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Possibilities of water-lithium bromide absorption power cycles for low temperature, low power and combined power and cooling systems

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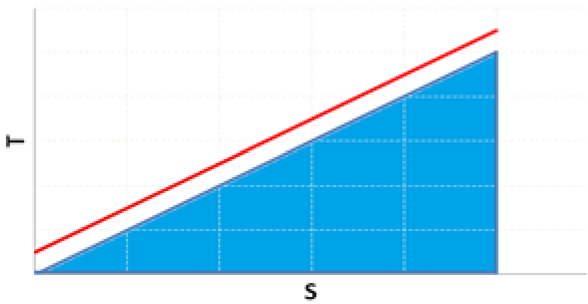
OUTLINE

- INTRODUCTION
- CONFIGURATIONS AND MODEL DESCRIPTION
- RESULTS
- CONCLUSION AND FUTURE WORK

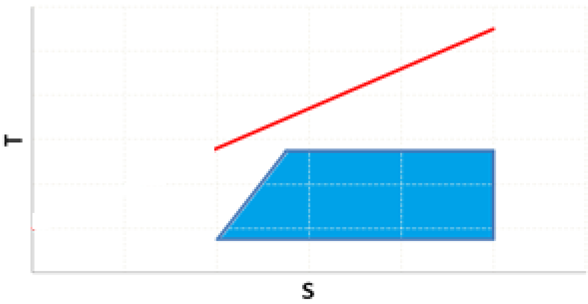
INTRODUCTION

- ISSUES IN LOW TEMPERATURE WASTE HEAT RECOVERY

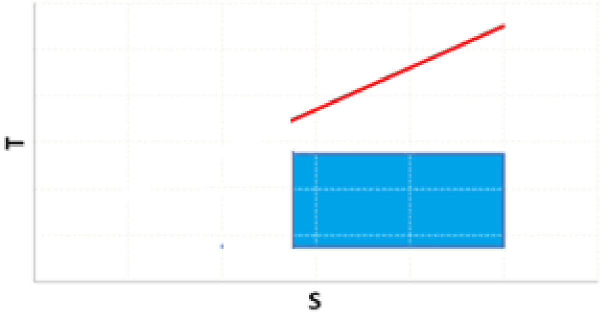
- **Large irreversibility in heat exchangers**
- **low utilization of the heat source**



Ideal WHR cycle



Ideal Rankine cycle



Carnot cycle in WHR

Standard / typical solutions = ORC

- **Industrial standard, robust, reliable**
- **Low heat of vaporization**
- **Still limited - negative effect growing with decreasing heat source temperature**
- **Result is still very low efficiency, hardly economical application**

INTRODUCTION

- WASTE HEAT RECOVERY TECHNOLOGIES

SOLUTIONS TO REDUCE IRREVERSIBILITY

Current

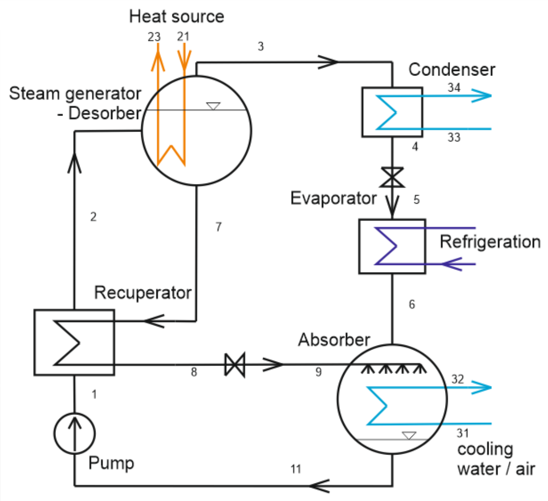
- **Lower latent heat compared to specific heat (ORC cycles)**

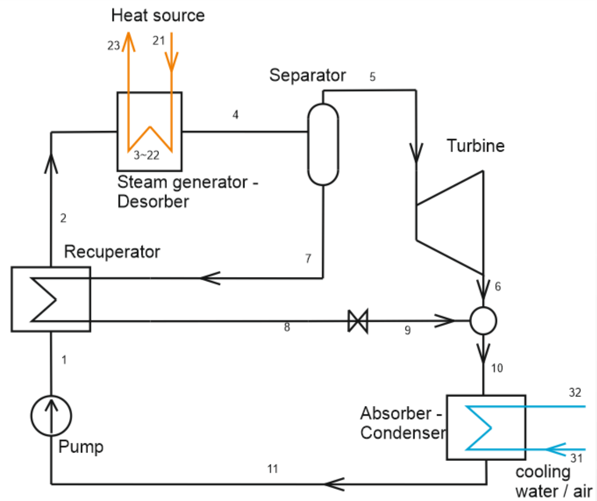
In research or only limited commercialization

