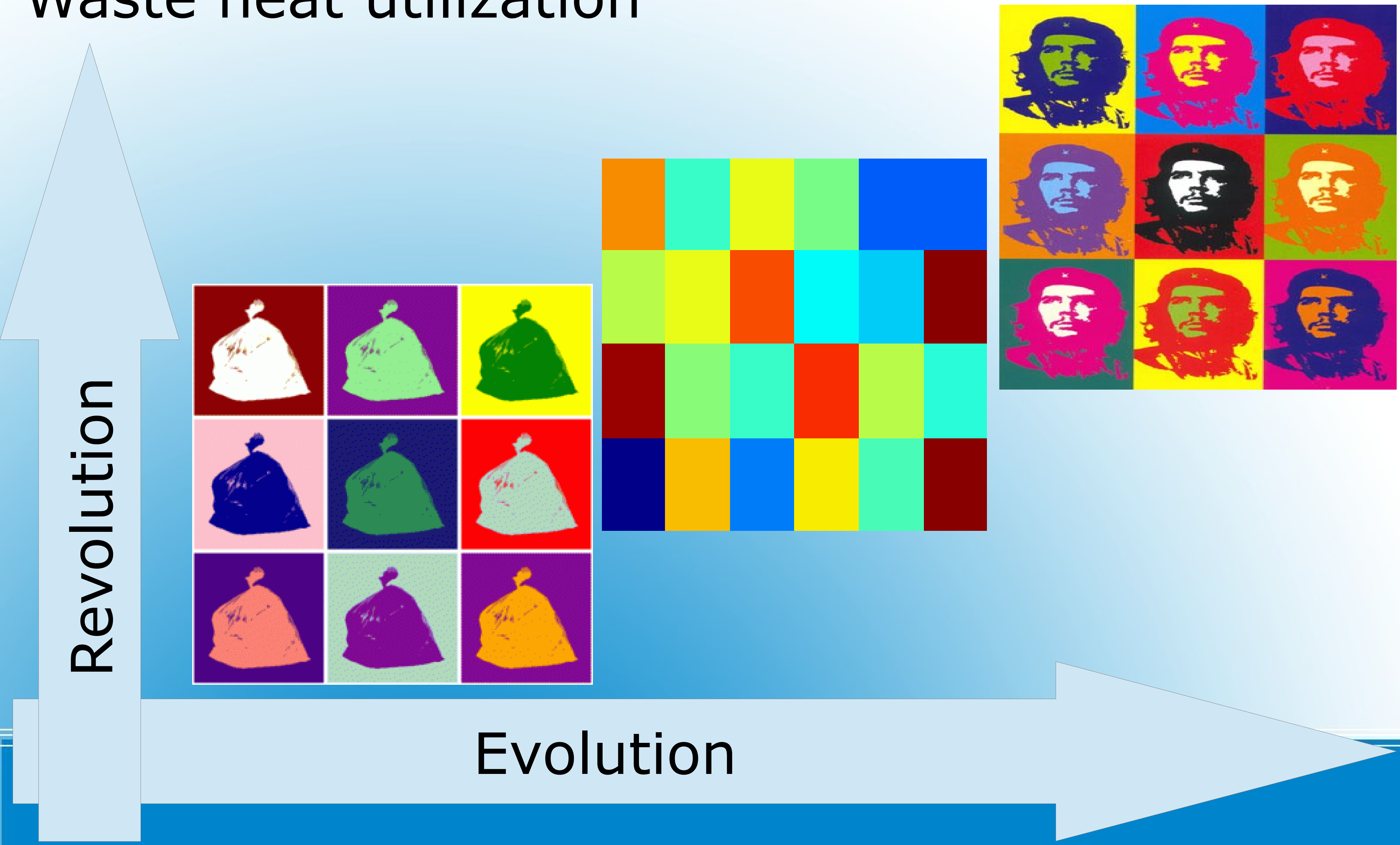
Outline

I. Waste heat utilization
II. ORC power generation
III. Optimization methodology
IV. Cycle sensitivity analysis
V. Conclusion

Questions to address:
What is waste heat?
How do I utilize it?
How much power?
Shall we go for it?

Waste heat utilization



Heat

Conserved quantity which only knows one direction!

Thermodynamic cycles transfer heat into a more valuable energy forms. Around 85 % of the worlds electricity demand is generated this way! How can heat be considered waste? Because the value of the energy is depending on the existing thermal contrast from which the energy quality is derived! Wrong?

