Heat management of decentralized adiabatic compressed air energy storage

IRES III
Parallel session C:
Combining thermal energy storage and power generation
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Content

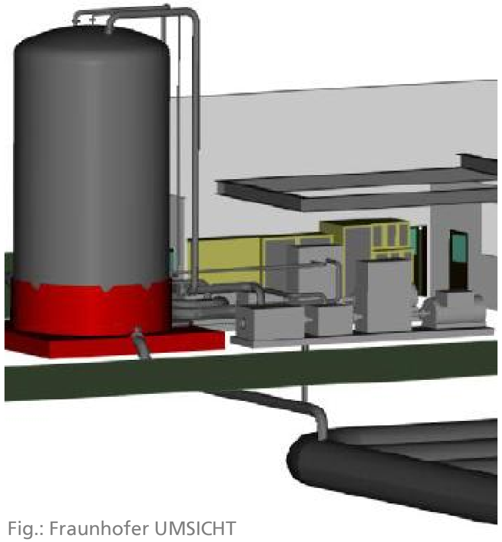

Fig.: Fraunhofer UMSICHT

(1) Basic CAES concepts

(2) Excess heat in CAES systems

(3) Heat management solutions

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Diabatic Compressed Air Energy Storage

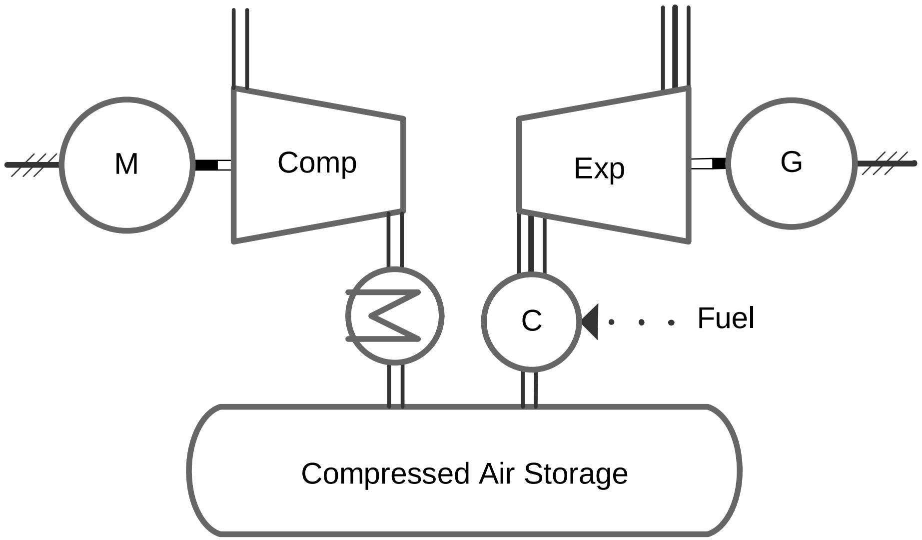
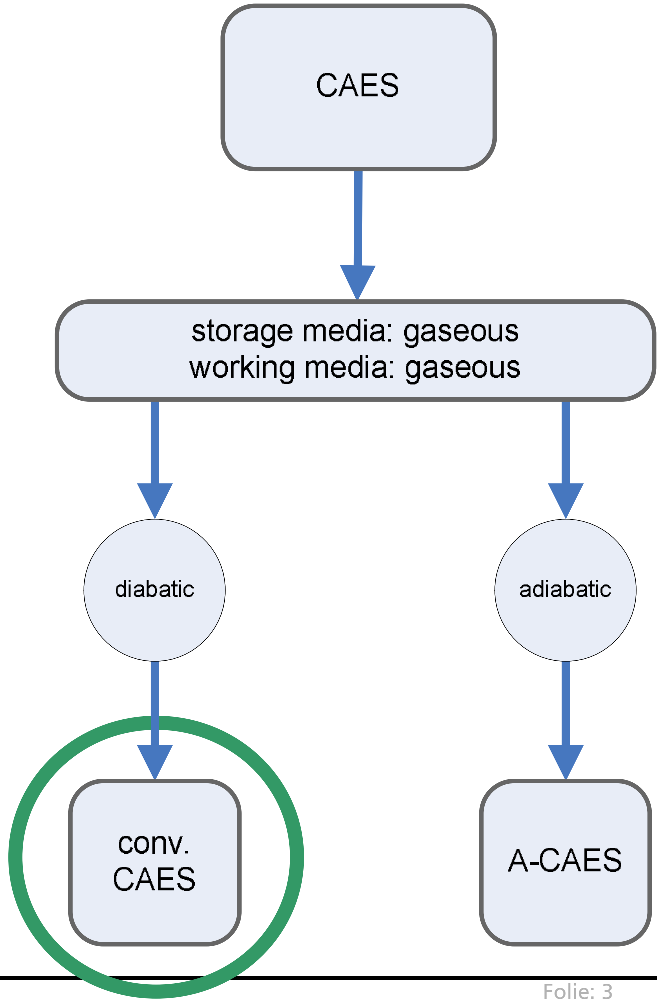


Fig.: Fraunhofer UMSICHT



Diabatic CAES

+ wide output power control range
+ Lower spec. investment cost

- Lower cycle efficiency of up to 0.55
- No real storage

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Adiabatic Compressed Air Energy Storage