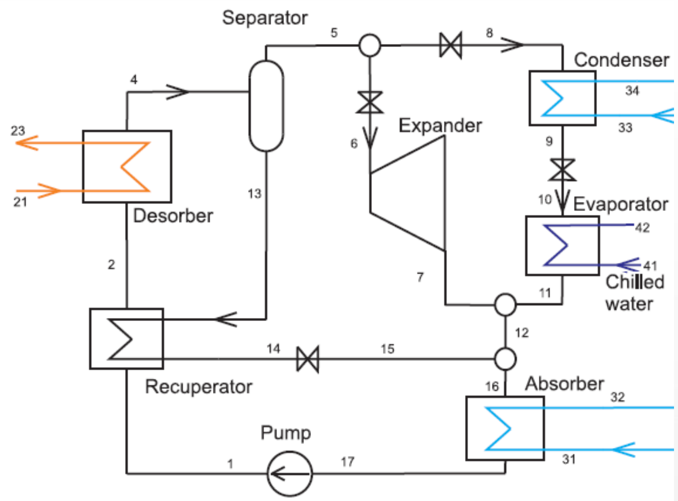
- **Variable boiling point**
  - **use of (zeotropic) mixture as working fluid –temperature match of hot and cold fluid due to temperature glide**
- **Supercritical state of working fluid**
  - **no boiling point, specific fluid for specific temperature**
- **Cascading of multiple cycles, multiple pressure systems**
- **Trilateral cycle with expansion from saturated liquid**

INTRODUCTION

- ABSORPTION POWER CYCLE (APC)



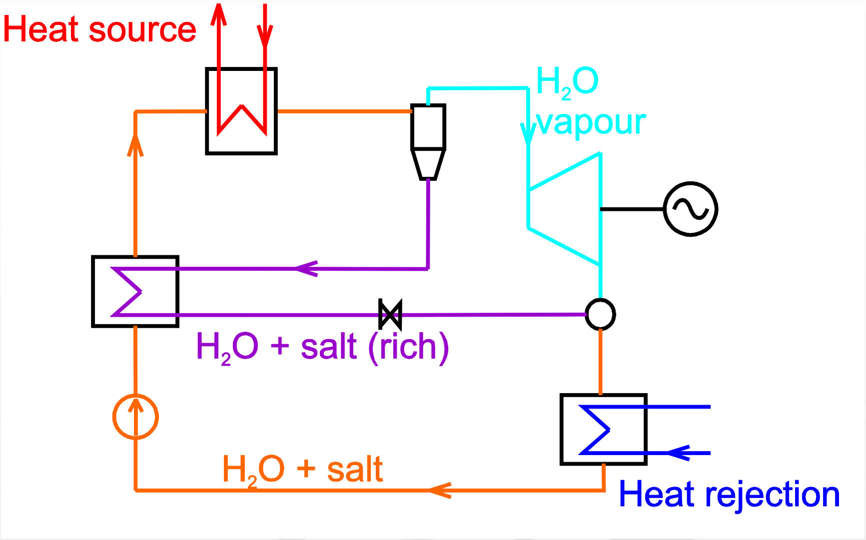


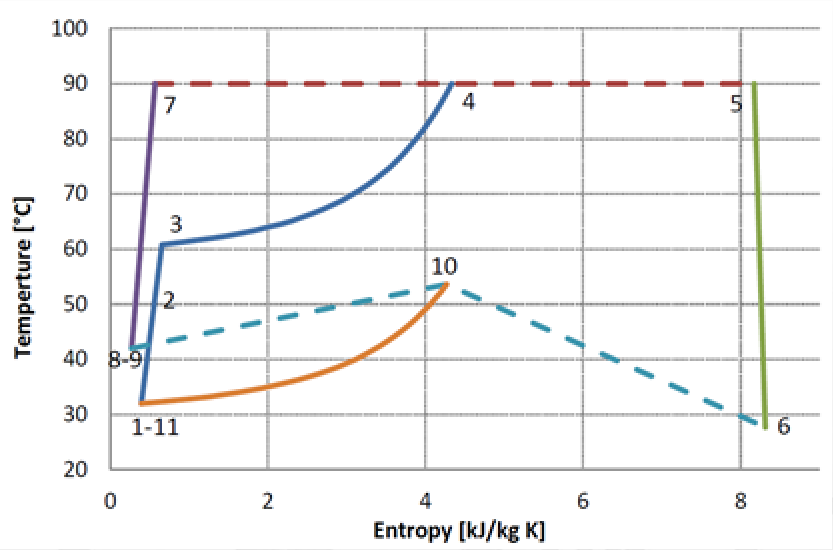


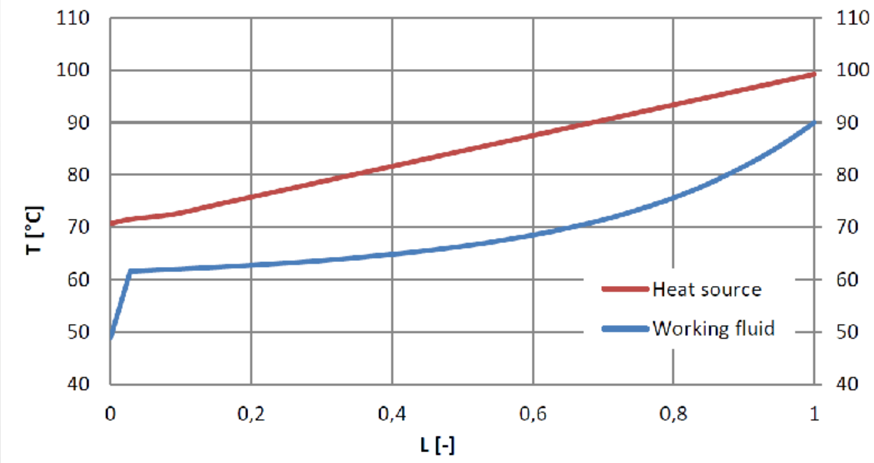
- **Working fluids enabling temperature glide of boiling point**
- **Range of possible working fluids**
  - **Cooling cycles – LiBr – H_2O, H_2O-NH_3 (commercial), other salts, ionic liquids – refrigerants mixtures (mostly only research work)**
  - **Power cycles – previous work limited to NH_3-H_2O, only few theoretical works about different working fluids, but their range should be same or larger than for cooling, not so limited by freezing problems**
  - **Possibility of combining into a single power & cooling system**