1st Law = "Value of energy"
$dU = \delta Q + \delta W$

2nd Law = "Temperature & Irreversiblity"
$dS = \delta Q/T + \delta W/T \geq 0$

Heat source Temperature [°C]	450	300	150
Heat sink Temperature [°C]	20	20	20
Carnot efficiency [%]	59	49	31

Waste heat accounts for 60 % of the industrial thermal pollution in the U.S.

High : > 650 °C
Medium: ~ 330 °C
Low: < 230 °C

ORC power generation

Utilizing heat by employing the Clausius-Rankine thermodynamic cycle with carbon based fluids.

Electric power generation from:

- Geothermal
- Biomass
- Industrial waste heat
- Solar thermal
- CHP
- Water desalination (thermal)

Why ORC?:

- Highly reliable electric power supply
- Starting from 1 kW – 100 MW
- Zero emissions
- Applicable with CHP
- Continuous power production
- Maintenance free
- Easy and fast to assemble

Minimum thermal requirements:

- $\Delta T = 60\ °C$
- "Heat source nature"

NO FUEL CONSUMPION AND NO POLLUTION = RENEWABLE ENERGY

Unconventional heat source

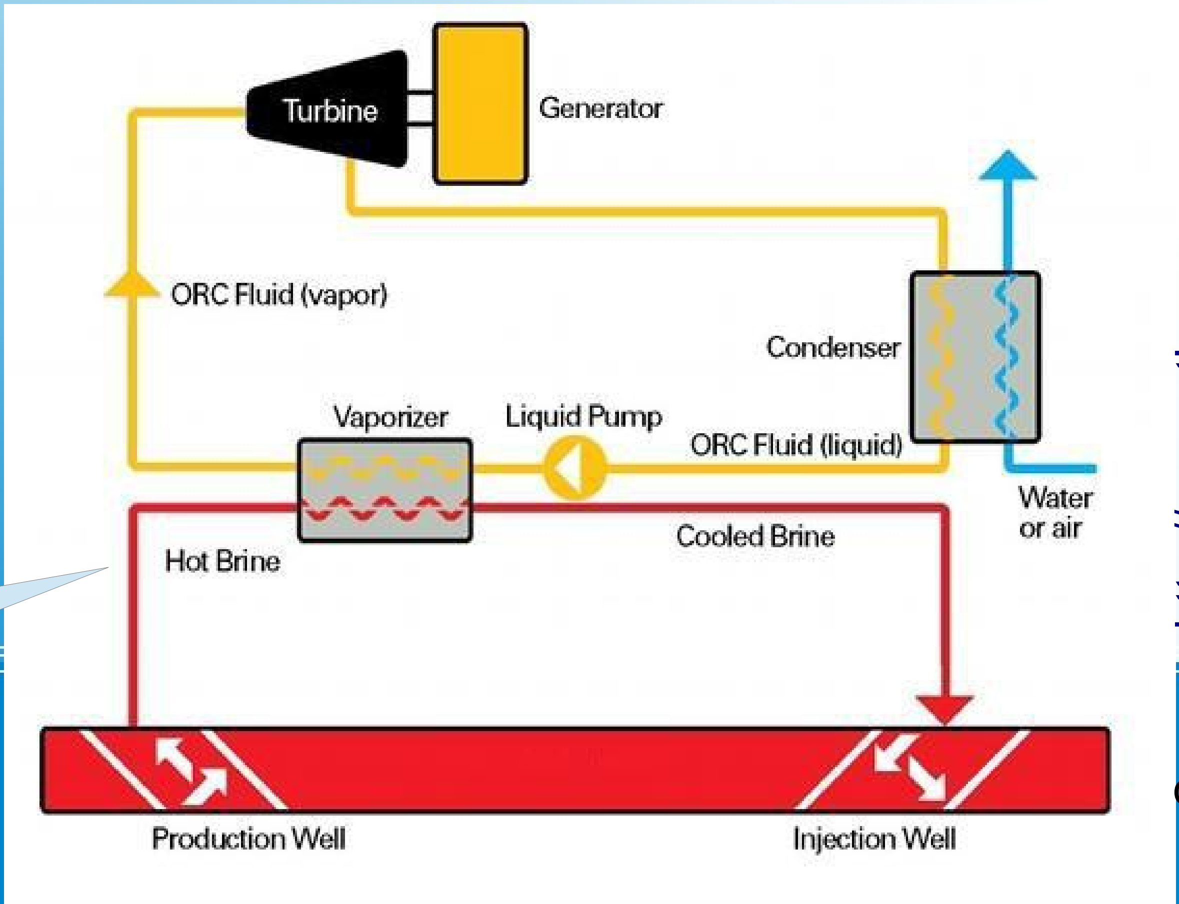
Energy companies with mature heavy and extra heavy crude oil fields employ sweeping as recovery enhancement in secondary and tertiary oil development!

