Dynamic simulation of possible heat management solutions for Adiabatic Compressed Air Energy Storage

EFFSTOCK
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Adiabatic Compressed Air Energy Storage

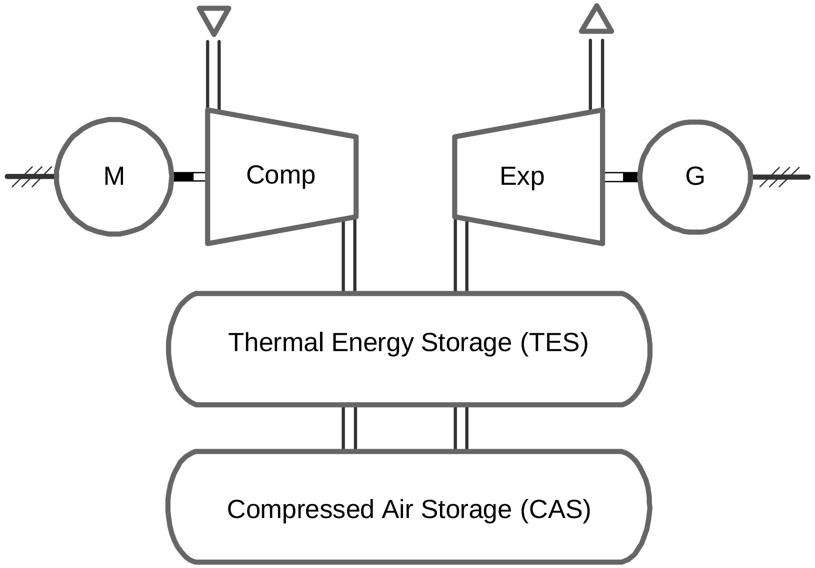
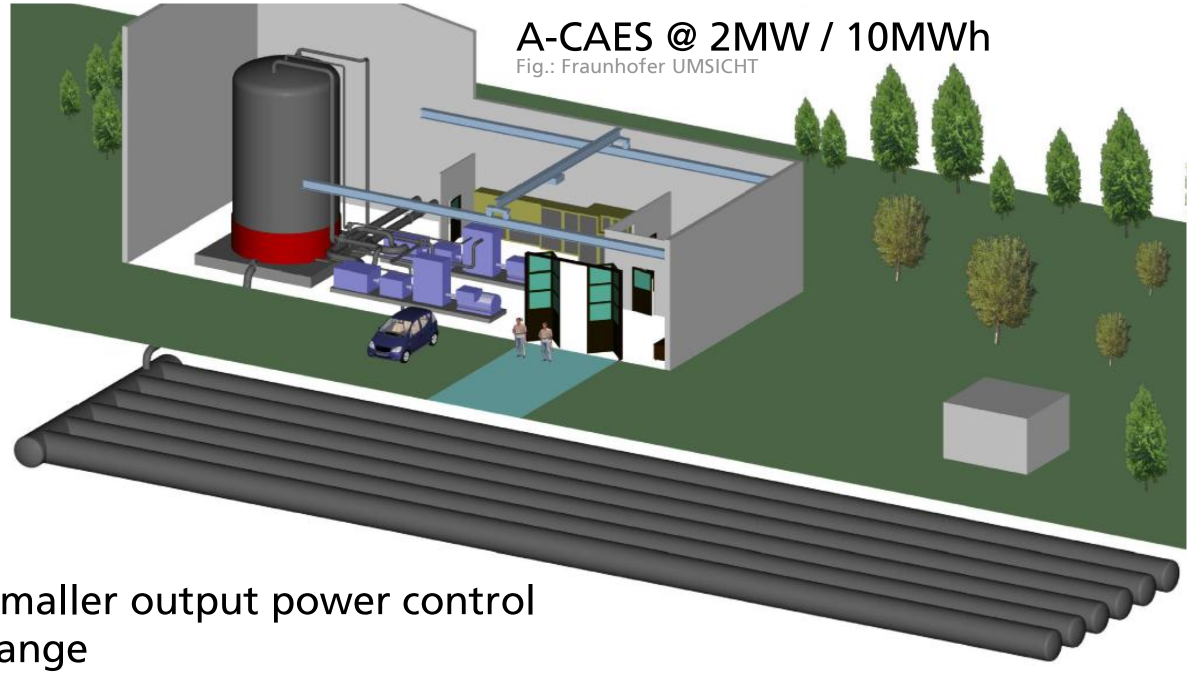


Fig.: Fraunhofer UMSICHT

A-CAES @ 2MW / 10MWh

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

(both compared to diabatic CAES)