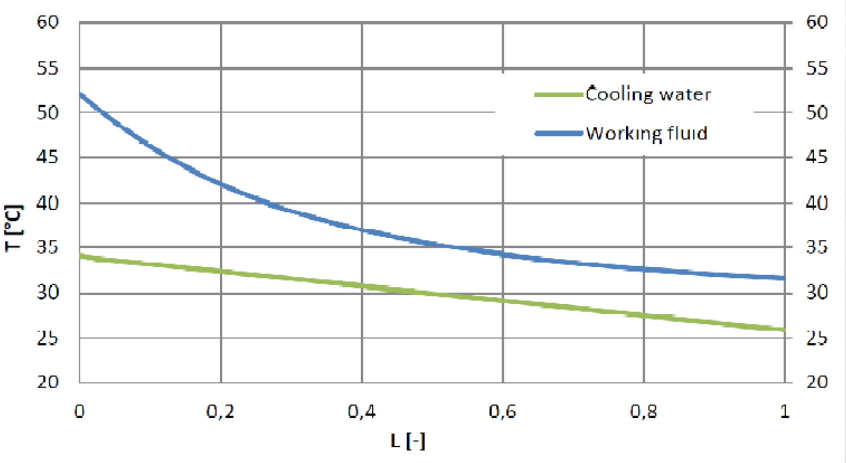
INTRODUCTION
APC technology operation

APC









INTRODUCTION
APC technology features

- Once through counterflow HXs
  - high exergy efficiency
- Cyclone separator of liquid and vapour
- Whole cycle under vacuum conditions
  - Similarly to absorption cooling
- Vapour free of LiBr and after separation is superheated
- Low pressure allows high efficiency turbine (but bulky)
- Working fluid handling mostly known from chillers

Potential issues

- Vacuum in whole working fluid area
- Corrosion from the solution
- Large temperature glide in HXs not proven

CASE SCENARIOS, MODELS DESCRIPTION
- GENERAL DESCRIPTION

Case scenarios

- Small scale WHR
- Low temperature geothermal
- Integration with low temperature solar thermal collector
- Bottoming of cascaded cycles
- Combined cooling and power cycle

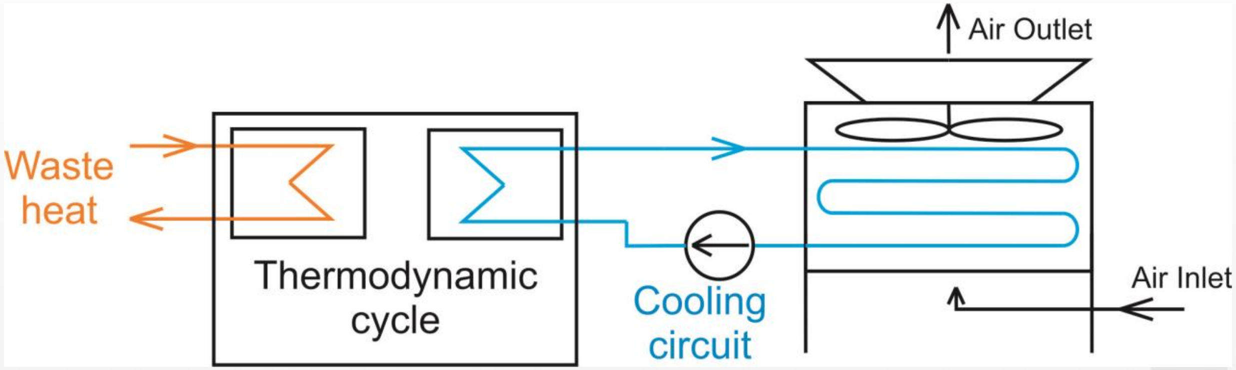
- Analysed potential of LiBr APC for each case
- Compared to ORC with R245fa used as a benchmark (simple and for solar also recuperated)