High pressurized water is injected into the ground so that the brine coming out of the production well has a higher oil content.

Heat soucre nature:

- 150 °C
- 500 kPa
- 4.53 kg/s
- Phase fraction of 0.98
- On Chevrons' oil fields in Indonesia, Kazakhstan, Middle East and the US

Approx. 7 MW thermal power per oil well



Source: http://www.atlascopco-gap.com/ (modified)

Methodology

Design a dynamic and flexible unit configuration.

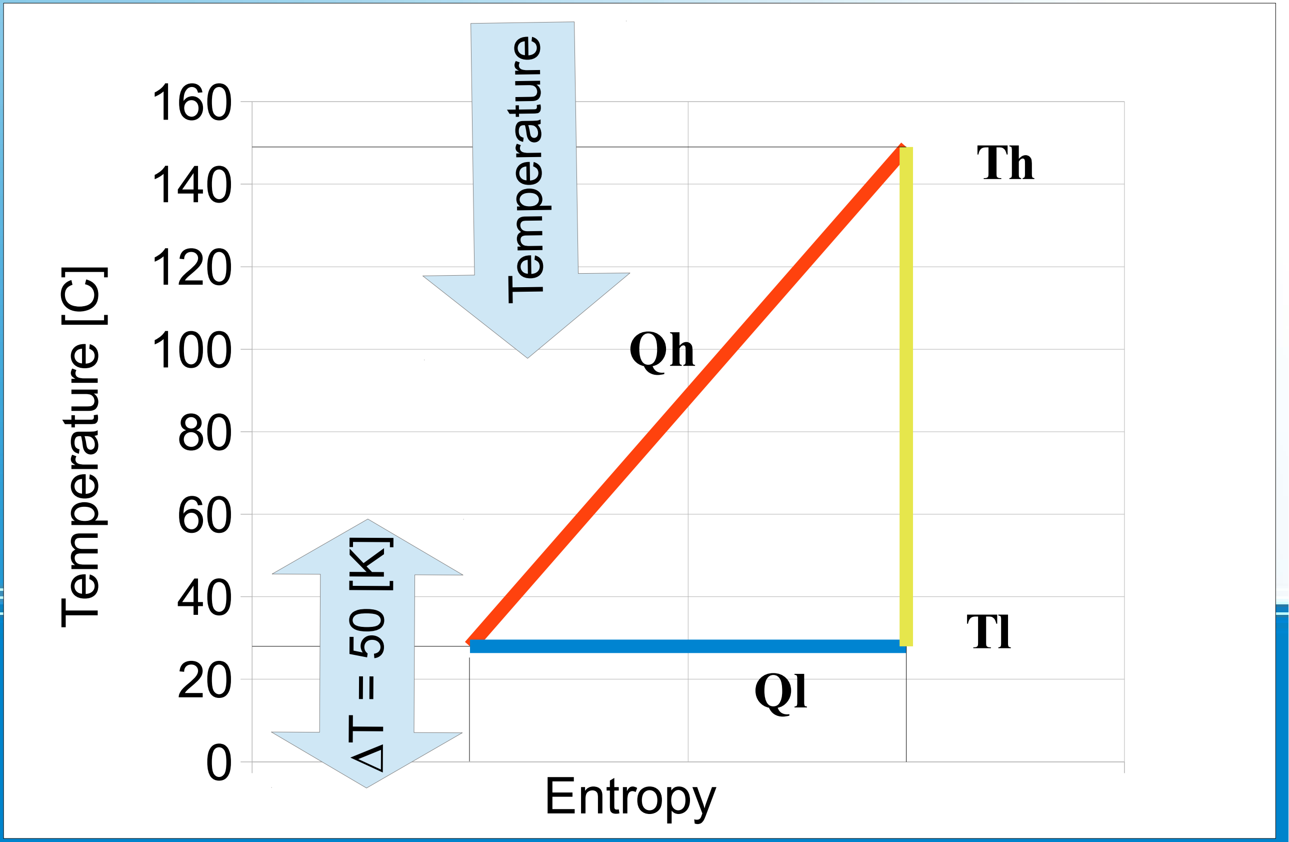
ORC plant:
- Cycle layout (Supercritical)
- Fluid and fluid properties (R134a)
- Equipment (Heat exchanger, expander, cooler, pump)

