Energy storage using an advanced CAES technology – adiabatic compressed gas energy storage

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Compressed Air Energy Storage—CAES

In Pumped Hydro Power Plants energy is stored in the difference of potential energy at two height levels:

$$E = m \cdot g \cdot \Delta h = \rho \cdot V \cdot g \cdot \Delta h = V \cdot \Delta p$$

Where *m* is the mass of the medium, *g* is gravity, *Δh* the height difference, *ρ* the density of the medium, *V* the Volume and *p* the pressure.

This is similar in CAES, however as the storage medium is a gas the 1st law of thermodynamics becomes part of the game. Energy is stored as work $w = p \cdot dV$ and also as heat *q*.

$$E = \Delta U = q + w$$

The Problem

The production of heat during the compression of a gas is a major handicap in CAES.

In „conventional“ CAES like in the ADELE [1] project the heat that was generated during the compression phase was to be stored above ground.

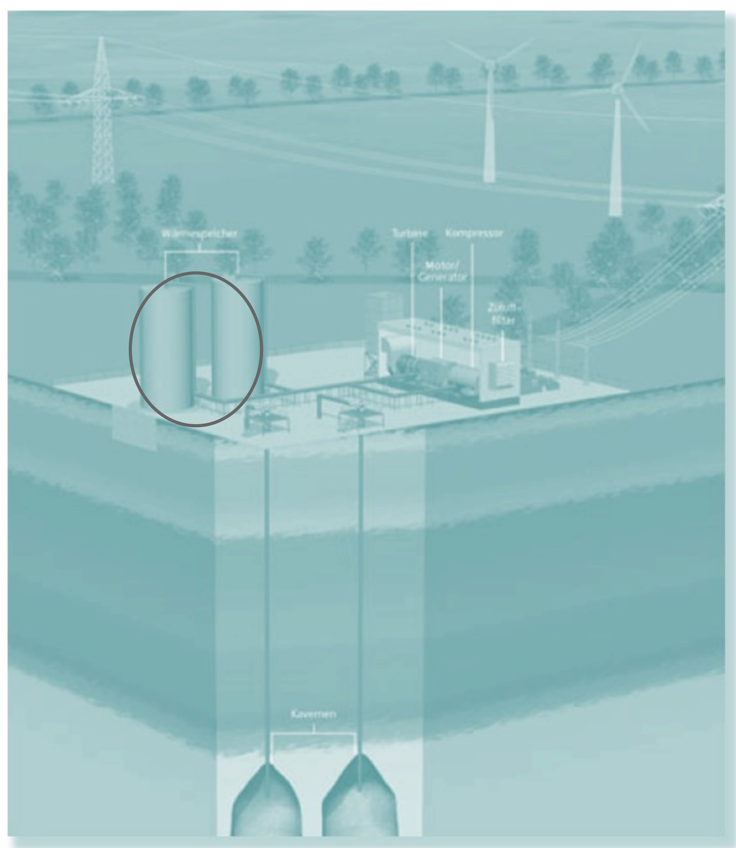
Temperatures in excess of 600 °C were being produced.

The storage of heat at such high temperatures was never resolved successfully.

Heat production also influences the efficiency of the process.

The efficiency of a compression / expansion process is given by the temperature ratio:
$\eta = T_1/T_2$

Conventional CAES	$\eta = 300/750 = 0.4$
erneo	$\eta = 300/320 = 0.94$



[1] „ADELE – Der adiabate Druckluftspeicher für die Elektrizitätsversorgung“ Broschure RWE-Power und DLR, http://www.dlr.de/Portaldata/1/

Its Reason

When compressing gas heat is produced and the temperature rises.

Gas temperature in conventional cavern wells and caverns however is limited to values far below 100°C.

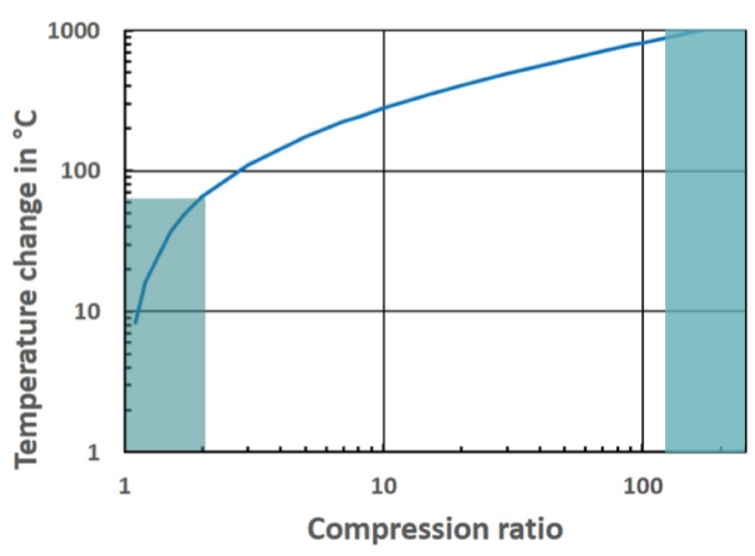
Therefore air cooling and later heating or heat storage at high temperatures are required.