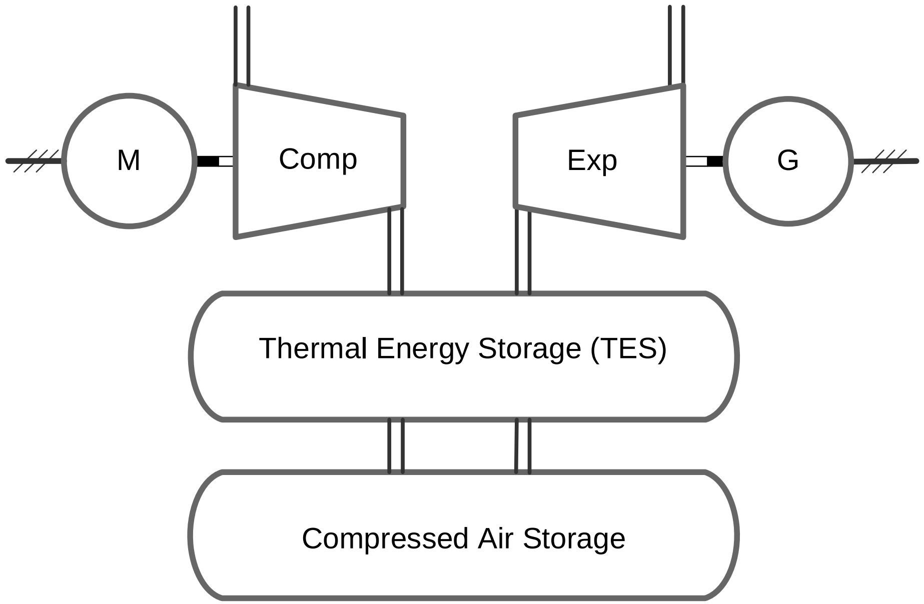
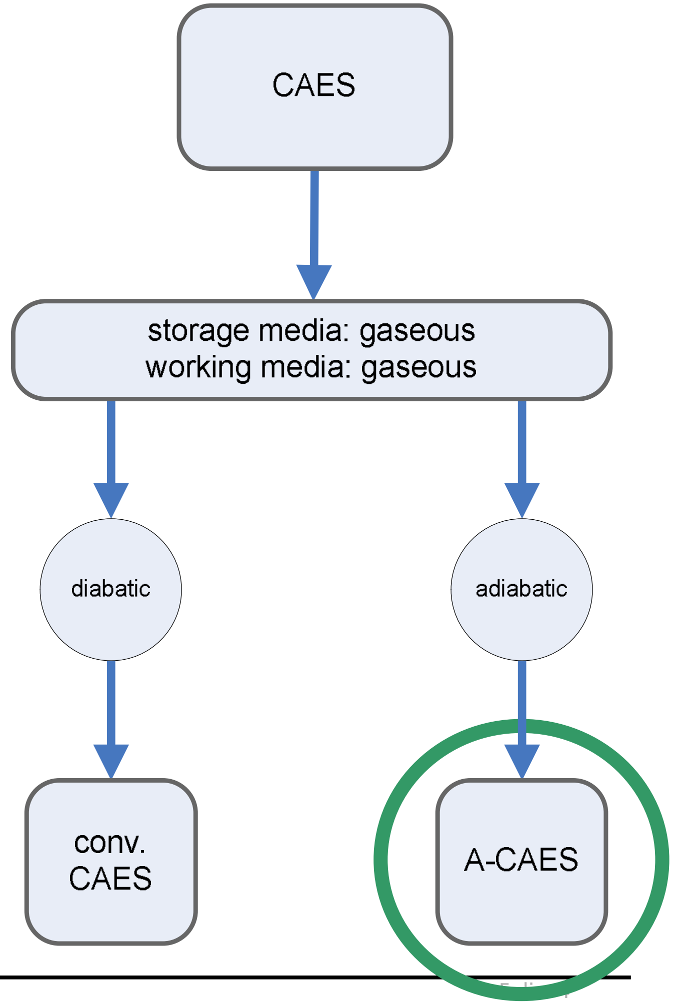


Fig.: Fraunhofer UMSICHT



Adiabatic CAES

- \+ Zero emission
- \+ High cycle efficiency of up to 0.7
- \+ Independent of fuel price volatility

- \- Smaller output power control range
- \- Higher spec. investment cost

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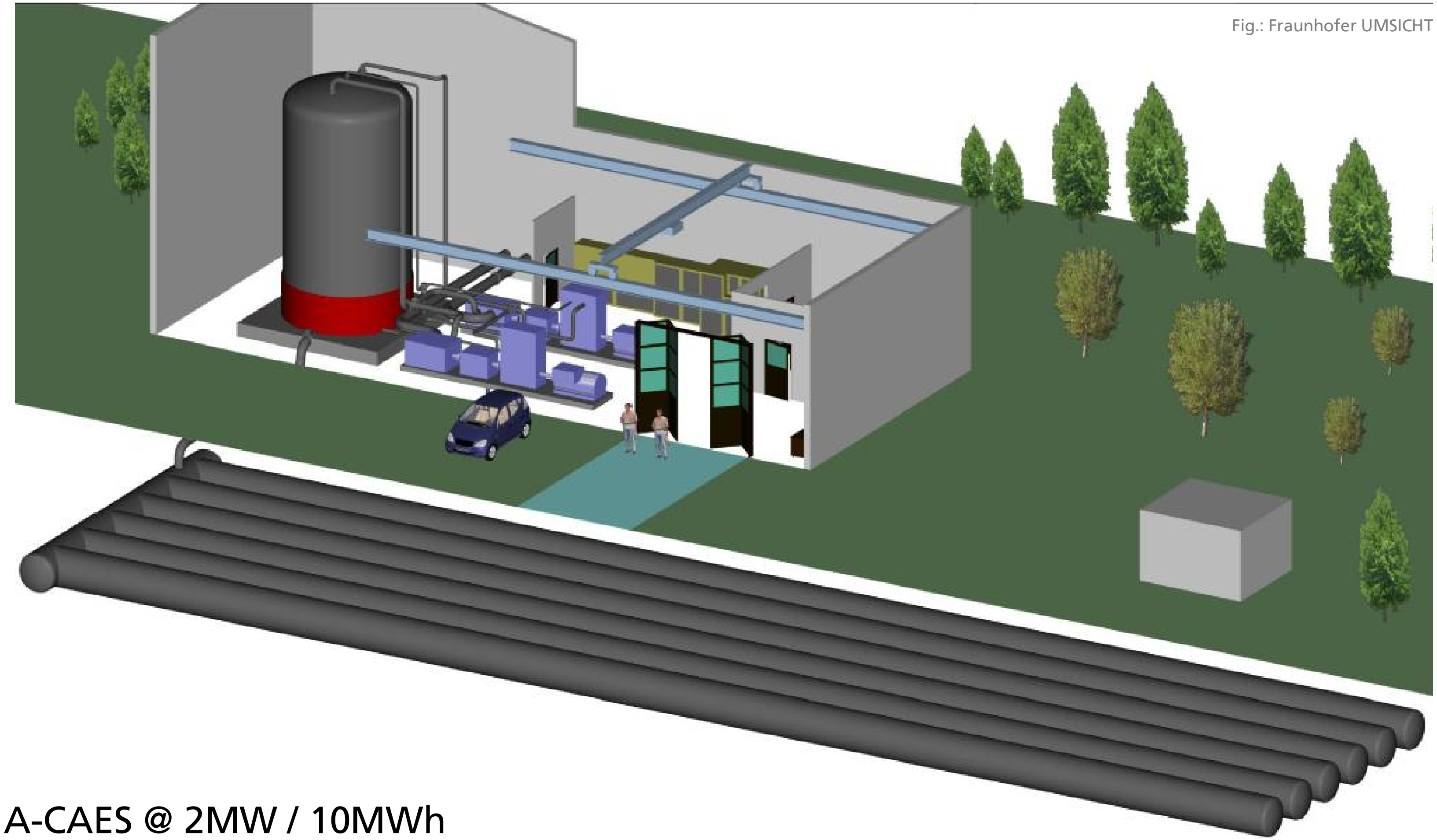
A-CAES plant layout