Changing boundaries:
- Thermal (Source and sink)
- Financial (Industrial size)

Organic fluid:

T_c = 101 °C

P_c = 4.06 MPa



Cycle optimization

Adjusting the elementary variables temperature and pressure.

$P_{net} \rightarrow Max. := Q_h - Q_l - P_{Pump} - P_{Cooler} + P_{expander}$

Maintained by the pump speed

With:

$Q_h = m_{ORC} (h_3 – h_2)$

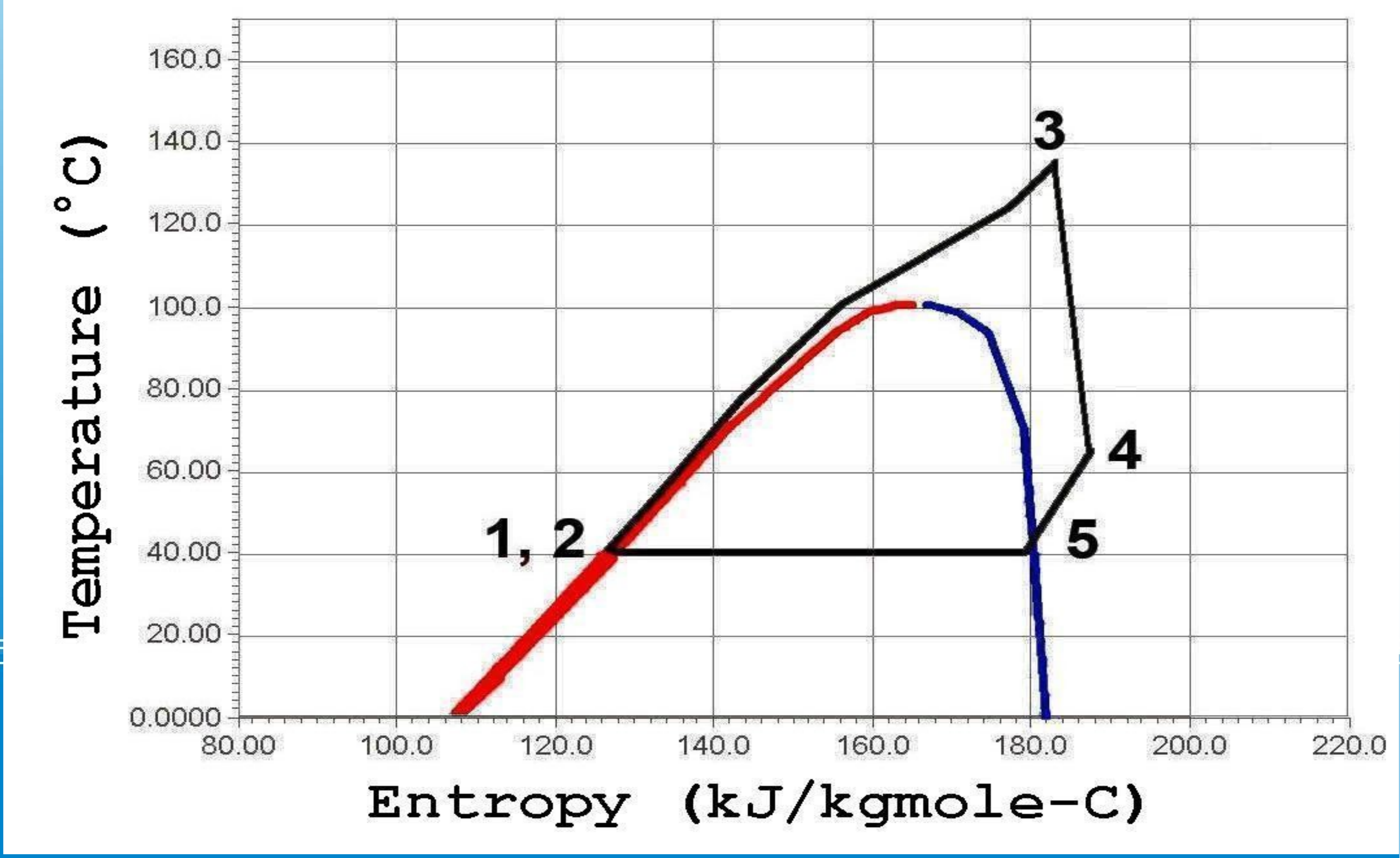
$= 7$ MW

And:

$UA = Q_h / LMTD$

Where:

UA = Heat transfer Conductance



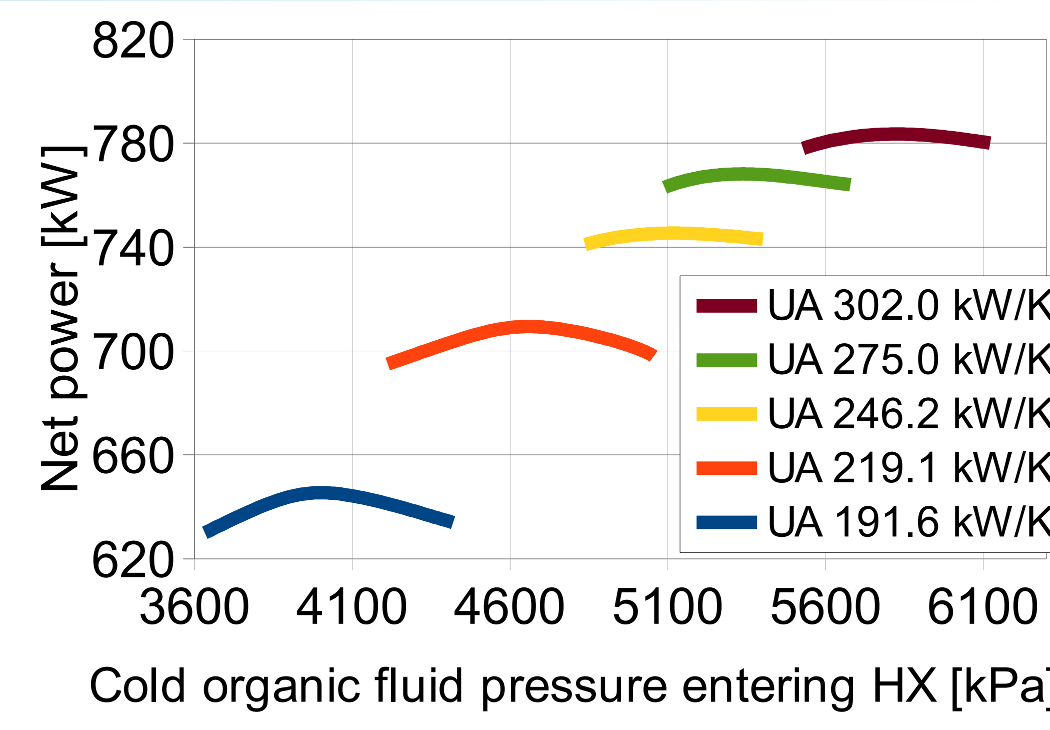
Heat Transfer

As the system is directly linked with the heat transfer: maximise the heat transfer.

- Positive "heat transfer conductance"/"organic fluid pressure" correlation
- Losses under suboptimal pressure operation higher for small heat transfer equipment than for large one
- Risk of subcritical operation for small heat transfer equipment higher than for large one

According to Karellas et al. the heat transfer improvements are governed by nonlinear supercritical fluid properties

(R134a, R227ea and R245fa - for A = 2.5 m², here ~ 60 m²)



Power

Net power performance of the plant for changing ambients.

