

ABSORPTION POWER CYCLES AS AN EFFICIENT MEAN OF LOW TEMPERATURE HEAT UTILIZATION

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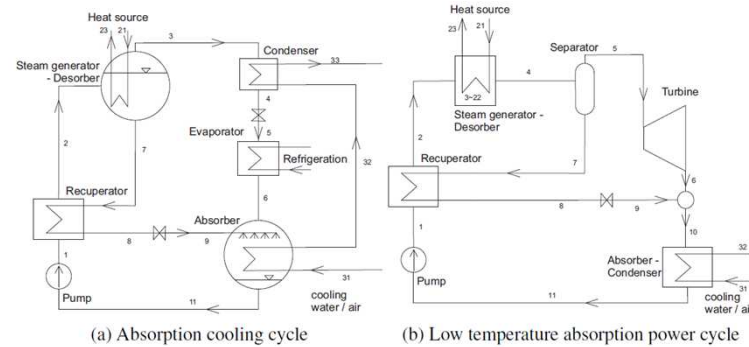
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INTRODUCTION

Absorption power cycle is one of the perspective options for low temperature applications. The multicomponent mixture as working fluid can provide very low exergy destruction in heat exchangers through variable temperature phase change. Absorption process has also an effect of lowering exhaust pressure of a turbine. Almost the only known absorption power cycle has been realized as Kalina cycle employing ammonia-water mixture as a working fluid, but there is relatively wide choice other working fluid absorbent-absorbate pairs. This work theoretically explores and compares the possibility of utilizing absorption power cycles with working fluids ammonia-water mixture, lithium bromide aqueous solution, organic absorbent amyl acetate with CO₂ and imidazolium type ionic liquid with two refrigerants.

ABSORPTION POWER CYCLES

- Multicomponent working fluids
 - Potential for temperature glide across boiling and condensation
 - High exergy efficiency of heat exchange
- Working fluids same as in absorption chillers and heat pumps
- Design similar to chillers, but turbine instead of condenser, valve and evaporator
- Perspective for modularity comparable with ORC units



Working fluids explored

- NH₃-H₂O – known as Kalina cycle, only commercialized absorption power cycle
- H₂O-LiBr solution – common in chillers, theoretically considered for power cycle
- Amyl-Acetate-CO₂ – theoretically considered for power cycle
- Imidazolium ionic liquid [EMIM]BF₄-H₂O – theoretically considered for chillers
- [EMIM]BF₄-2,2,2-trifluoroethylene (TFE) – theoretically considered for chillers
- Isobutane ORC and water RC for reference

MODELS

Boundary conditions

Heat source – hot air stream, 1 MW heat content, temperature 100°C and 200°C
Heat sink – 15°C, 100 kPa air in air cooled condenser

Assumptions

Steady state, working fluid in thermodynamic equilibrium,
Pinch points – 20°C at heat source, 10°C air cooled condenser and recuperator
Equipment η – turbine 80%, pumps 70%, air fan 70% (condenser air Δp 150 Pa)

Used methods

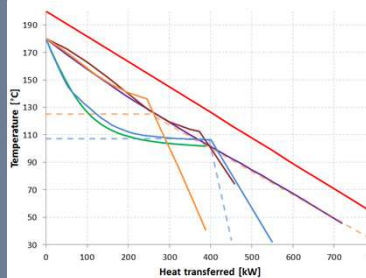
- NH₃-H₂O, H₂O-LiBr, ORC and steam cycles based on empirical property correlations
- Amyl-Acetate-CO₂, [EMIM]BF₄-H₂O, [EMIM]BF₄-TFE based on PengRobinson method
- Calculations performed using Aspen-Plus, Engineering Equation Solver
- Optimization for maximal power output from the heat source
 - Maximal working fluid flow within limits heat source pinch point
 - Adjusted pressure levels and concentration (reference cycles only pressure levels) for maximal power output
 - Included heat rejection effect – fan power requirement while satisfying condenser pinch point