Models

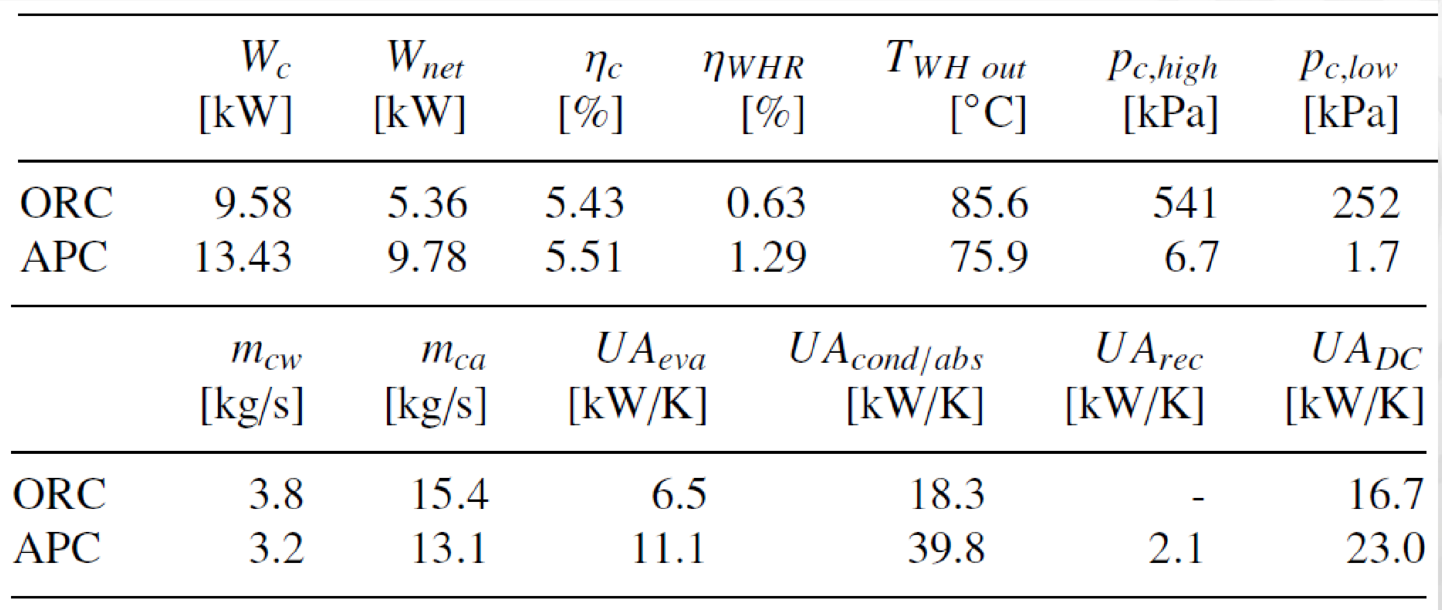
- Based on mass and energy balance
- Heat transfer defined by selected pinch points
- Included effect of heat rejection parasitic load (dry cooler circuit or air cooled condenser, coolant pressure drop)
- Boundary conditions
  - See the manuscript
- Calculated in Engineering Equation Solver
- Each cycle model optimized for maximal power production

CASES – Waste Heat Recovery

Heat source: 100°C, 10 kg/s hot air



(ORC only non-regenerative as it hasn't thermodynamic benefit)

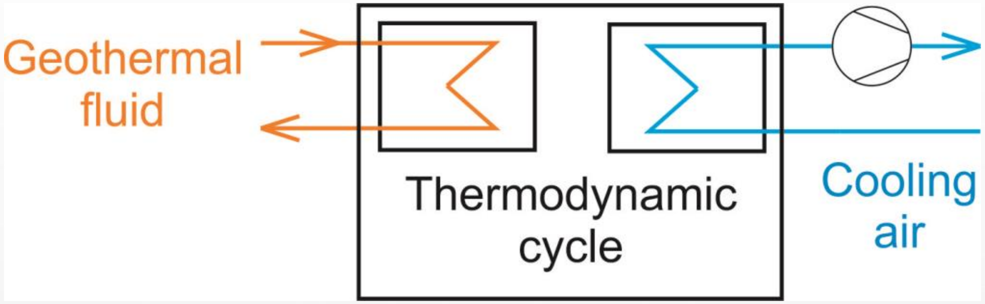


	W_c [kW]	W_{net} [kW]	η_c [%]	η_{WHR} [%]	$T_{WH\ out}$ [°C]	$p_{c,high}$ [kPa]	$p_{c,low}$ [kPa]
ORC	9.58	5.36	5.43	0.63	85.6	541	252
APC	13.43	9.78	5.51	1.29	75.9	6.7	1.7