This negatively influences the CAES efficiency!

Temperature change is directly dependent on the compression ratio, not pressure difference!

In conventional CAES the compression ratio Π = p2/p1 is greater than 70 and the temperatures are in excess of 500 °C.

At compression ratios of below 2 the temperature changes remain in the range of between 10 to 60 °C.



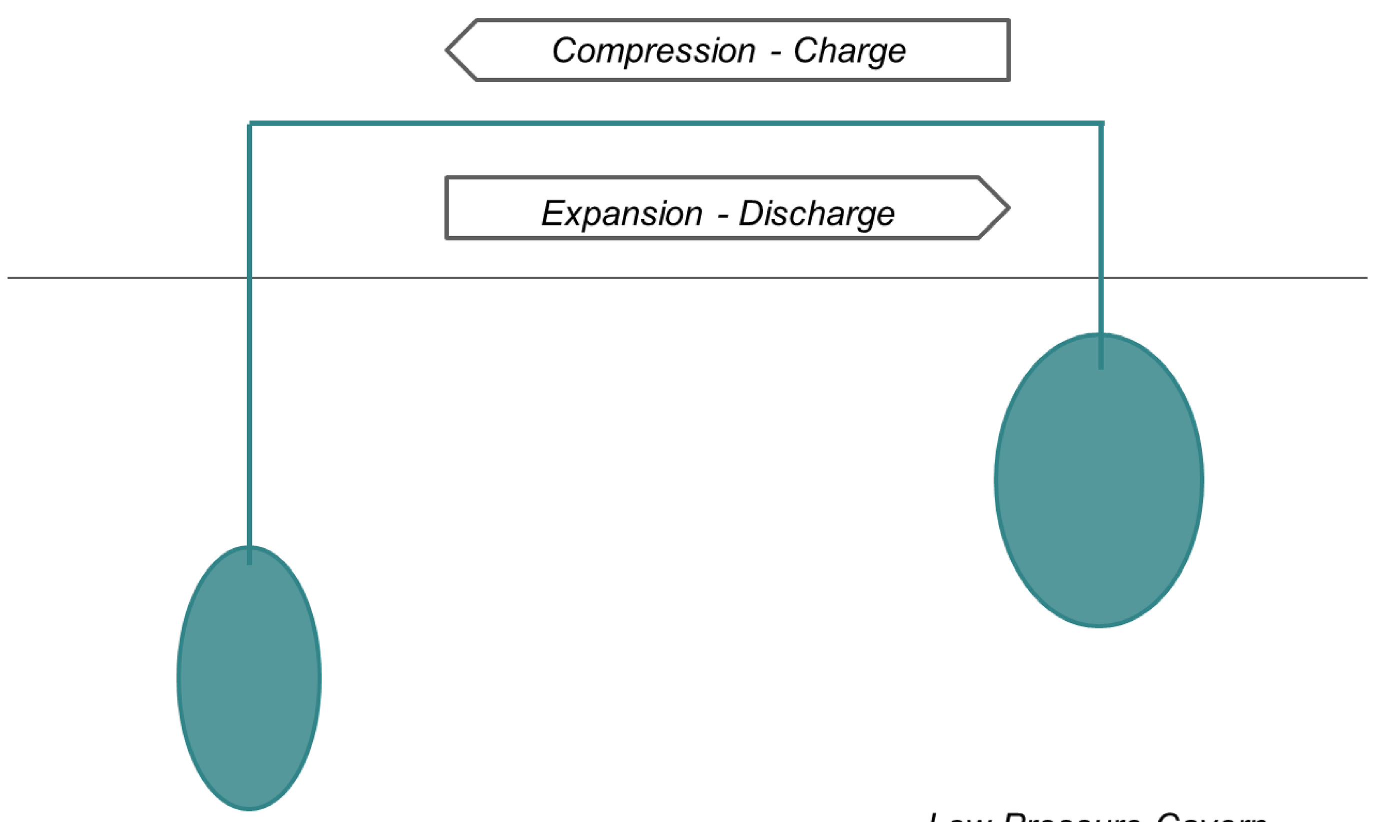
The Solution

If the gas is e.g. exchanged between 1 and 150 bar, the compression ratio is 150 and temperature change is high. The energy stored in compression is Δp·V.