Excess heat in CAES systems

Excess heat in adiabatic CAES plant

Excess heat - compression heat exceeds useable heat for expansion

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

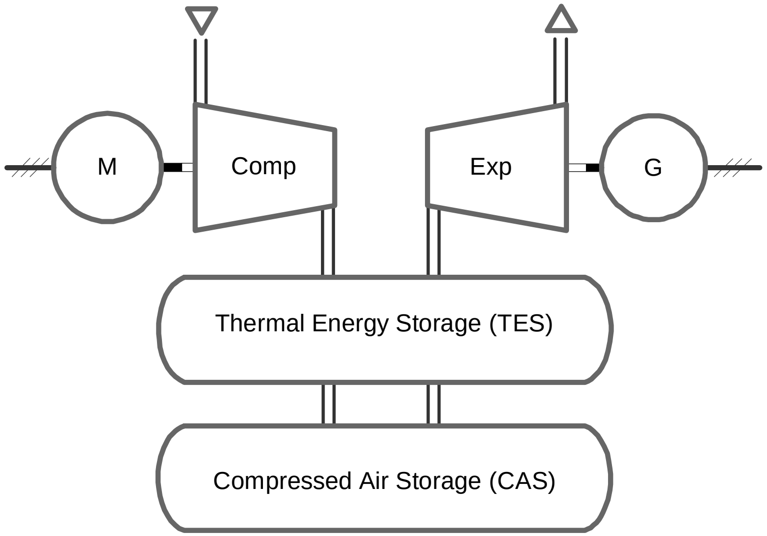


Fig.: Fraunhofer UMSICHT

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

Two basic principles for excess heat:

(1) Non-isentropic compression and expansion

(2) Condensation and separation of humidity of ambient air

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Principle 1
Non-isentropic compression and expansion