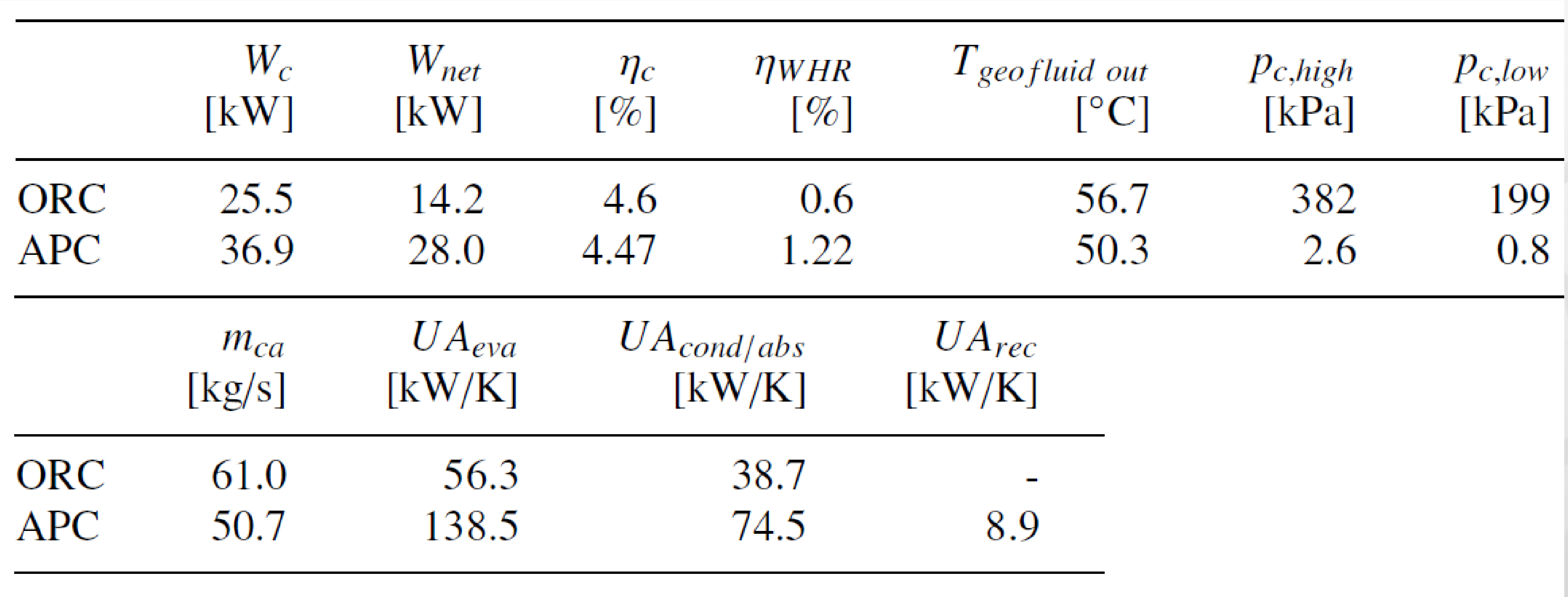
	m_{cw} [kg/s]	m_{ca} [kg/s]	UA_{eva} [kW/K]	$UA_{cond/abs}$ [kW/K]	UA_{rec} [kW/K]	UA_{DC} [kW/K]
ORC	3.8	15.4	6.5	18.3	-	16.7
APC	3.2	13.1	11.1	39.8	2.1	23.0

CASES – Low Temperature Geothermal

Heat source: 70°C, 10 kg/s geothermal water



(ORC non-regenerative as it hasn‘t thermodynamic benefit)



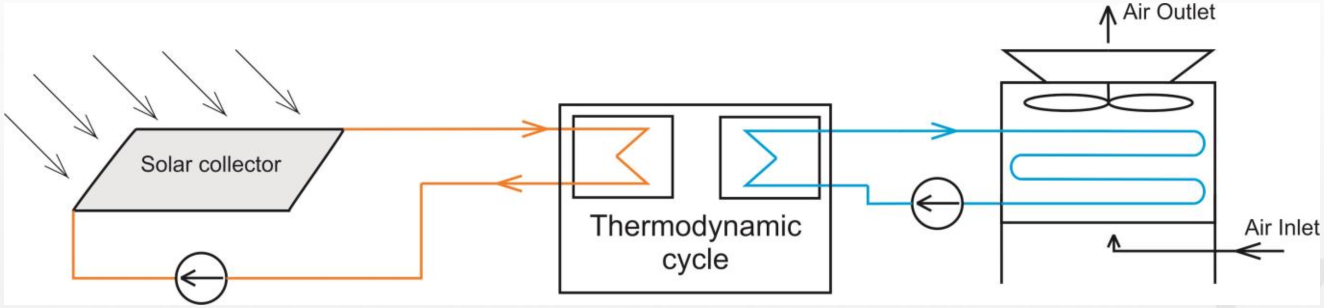
	W_c [kW]	W_{net} [kW]	η_c [%]	η_{WHR} [%]	$T_{geofluid\ out}$ [°C]	$p_{c,high}$ [kPa]	$p_{c,low}$ [kPa]
ORC	25.5	14.2	4.6	0.6	56.7	382	199
APC	36.9	28.0	4.47	1.22	50.3	2.6	0.8

	m_{ca} [kg/s]	UA_{eva} [kW/K]	$UA_{cond/abs}$ [kW/K]	UA_{rec} [kW/K]
ORC	61.0	56.3	38.7	-
APC	50.7	138.5	74.5	8.9