T_l 28 °C	Heat transfer conductance			UA [kW/K]	
T_h 149 °C	191.6	219.4	246.2	275.0	302.0
Pump head [m]	ORC net power Pnet [kW]				
293	521	551	556	~~558~~	~~560~~
Critical	-	-	-	-	-
323	~~531~~	~~578~~	~~591~~	~~565~~	~~569~~
343	~~531~~	589	611	620	624
373	~~574~~	614	629	633	636
393	524	599	634	651	659
413	505	595	638	659	669
	494	589	639	663	675
	480	581	636	664	679
	465	571	631	663	680
	447	560	623	660	681
	432	552	615	654	667
	5	**8.8**	**9.1**	**9.5**	**9.7**

T_l 19 °C	Heat transfer conductance			UA [kW/K]	
T_h 149 °C	191.6	219.4	246.2	275.0	302.0
Pump head [m]	ORC net power Pnet [kW]				
293	630	648	649	652	~~654~~
Critical	-	-	-	-	-
323	~~644~~	~~678~~	~~690~~	~~622~~	~~685~~
343	~~645~~	695	709	741	717
373	637	708	734	745	750
393	633	708	741	755	762
413	630	705	745	763	772
	612	698	745	767	778
	600	691	743	768	782
	590	662	731	767	783
	578	674	730	764	783
	563	665	726	758	780
	0	**10.1**	**10.6**	**11.0**	**11.2**

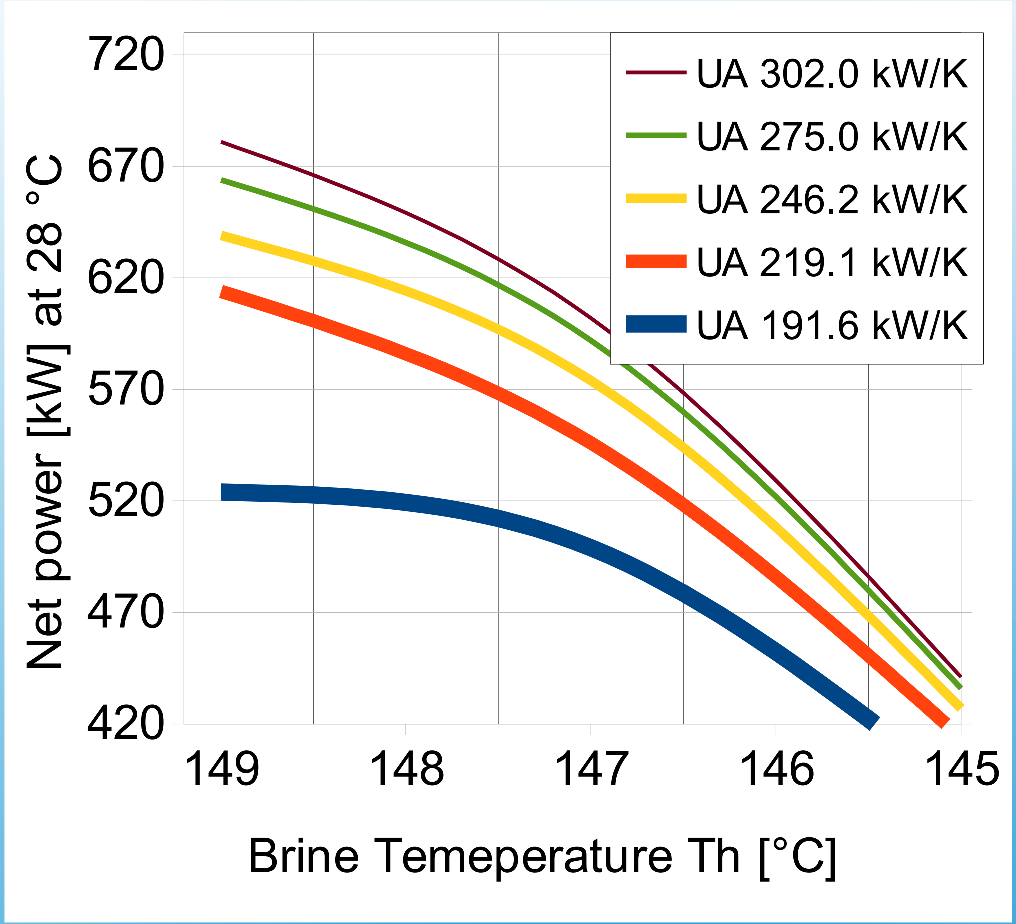
T_l 10 °C	Heat transfer conductance			UA [kW/K]	
T_h 149 °C	191.6	219.4	246.2	275.0	302.0
Pump head [m]	ORC net power Pnet [kW]				
293	751	758	760	762	763
Critical	-	-	-	-	-
323	~~777~~	~~787~~	~~792~~	~~794~~	~~795~~
343	790	803	808	812	812
373	807	824	832	835	837
393	808	832	842	847	849
413	808	838	850	856	860
433	801	839	855	862	867
453	796	837	857	867	872
473	787	834	857	867	875
493	780	827	854	868	876
513	772	819	849	865	875
Cycle η [%]	**11.5**	**12.0**	**12.2**	**12.5**	**12.5**