The same work of compression can be stored between a pressure 100 and 250 bar, however this requires a second storage volume. The **compression ratio** is **2.5** and **temperature change < 60 °C**.

Heat can be stored at much lower temperature e.g. in a water reservoir.

The thermodynamic efficiency is in the order of 90 % instead of 40 %.



The Advantages

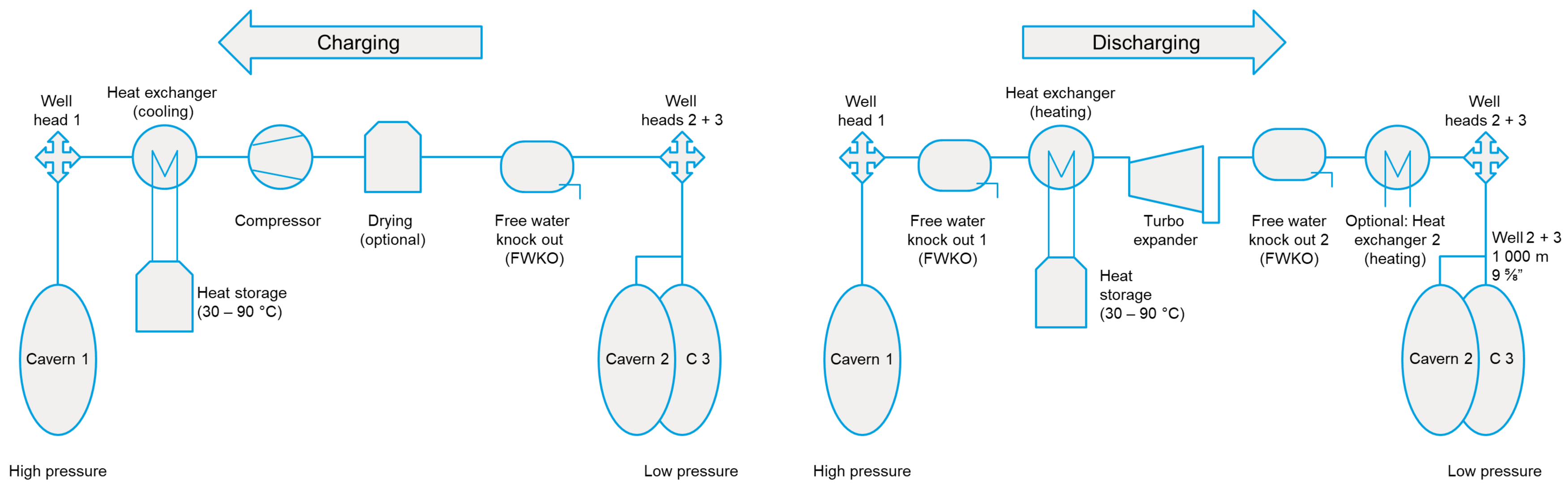
- Reduced compression heat.

- Therefore no losses due to cooling or no heat storage required.
- “Moderate“ wear of caverns and wells.
- Temperature changes in caverns app. 10 … 20 °C.
- Pressure changes, depending on operation mode between 20 … 40 bar / d (e.g)
- No restriction e.g. in depth for the layout of caverns.
- Can be realised in existing natural gas storage caverns or in caverns converted for CAES.
- Heat storage at temperatures between 30 – 90 °C will increase efficiency. Operation without heat storage is possible.
- Efficiency between 70 and 90 % depending on required operation and storage (optimized concept).

Examples

Existing Gas Storage 7 MW 50 MWh

In natural gas storage facilities using salt caverns all components for energy storage are present except an expansion turbine. The power however is limited by the possible flow rate which is determined by the well size and the resulting pressure loss.



Discharge power	5 - 7	MW
Discharge capacity	50	MWh
Discharge duration (h)	8	h
Rate (Nm3/h)	250 000	Nm^3/h
Efficiency	78	%
Heat reservoir (water)	1 200	m^3