A-CAES @ 2MW / 10MWh

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Excess heat in CAES systems

Excess heat in CAES systems

Excess heat - compression heat exceeds useable heat for expansion

à **Excess heat in A-CAES system could lead to a TES-overload.**

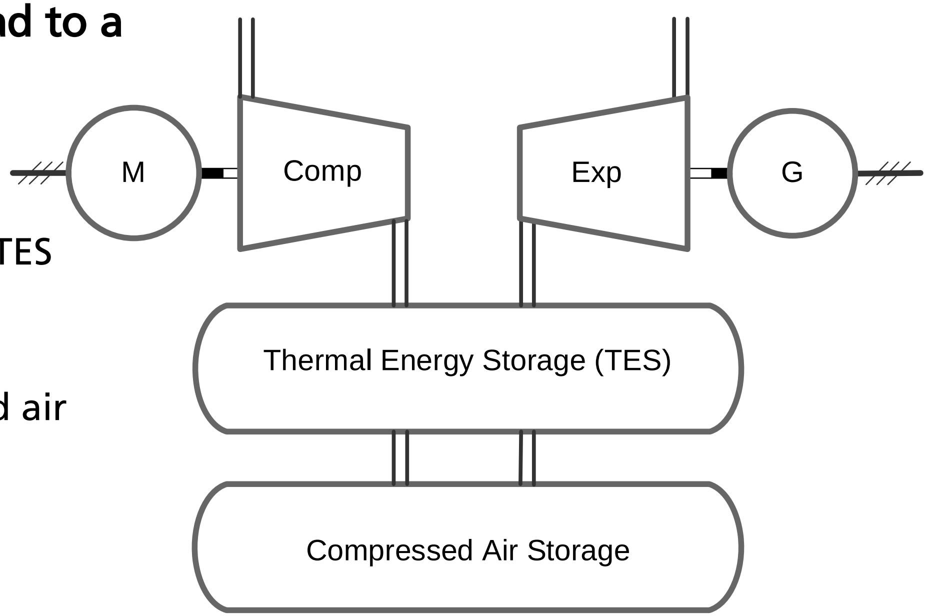

Fig.: Fraunhofer UMSICHT

Consequences:

- Air cannot be cooled down enough in the TES
- Higher compressor stages suffer greater thermal stresses
- Storage temperature inside the compressed air storage reaches safety relevant values
- Overall efficiency of the system decreases

Basic principles:

- Non-isentropic compression and expansion
- Condensation and separation of humidity of ambient air

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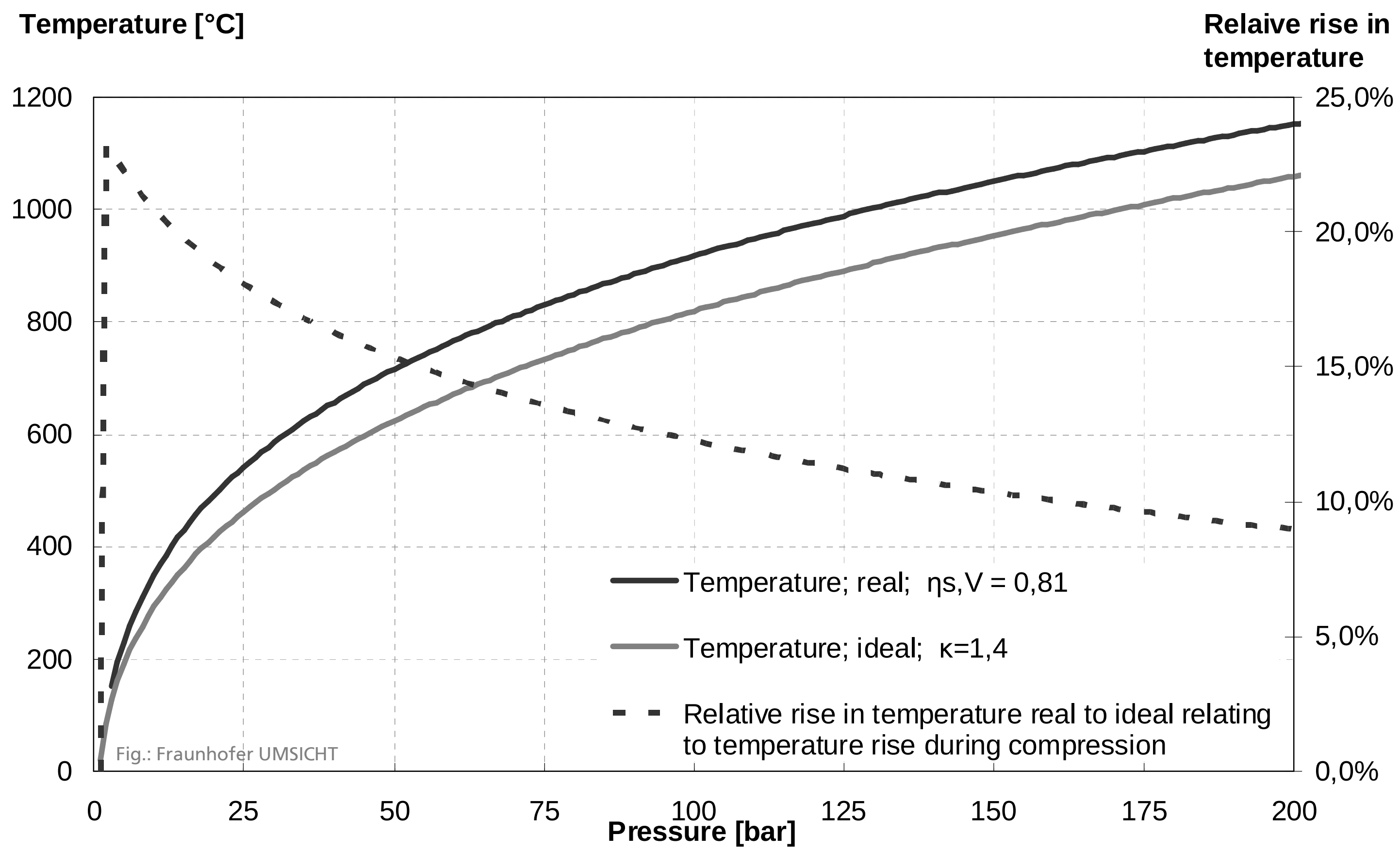
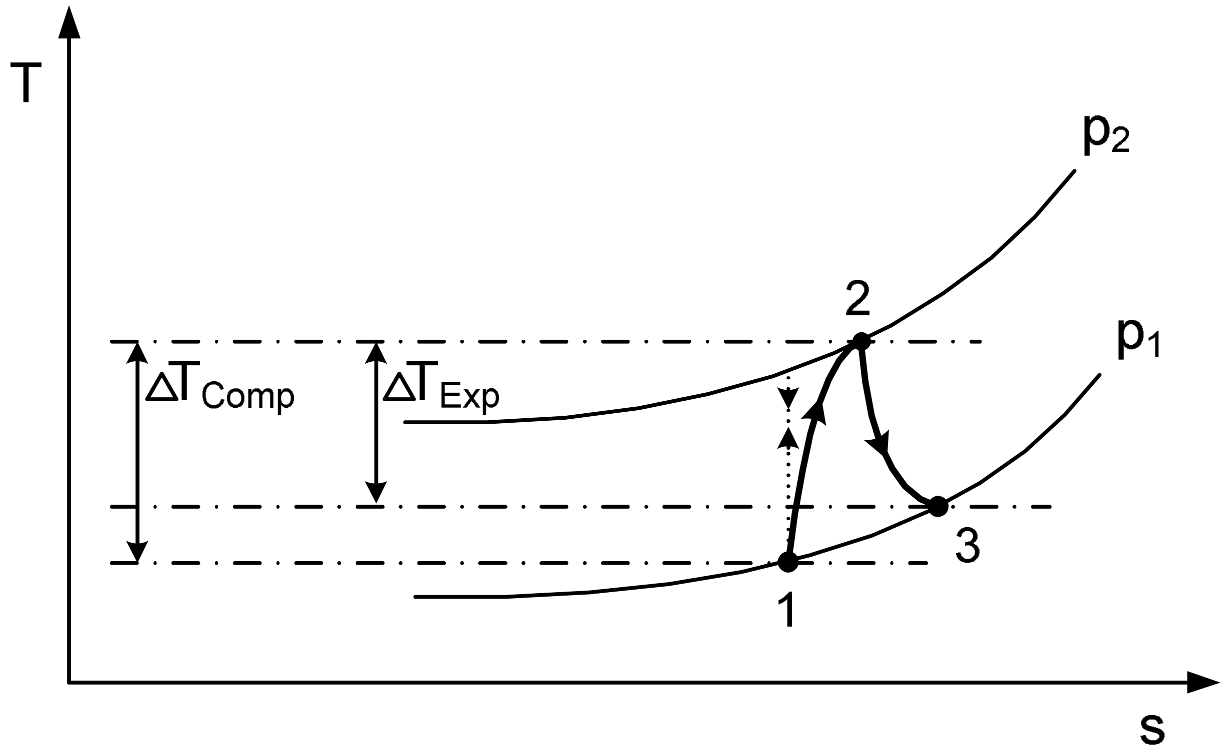
How hot compressed air can get!



