ZeoStore – a vapor-based Carnot Battery using zeotropic mixtures with high temperature glide

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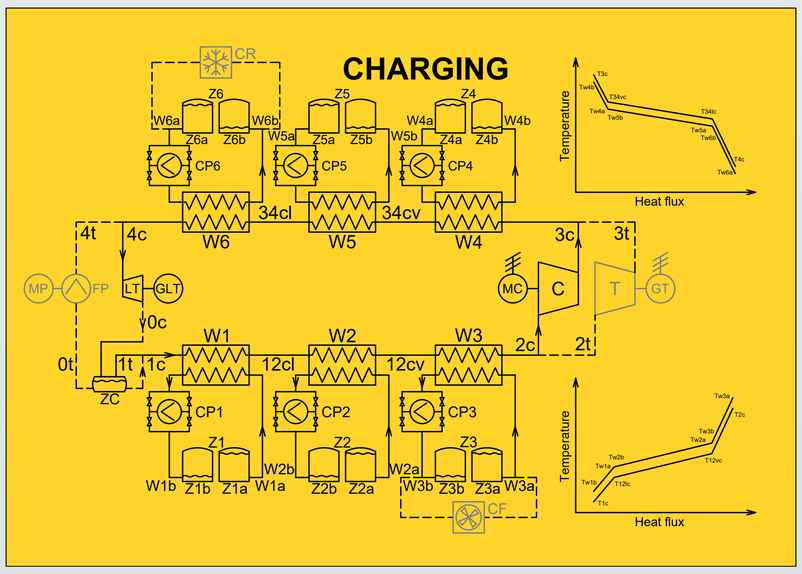
This architecture was inspired by the Carnot battery solutions presented and discussed in the literature [1,2]. When analyzing the solutions presented there, it should be noticed that the key to achieving high roundtrip efficiency of the energy storage is the minimization of exergy losses arising mainly in turbomachinery and heat exchangers. Therefore, the minimization of exergy losses comes down to, firstly, increasing the flow efficiency of the thermal turbomachinery taking part in the process, and secondly, minimizing the mean temperature differences in the heat exchangers. From the point of view of exergy losses in heat exchangers, high temperature cycles, i.e. Brayton cycles in particular, have an advantage because the exergy loss is relatively lower [3]. On the other hand, systems using vapor cycles are more promising due to the much smaller proportion of pumping (compression) work which becomes significant for the system operating back and forth. Exergy losses have a significant impact on the attractiveness of the entire system, as they determine its efficiency. Another decisive feature of an energy storage is its investment cost. In the case of Carnot batteries, the cost of the heat storage is important. The heat storage should consist of the cost-efficient and abundant materials. Taking into account the above considerations, an attractive variant of the Carnot battery technology would be a system that:

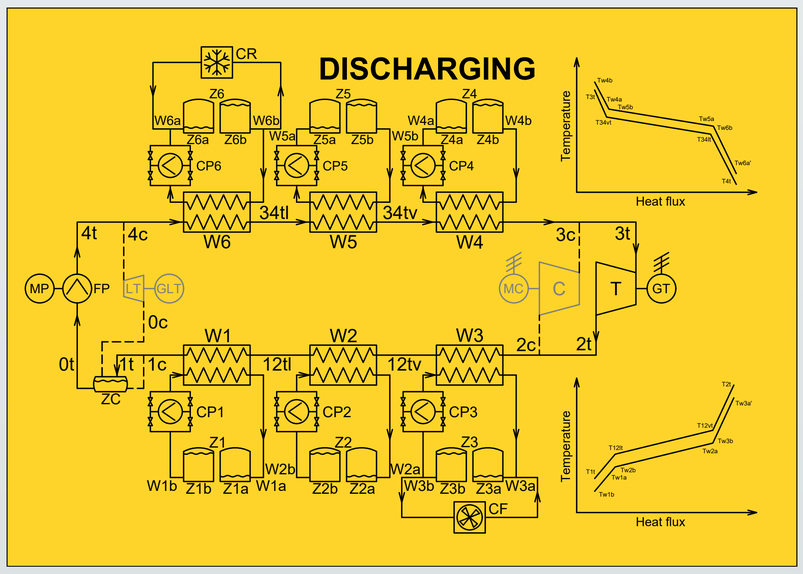
1. Uses a vapor cycle.
2. Operates in subcritical conditions where the pumping work and operating pressures are low.
3. Uses water as a heat storage medium, which is, in many places, cheap and available.