Up to -27 % in power for T_l changes

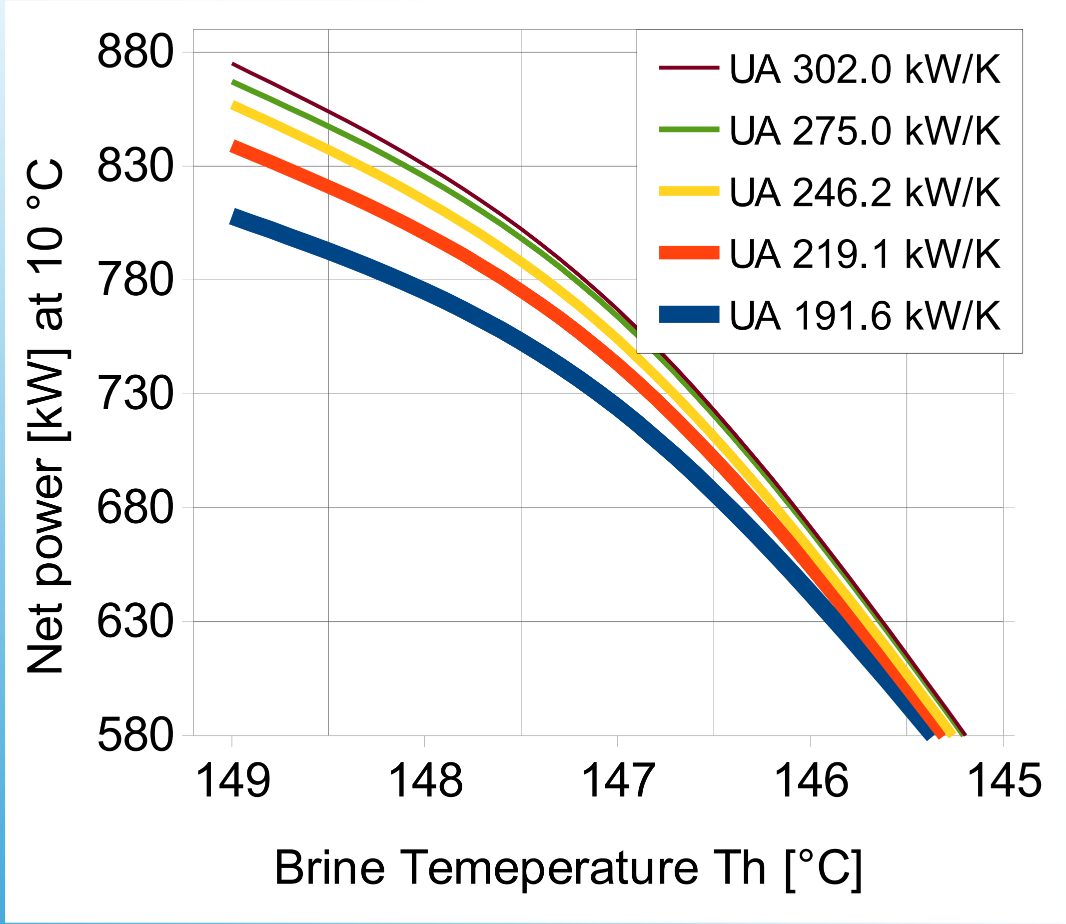
Up to -2.2 % in η for UA changes

Up to -10 % in power for p changes

Deteriorating brine temperature



At 28 °C ambient temperature



At 10 °C ambient temperature

HX choice determined by:

- Heat source temperature deterioration rate
- Value of additional “free” power
- Cycle flexibility

Conclusion

1. Cycle working pressure and heat exchanger surface area have to increase proportionally.

2. Low cost equipment and aggressive design vs. high performance flexible long term performance ORC.

3. Power and efficiency improvements just by adjusting the cycle working Pressure.

4. Deviations from the ideal operation under hot ambient conditions higher than under cold ones.

5. **ORC power generation is always “green” because it does not require fossil fuels!**

Thank you – Questions?

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