Non-isentropic compression and expansion



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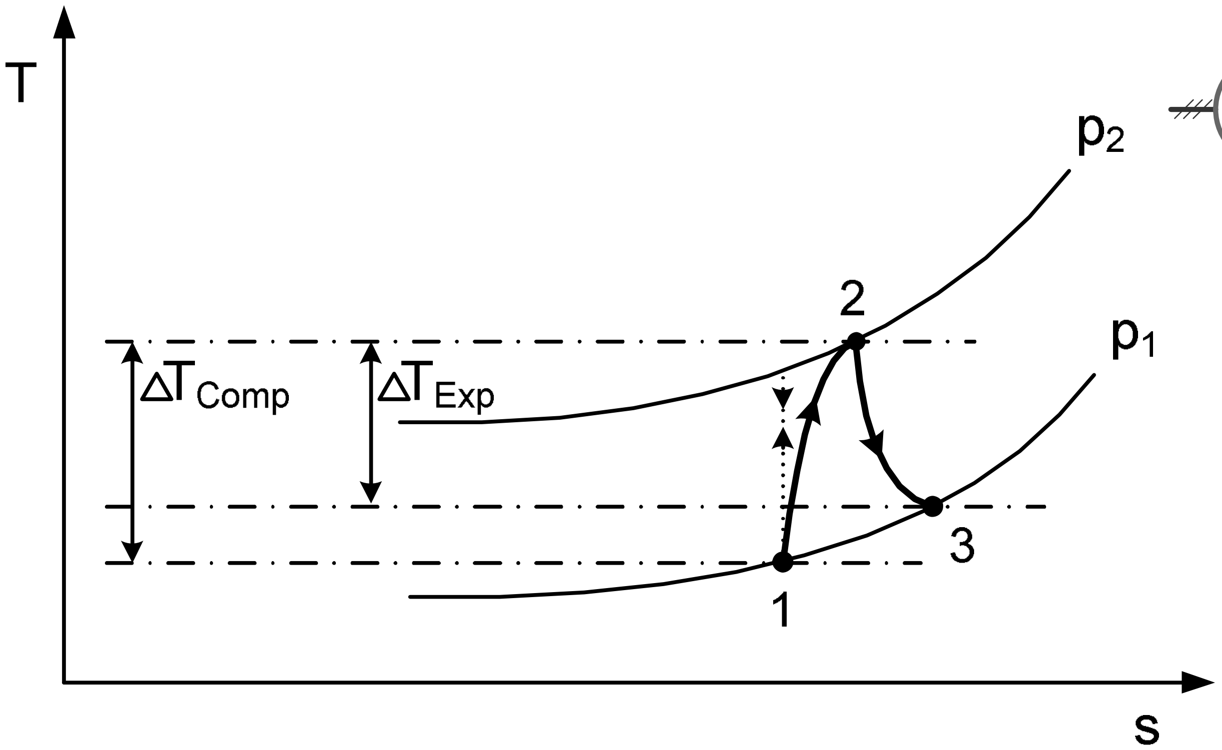