RESULTS

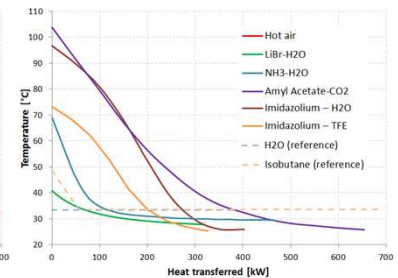
Heat source 200°C

Working fluid	W_{net} [kW]	$\eta_{cycle,gross}$ [%]	$\eta_{utiliz,gross}$ [%]	$\eta_{utiliz,net}$ [%]	$x_{turb,out}$ [%]
NH ₃ -H ₂ O	70.6	14.3	7.8	7.1	96.0
LiBr-H ₂ O	63.4	17.8	6.9	6.3	94.9
Amyl Acetate-CO ₂	57.9	9.3	6.7	5.8	93.4
Imidazolium – TFE	57.3	15.7	6.1	5.7	100.0
Imidazolium – H ₂ O	50.0	12.3	5.6	5.0	100.0
Isobutane (reference)	85.2	12.6	10.0	8.5	100.0
Isobutane recup. (reference)	87.6	13.0	10.3	8.8	100.0
H ₂ O (reference)	57.7	14.7	6.6	5.8	89.7

Q-t curves – heat addition



heat rejection (cooling fluid not shown)

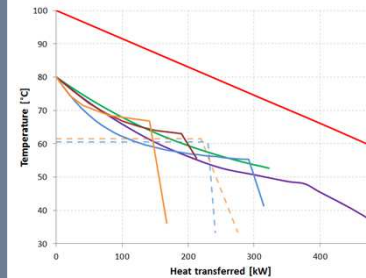


- NH₃-H₂O and Amyl Acetate-CO₂ have zero flow through recuperator, zero liquid fraction after boiler

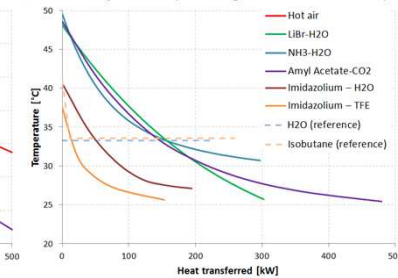
Heat source 100°C

Working fluid	W_{net} [kW]	$\eta_{cycle,gross}$ [%]	$\eta_{utiliz,gross}$ [%]	$\eta_{utiliz,net}$ [%]	$x_{turb,out}$ [%]
NH ₃ -H ₂ O	14.0	5.5	1.7	1.4	98.3
LiBr-H ₂ O	16.3	6.1	2.0	1.6	98.4
Amyl Acetate-CO ₂	9.6	3.6	1.8	1.0	100.0
Imidazolium – TFE	9.0	8.7	1.5	0.9	99.3
Imidazolium – H ₂ O	10.0	6.8	1.4	1.0	93.7
Isobutane (reference)	10.6	5.9	1.6	1.1	100.0
Isobutane recup. (reference)	10.6	5.8	1.6	1.1	100.0
H ₂ O (reference)	10.4	6.4	1.5	1.0	95.5

Q-t curves – heat addition



heat rejection (cooling fluid not shown)



DISCUSSION

- Temperature glide for high exergy efficiency heat exchangers for absorption cycles
- Overallly higher temperature heat sources advantageous for RC / ORC – higher efficiency and simplicity
- LiBr-H₂O cycle obtains maximum power from low temperature sources
- Poor performance of less traditional absorption cycle fluids
 - Temperature match in heat exchangers doesn't secure high overall efficiency
 - High cycle efficiency but low heat transfer or high turbine outlet temperature
 - Potential issue with theoretical vs. real fluid properties for less traditional absorption working pairs – need for fluid property validation
- LiBr cycle operates entirely in vacuum, NH₃-H₂O above 1 MPa, Amyl-Acetate-CO₂ up to 22 MPa, other in order of bars
- LiBr cycle has potential for high turbine efficiency at low power, but as a bulky unit
- Potential corrosion risk of certain working fluids

CONCLUSION

Potential domain of absorption cycles is for heat sources with lower temperature (around 100°C), while the ORC can provide higher power output for the 200 °C heat source. Theoretical calculations of ionic liquid based absorption cycles do not show improvement in heat utilization performance to other absorption cycles nor ORC.