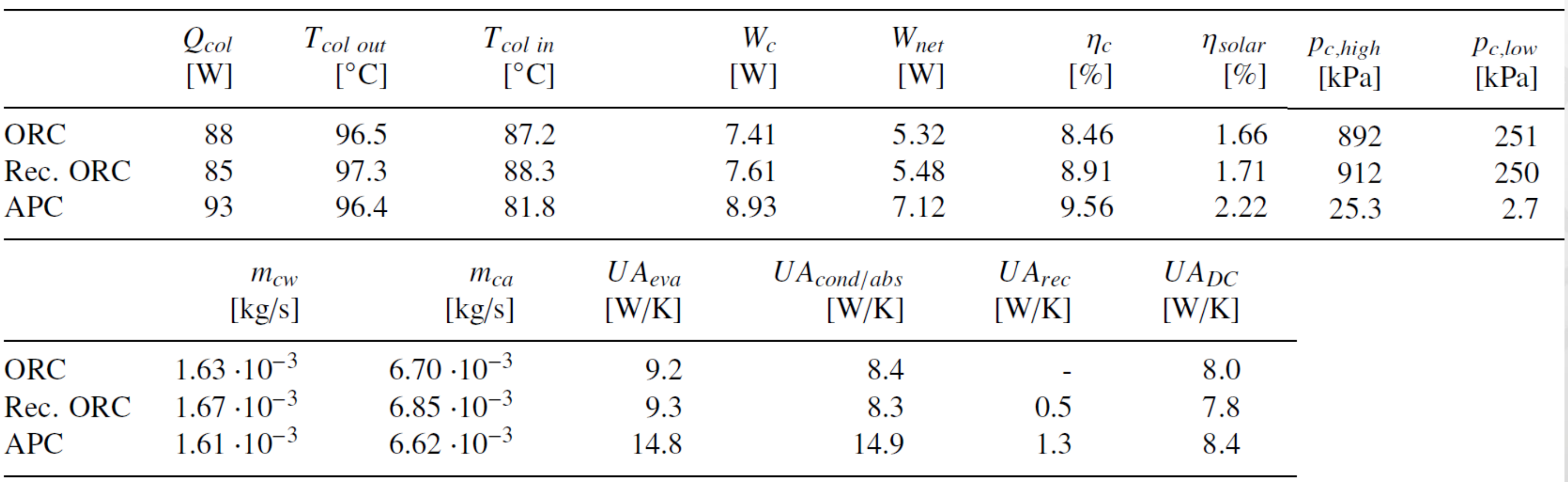
CASES – Low Temperature Solar

Heat source: solar vacuum collector

Case of location ans time – Prague, May (G = 321 W/m², T_{amb} =14°C), collector Eurosun Sunstar DF 100/6



(ORC also regenerative)



	Q_{col} [W]	$T_{col\ out}$ [°C]	$T_{col\ in}$ [°C]	W_c [W]	W_{net} [W]	η_c [%]	η_{solar} [%]	$p_{c,high}$ [kPa]	$p_{c,low}$ [kPa]
ORC	88	96.5	87.2	7.41	5.32	8.46	1.66	892	251
Rec. ORC	85	97.3	88.3	7.61	5.48	8.91	1.71	912	250
APC	93	96.4	81.8	8.93	7.12	9.56	2.22	25.3	2.7

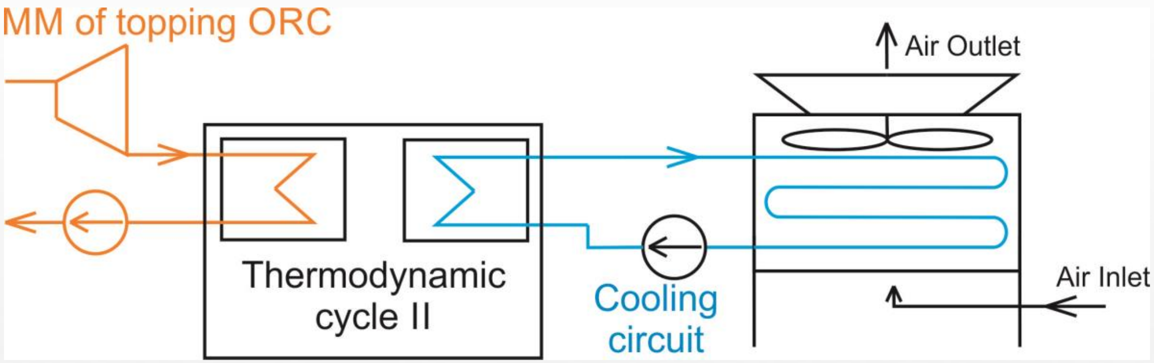
	m_{cw} [kg/s]	m_{ca} [kg/s]	UA_{eva} [W/K]	$UA_{cond/abs}$ [W/K]	UA_{rec} [W/K]	UA_{DC} [W/K]
ORC	$1.63 \cdot 10^{-3}$	$6.70 \cdot 10^{-3}$	9.2	8.4	-	8.0
Rec. ORC	$1.67 \cdot 10^{-3}$	$6.85 \cdot 10^{-3}$	9.3	8.3	0.5	7.8
APC	$1.61 \cdot 10^{-3}$	$6.62 \cdot 10^{-3}$	14.8	14.9	1.3	8.4

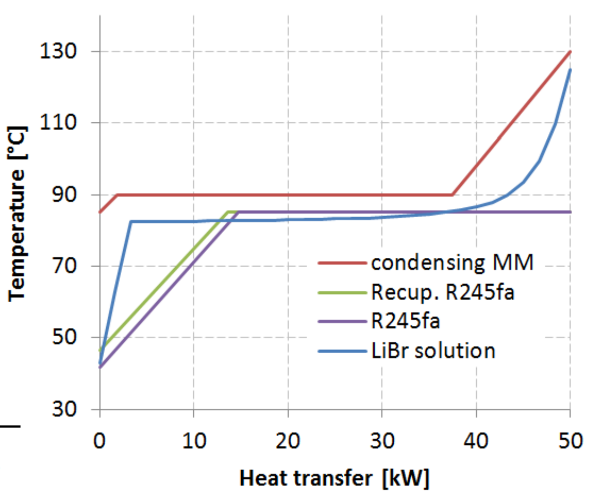
Ongoing more detailed analysis for an annual performance