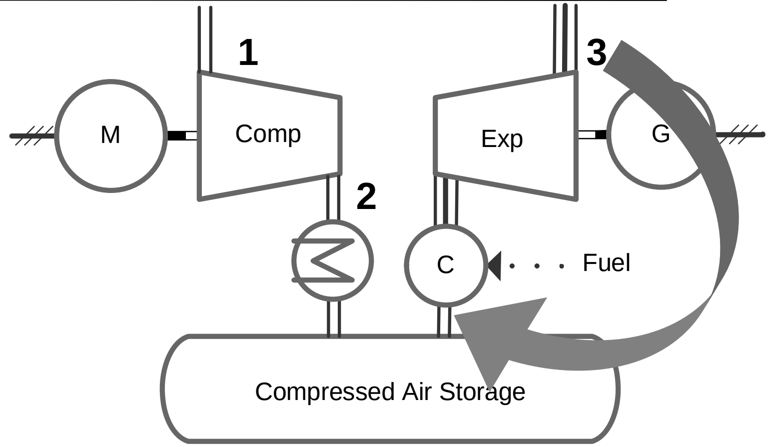
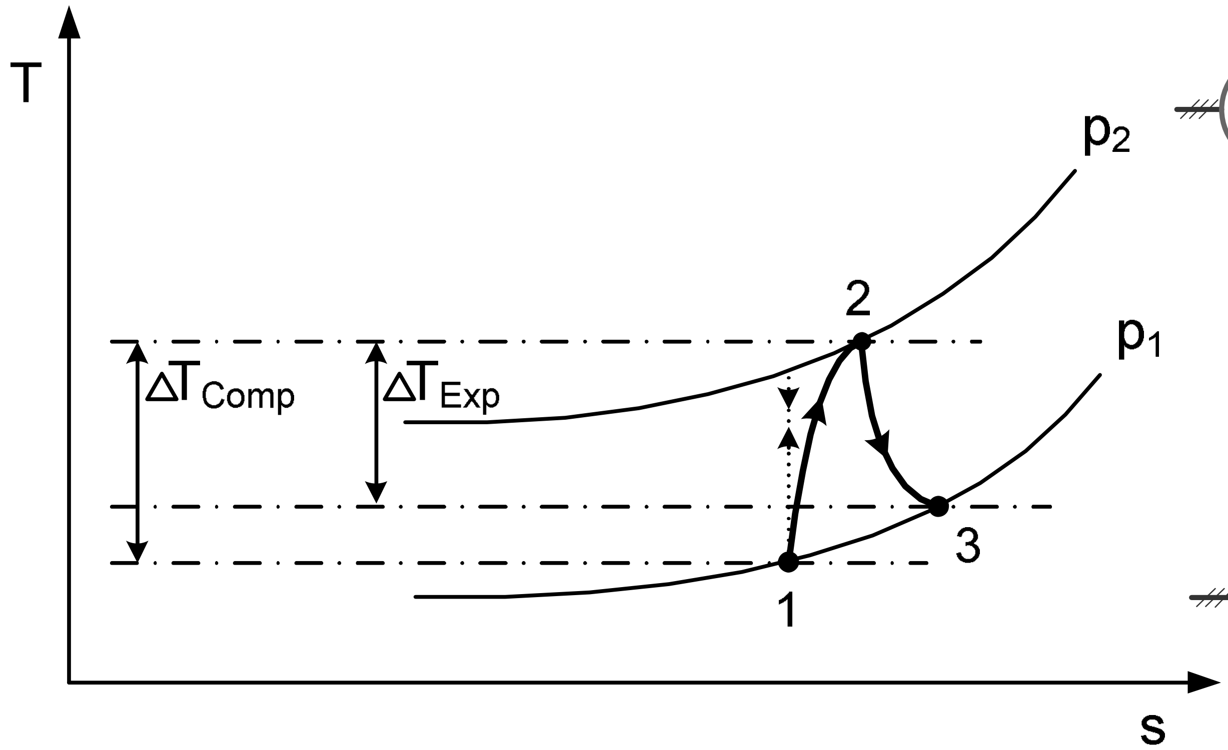
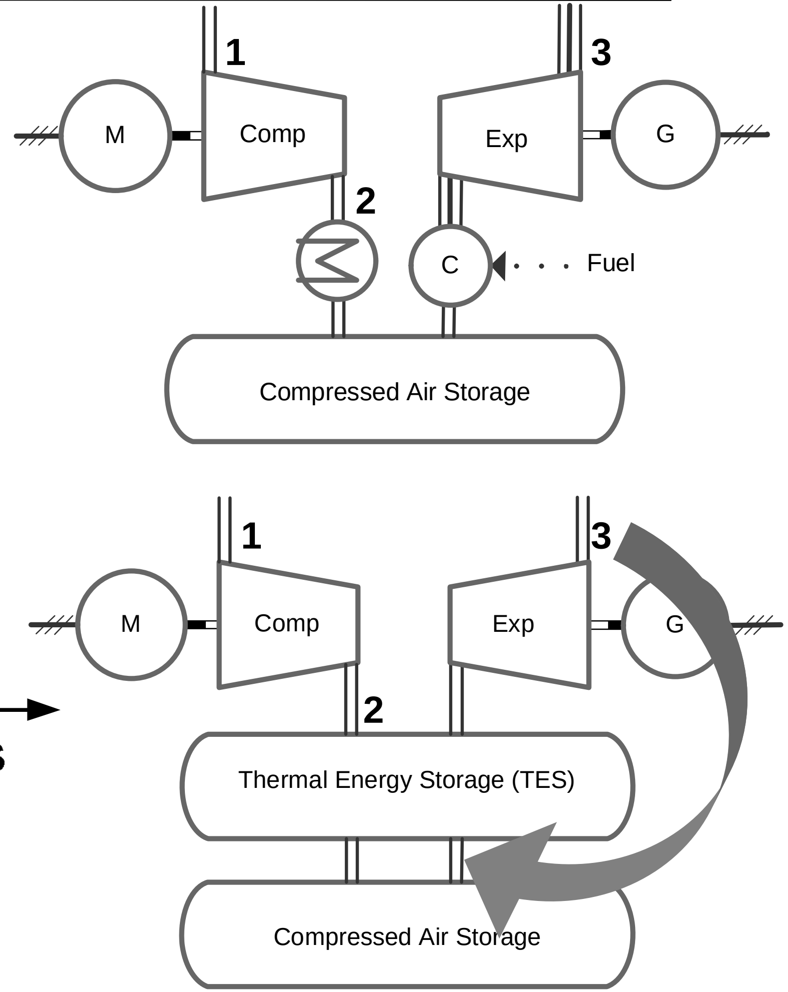
Non-isentropic compression and expansion