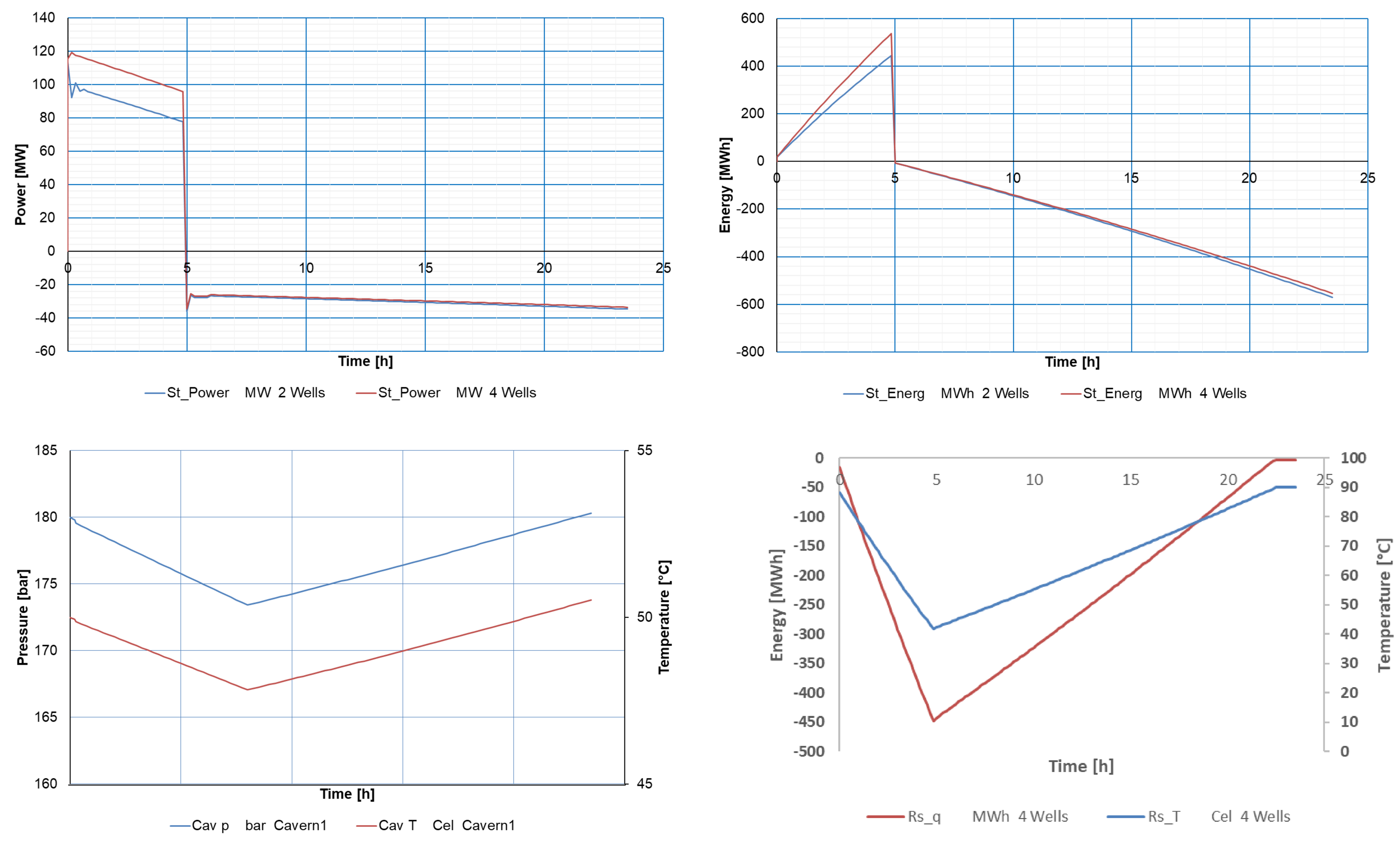
Cavern design			
Number of caverns:	3 (1 high p, 2 low p)	Geom. Volume:	500 000 m³ (each)
p_{min} / p_{max}:	60 / 180 bar	Depth LCCS:	1 000 m (each)
Completion:	9 ⅝“ in 13 ⅜“ LCC	Storage medium:	Natural gas

New facility - 100 MW - 500 MWh - Air

In a new built storage facility caverns can be placed at the optimum depth, a larger diameter for the wells can be taken as well as more wells per cavern to allow for a higher flow rate. Also air can be used as storage gas.

Discharge power	100 – 120	MW
Discharge capacity	440 / 530	MWh
Discharge duration (h)	5	h
Rate (Nm3/h)	2 600 000	Nm^3/h
Efficiency	76 / 95	%
Heat reservoir (water)	8 000	m^3

Cavern design			
Number of caverns:	3 (1 high p, 2 low p)	Geom. Volume:	800 000 m³ (each)
p_{min} / p_{max}:	60 / 260 bar	Depth LCCS:	1 500 / 1 200 m
Completion:	14”	Storage medium:	Air
2 scenarios with 2 wells and 4 wells per cavern and 3 stages for compression/expansion			



Power - Stored Energy - Pressure and Temperature in Cavern1 - Temperature and stored Heat