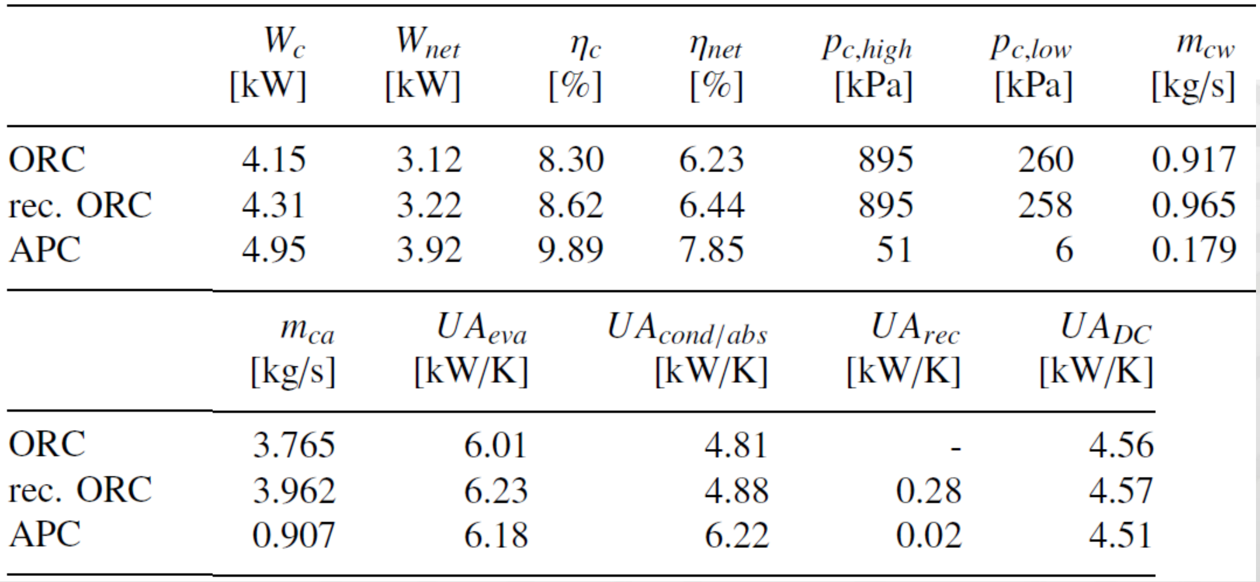
CASES – Bottoming cycle

Heat source: Desuperheating, condensing and subcooling MM

Condensation pressure 74 kPa ~ 90 °C







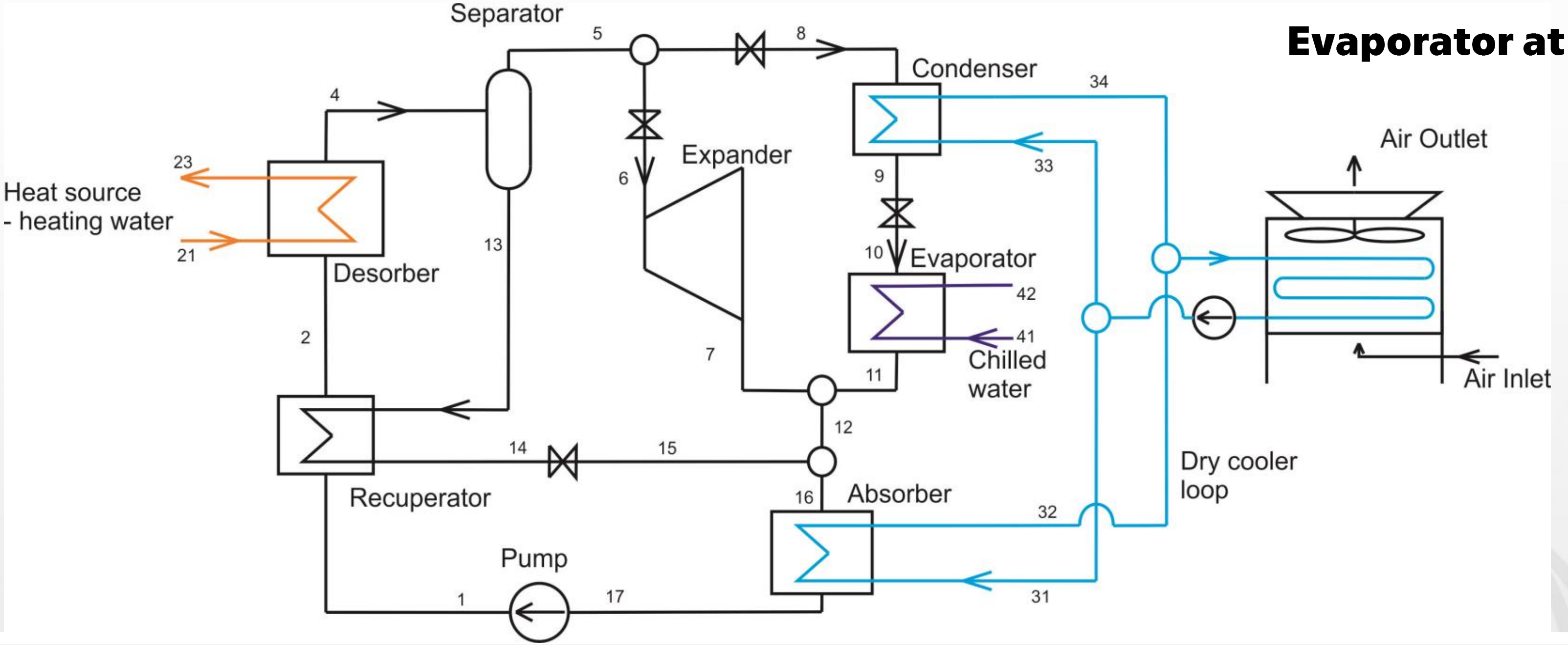
	W_c [kW]	W_{net} [kW]	η_c [%]	η_{net} [%]	$p_{c,high}$ [kPa]	$p_{c,low}$ [kPa]	m_{cw} [kg/s]
ORC	4.15	3.12	8.30	6.23	895	260	0.917
rec. ORC	4.31	3.22	8.62	6.44	895	258	0.965
APC	4.95	3.92	9.89	7.85	51	6	0.179