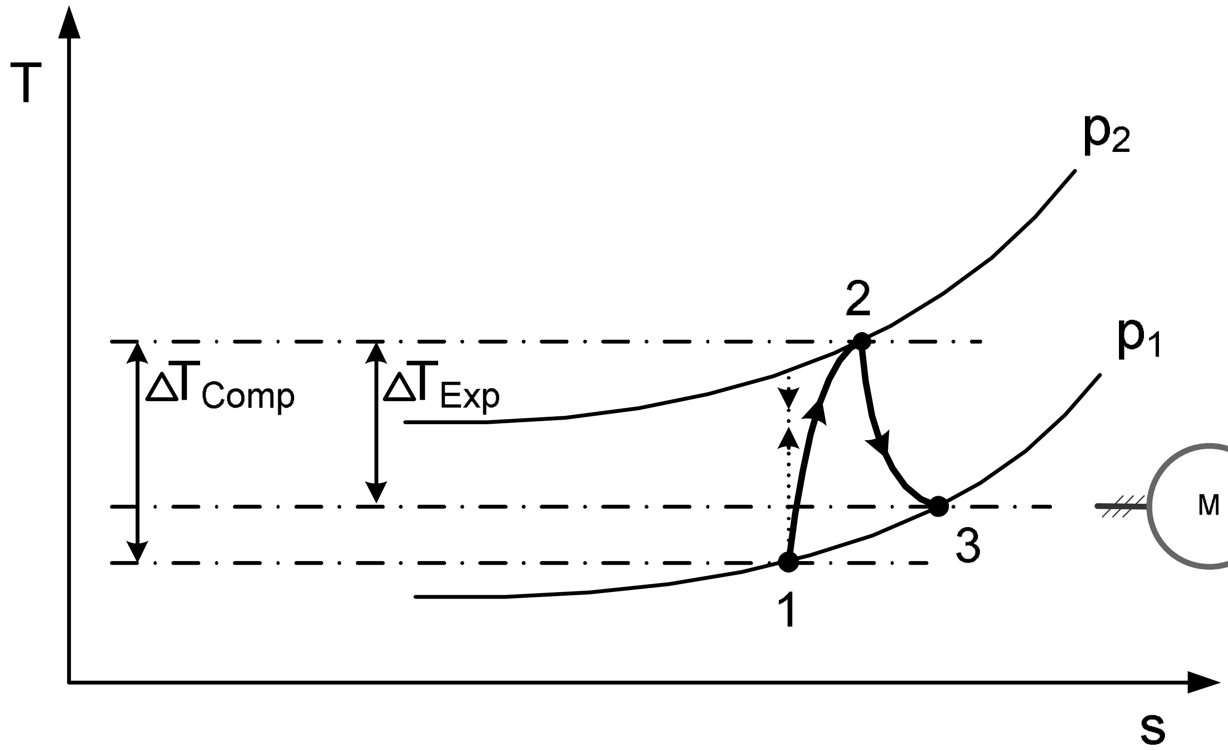
Non-isentropic compression and expansion

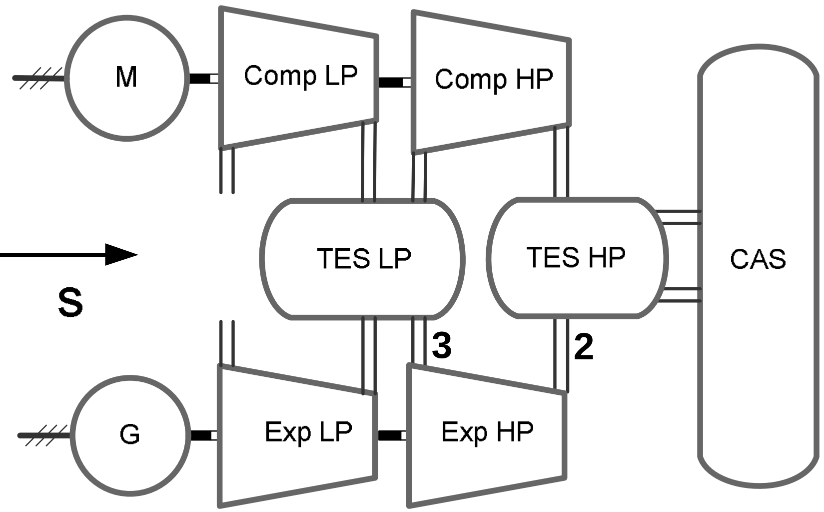




- No heat recuperation for A-CAES

Non-isentropic compression and expansion



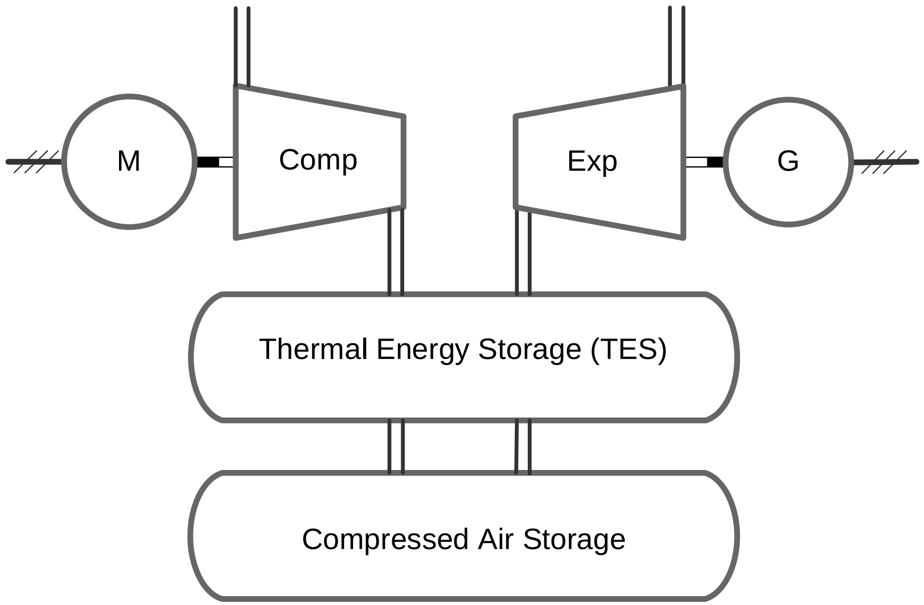


- No heat recuperation for A-CAES
- Multi-stage expansion problematic for A-CAES

Influence of air humidity

- Ability of air to carry water increases with temperature and decreases with pressure

- Separated free water decreases the heat capacity flow of air during expansion



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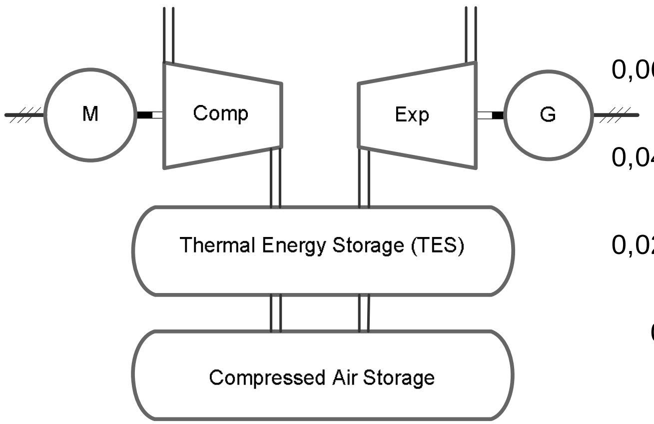