Such a system could be a site-independent successor of the pumped hydroelectric storage technology.

A Carnot battery system using zeotropic mixtures with high temperature glide is a potential candidate for such a technology. This approach has been considered before for example by Bernehed [4] who proposed using a water-ammonia mixture or by Koen et al. [5] who proposed using a mixture of ethane, propane, butane and pentane of carefully tailored compositions in order to achieve relatively constant effective specific heat capacity during phase change.

It appears that many mixtures of various working fluids can have similar characteristics described by Koen et al. For example, a mixture of **3-methylpentane, dimethyl ether, neopentane and propylene oxide** at compositions of **0.2430, 0.1625, 0.3459, 0.2486**, respectively, performs even better than the one proposed by Koen et al. A roundtrip efficiency of 53.6% has been achieved under the assumption that the smallest temperature difference in the heat exchangers is 2 K, efficient radial turbomachinery is applied (89% efficiency for the turbine and 83% efficiency for the compressor) and the combined electric and mechanical efficiency is equal to 94%. In a large, mature system in which very efficient axial turbomachinery is applied one can expect roundtrip efficiencies significantly exceeding 60%.



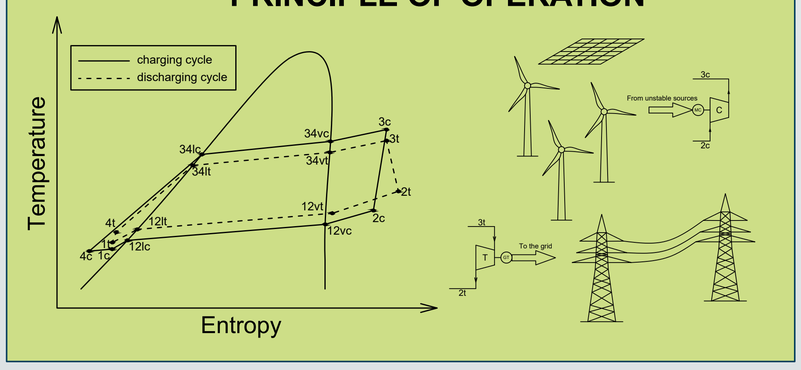


MC - compressor motor
GLT - liquid expander electric generator
T - turbine
FP - feed pump
GT - turbine electric generator
MP - feed pump motor
AC - working fluid chiller

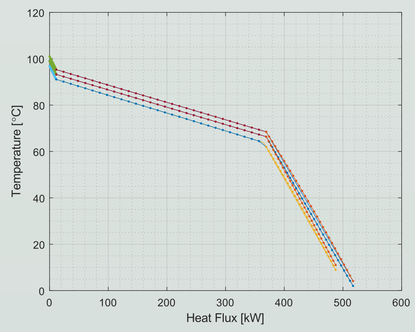
Z1, Z2, Z3, Z4, Z5, Z6 - heat and cold storage
Z1a, Z2a, Z3a, Z4a, Z5a, Z6a, Z1b, Z2b, Z3b, Z4b, Z5b, Z6b - water tanks
W1, W2, W3, W4, W5, W6 - heat exchangers
CP1, CP2, CP3, CP4, CP5, CP6 - circulation pump systems
ZC - working fluid tank
C - compressor
LT - liquid expander