	m_{ca} [kg/s]	UA_{eva} [kW/K]	$UA_{cond/abs}$ [kW/K]	UA_{rec} [kW/K]	UA_{DC} [kW/K]
ORC	3.765	6.01	4.81	-	4.56
rec. ORC	3.962	6.23	4.88	0.28	4.57
APC	0.907	6.18	6.22	0.02	4.51

CASES – Combined Power and Cooling Cycle

Heat source: 80°C, 1 kg/s water (district heating parameters)

Evaporator at 5°C



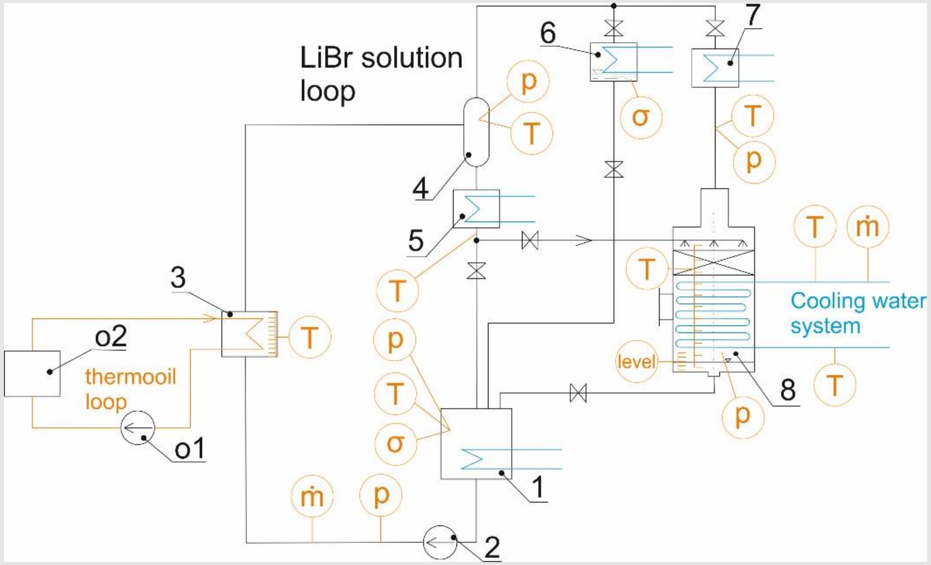
	W_c [kW]	W_{net} [kW]	$Q_{chiller}$ [kW]	COP [-]	η_{net} [%]	$T_{heat\ source\ out}$ [°C]	$p_{c,low}$ [kPa]	m_{cw} [kg/s]
Cooling only	-0.001	-3.35	37.6	0.83	-	69.1	0.87	3.02
50% cooling, 50% power	1.60	-0.68	18.8	-	-	69.1	0.87	2.05
Power only	3.20	1.99	0	-	4.37	69.1	0.87	1.08
Power only, optim. abs. p	4.49	3.14	0	-	3.37	57.7	3.03	1.17

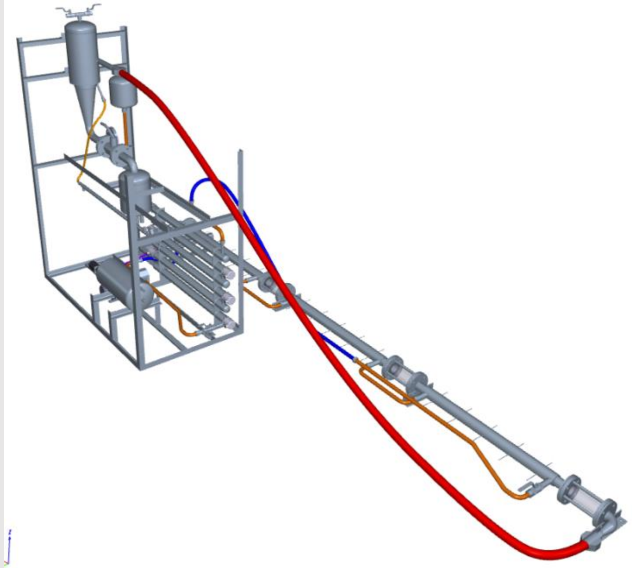
CONCLUSION & FUTURE WORK

- **Low T applications – potential of LiBr APC for significant performance increase**
- **Parasitic load plays a very important role – suitable for zeotropic mixture fluids including LiBr APC**
- **Larger equipment in general**
  - **Suitable for efficient small turboexpander**
  - **Larger heat exchangers**

CONCLUSION & FUTURE WORK

- **Experimental verification of LiBr APC equipment**
  - **Investigation of phase change behaviour in counterflow desorber, separator, later absorber**





- **Demonstration LiBr APC unit**
  - **Including expander**
  - **Closer to real operation system but less possibilities for detailed phase change investigation**

QUESTIONS?

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