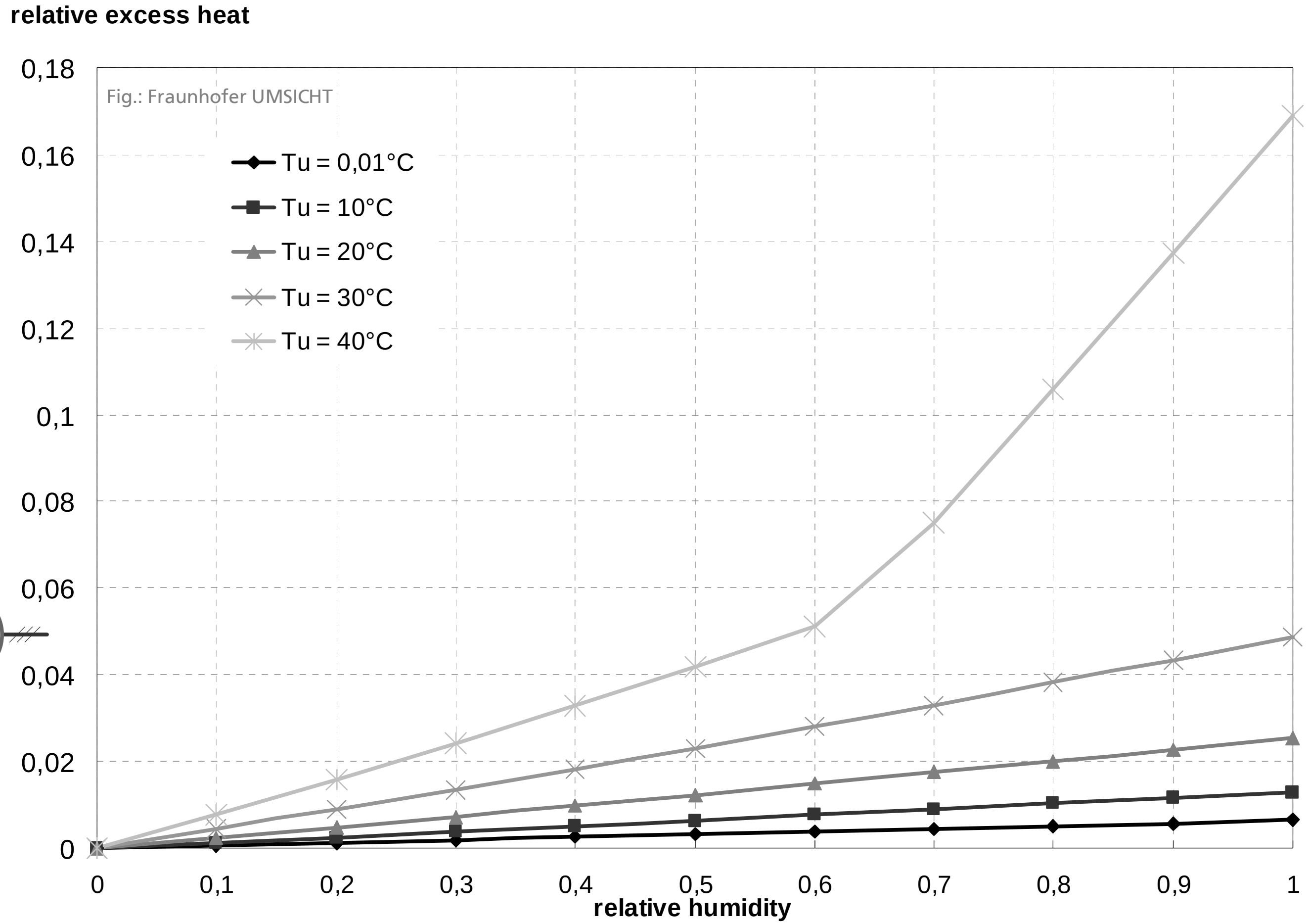

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Heat management solutions

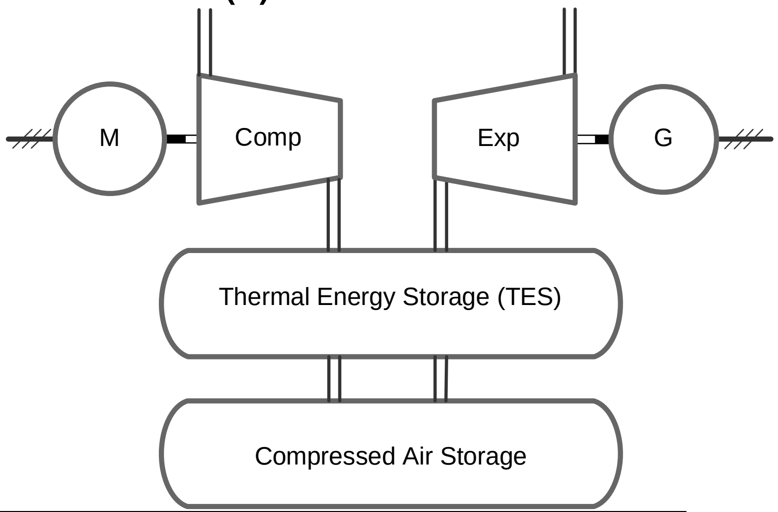
Heat management solutions for TES load balancing

Basic intention of heat management:

à Enabling cyclic operation through an equilibrated TES load balance

Possible solutions:

- Controlled re-cooling of the TES or air flow directly (1)
- Passive adaptation of thermal losses to excess heat (2)
- Injection of water to the airflow during reheating in the TES (3)
- Combined use of excess heat (4)
  (e.g. for an ORC-process, district heating)



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Assessment of heat management solutions

	Financial effort	Technical effort	Operational Flexibility	Plant Effi-ciency
(1) Re-cooling	--	O	++	--
(2) Adaptation of thermal losses	++	++	-	--
(3) Water injection	-	--	+	++
(4) Combined use of excess heat	O	-	O	+

Table: Qualitative Assessment of possible heat management solutions for adiabatic compressed air storage plants ranging from highly favourable (++) to highly unfavourable (--)

- No single solution satisfies all needs!
- Since excess heat could be harvested on a relatively high temperature level the deployment of solution 3 or 4 should be investigated in detail

à Demand for quantitative analysis of possible plant layouts

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Challenges for quantitative evaluation of heat management solutions