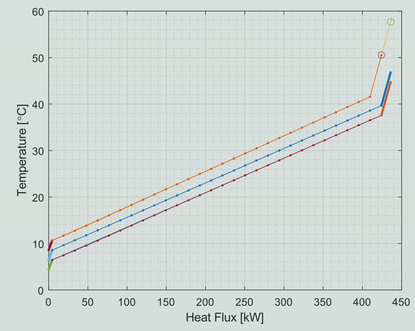
SYMBOLS

PRINCIPLE OF OPERATION



HEAT EXCHANGER BALANCE



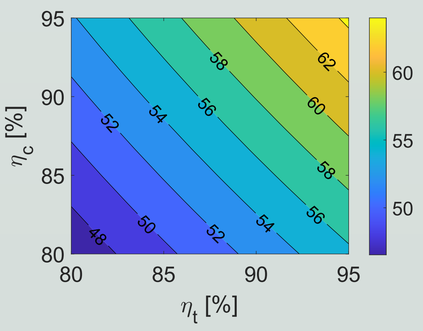


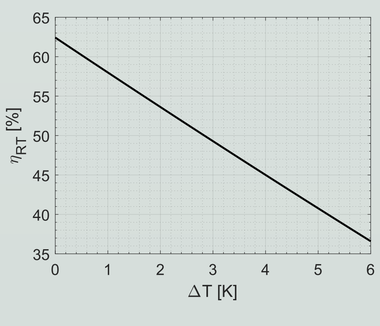
	Case 1	Case 2	Case 3	Case 4
Turbine efficiency [%]	83.0	89.0	92.0	94.0
Compressor efficiency [%]	79.0	83.0	86.0	90.0
Feed pump efficiency [%]	45.0	60.0	70.0	80.0
Expander efficiency [%]	50.0	70.0	80.0	85.0
Motor efficiency [%]	91.0	94.0	97.0	99.0
Generator efficiency [%]	91.0	94.0	97.0	99.0
Circulation pumps efficiency [%]	50.0	70.0	80.0	85.0
Roundtrip efficiency [%]	43.8	53.6	61.5	68.5

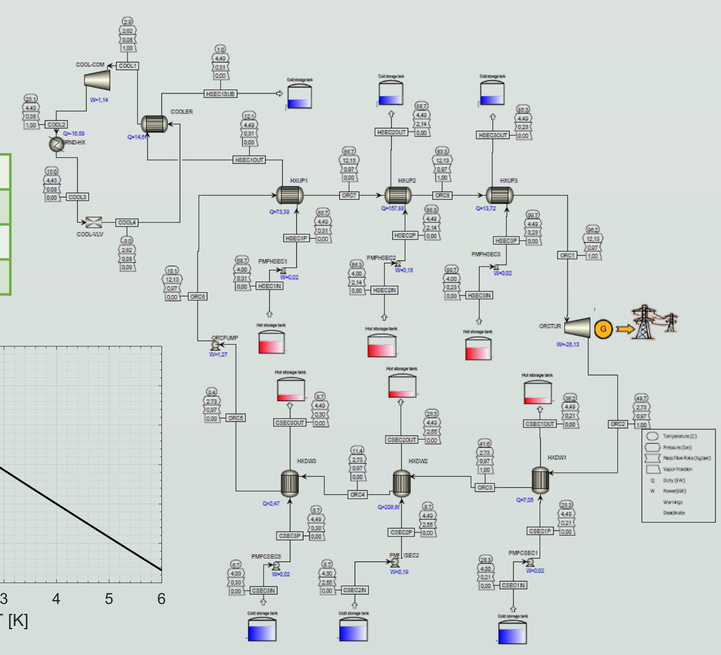
	4 K	3 K	2 K	1 K
Roundtrip efficiency [%]	45.0	49.3	53.6	58.0

RESULTS FOR OPTIMIZED 4 FLUID MIXTURE

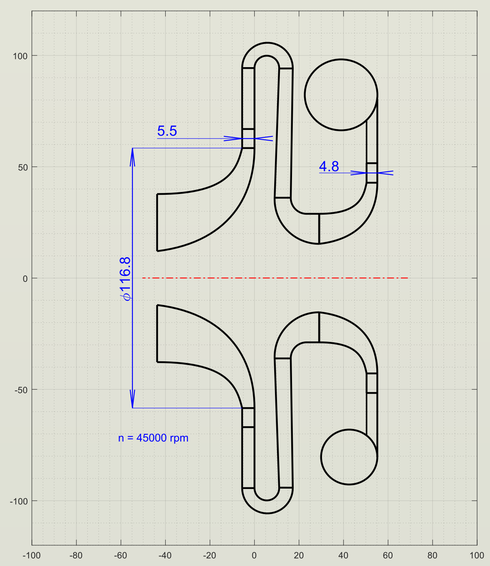
Compressor suction	145 kPa(abs)
Compressor dischrge	772 kPa(abs)
Pressure ratio	5.32
Storage density	1 kWh per 1 m^3 of water

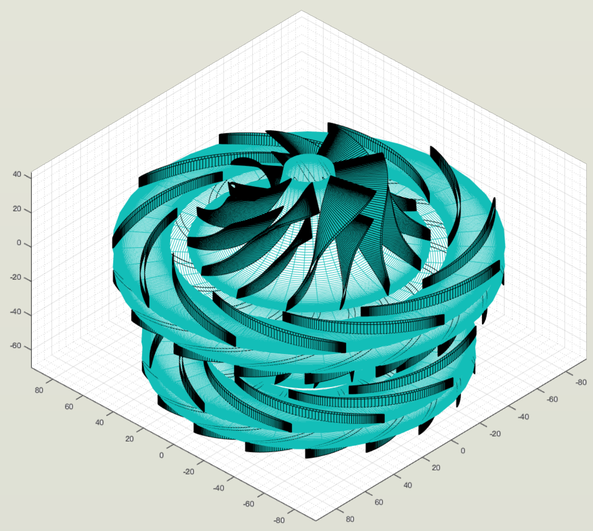


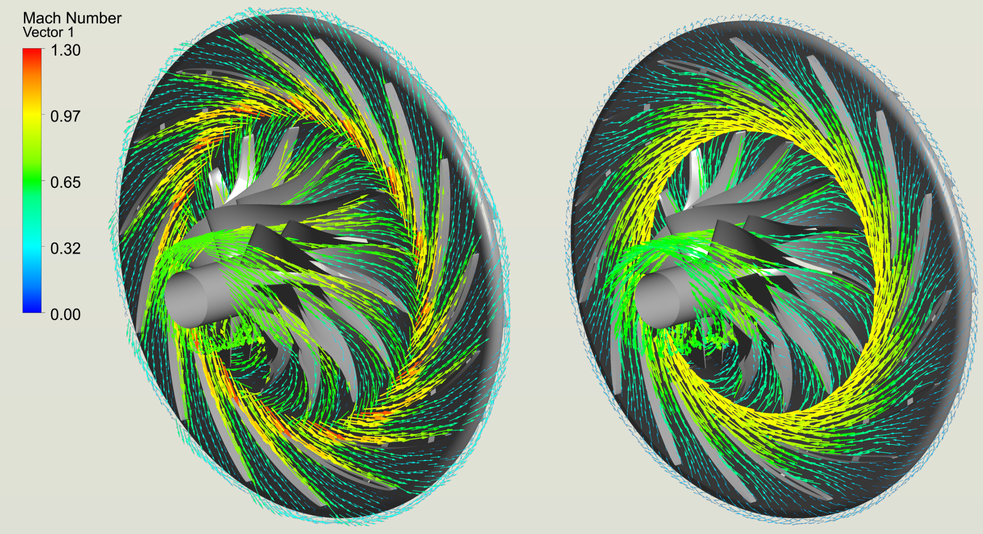




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References

[1] Dumont O., Frate G. F., Pillai A., Lecompte S., De Paepe M., Lemort V. Carnot battery technology: A state-of-the-art review. Journal of Energy Storage, Vol. 32, 2020.
[2] Novotny V., Basta V., Smola P., Spale J. Review of Carnot Battery Technology Commercial Development. Energies, Vol. 15, Issue 2, 2022.
[3] Steinmann W. D. The CHEST (Compressed Heat Energy STorage) concept for facility scale thermo mechanical energy storage. Energy, Vol. 69, 2014.
[4] Bernehed A. ZeoPTES: Zeotropic Pumped Thermal Energy Storage with an Ammonia–Water Mixture as Working Fluid. Energy Technology, Vol. 9, Issue 11, 2021.
[5] Koen A., Farres-Antunez P., Macnaghten J., White A. A low-temperature glide cycle for pumped thermal energy storage. Journal of Energy Storage, Vol. 42, 2021.

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