- Time dependant storage losses
- Decreasing isentropic efficiencies in part load operation
- Varying ambient conditions (temperature, humidity)

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Challenges for quantitative evaluation of heat management solutions

- Time dependant storage losses
- Decreasing isentropic efficiencies in part load operation
- Varying ambient conditions (temperature, humidity)

à Stationary calculations at design point are not sufficient for a proper plant design

Solution: Dynamic TES Model for the design of adiabatic CAES systems

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Dynamic Model of a stratified TES

Fig.: Ruhr-University Bochum

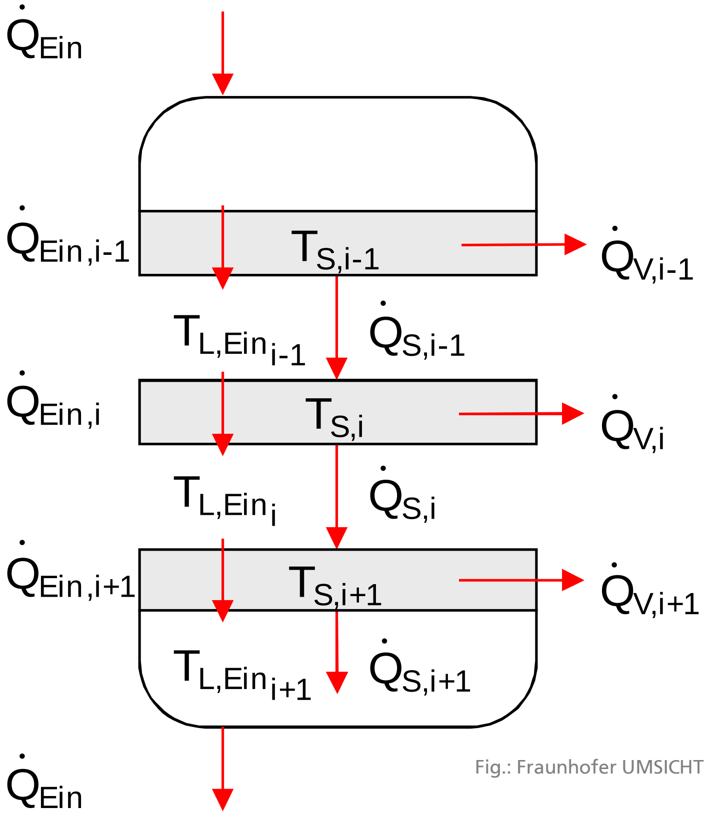


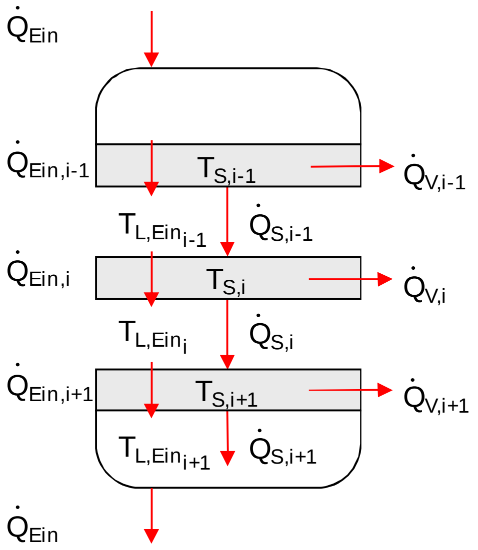
Fig.: Fraunhofer UMSICHT

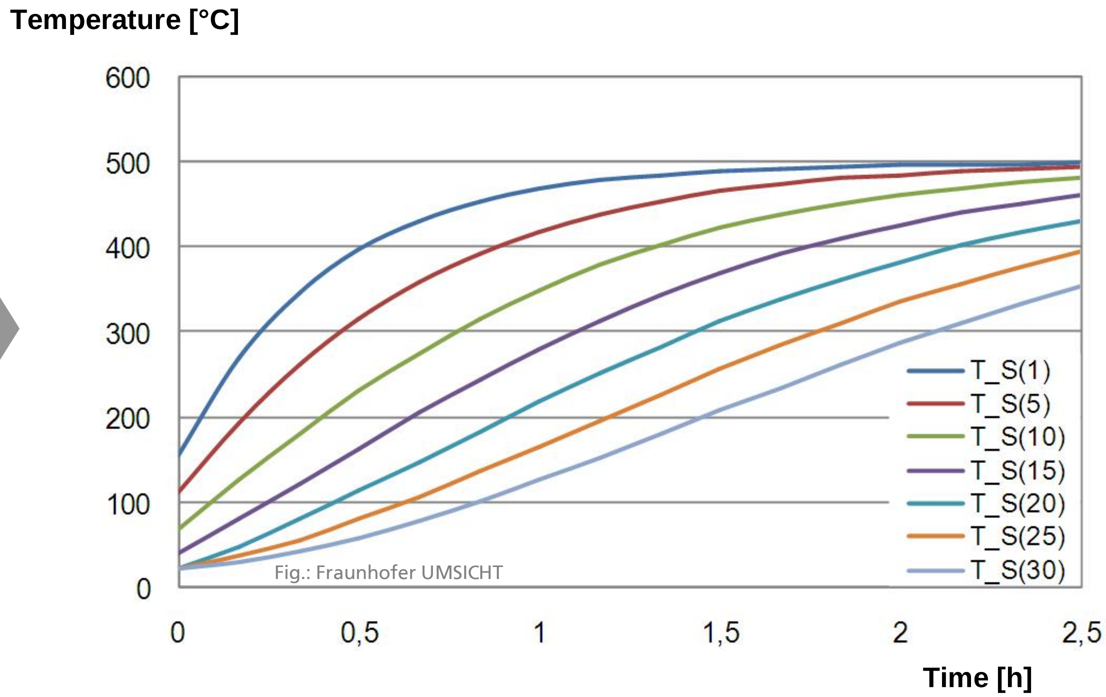
- High temperature CAES-TES
- Molten salt at T_{max} = 500°C

- One dimensional finite element approach
- Underlying real gas property models

Dynamic Model of a stratified TES

Loading of TES:





Conclusion

Conclusion

- There is excess heat in the TES of an adiabatic CAES plant
  - § Excess heat due to non-isentropic compression and expansion could be avoided by omitting heat recuperation and multi stage TES
  - § Condensation of the air humidity as a second reason for excess heat in the TES cannot be avoided that easily

à Necessity for TES heat management for safe and efficient operation of the A-CAES plant

- Four promising TES balancing solutions are proposed and evaluated qualitatively
- For a quantitative evaluation a dynamic computer model is proposed and currently under development

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