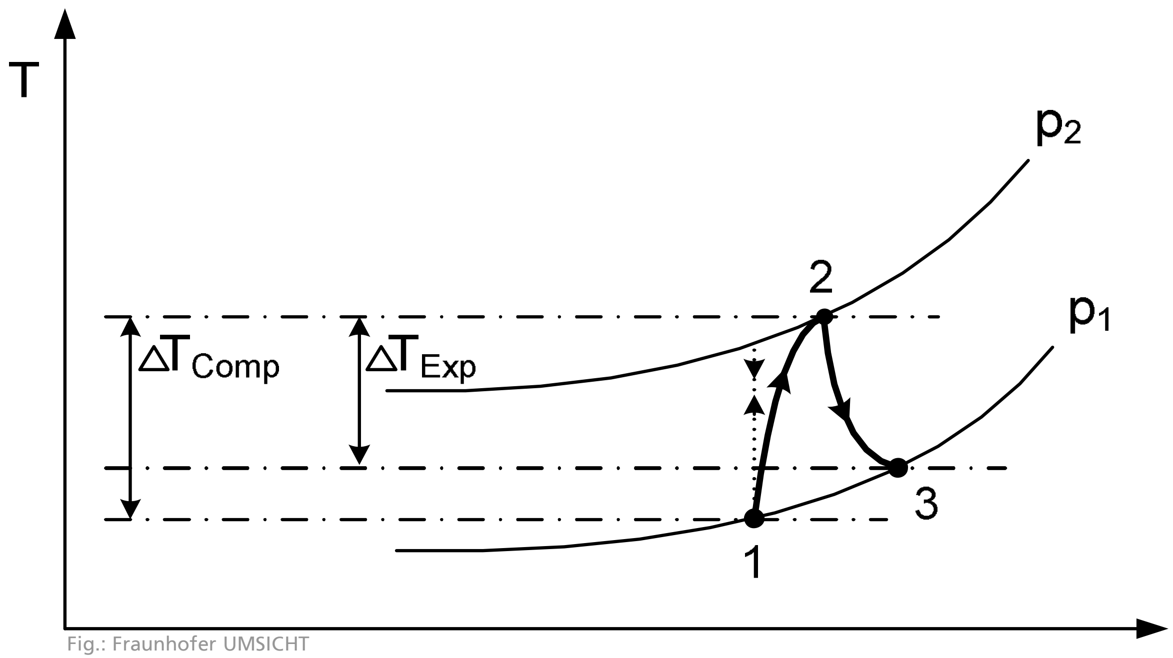

Fig.: Fraunhofer UMSICHT

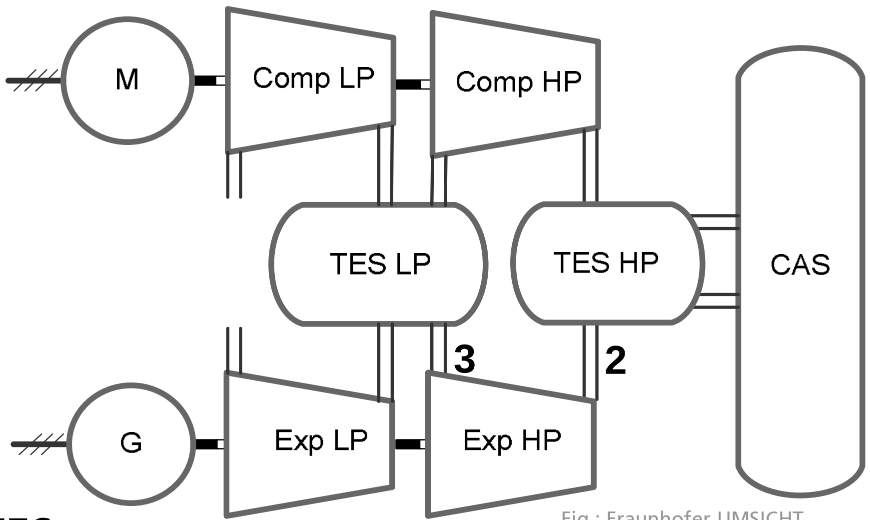

Fig.: Fraunhofer UMSICHT

à Accumulation of excess heat in the low pressure TES

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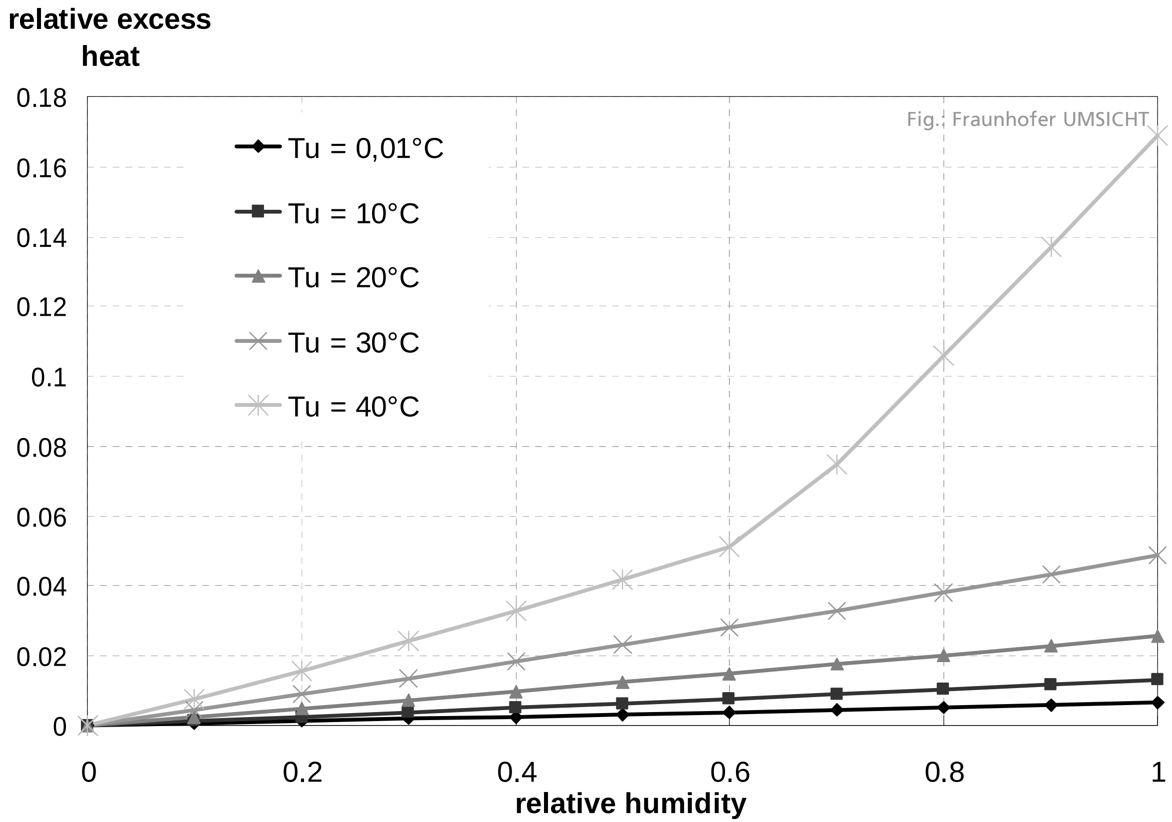
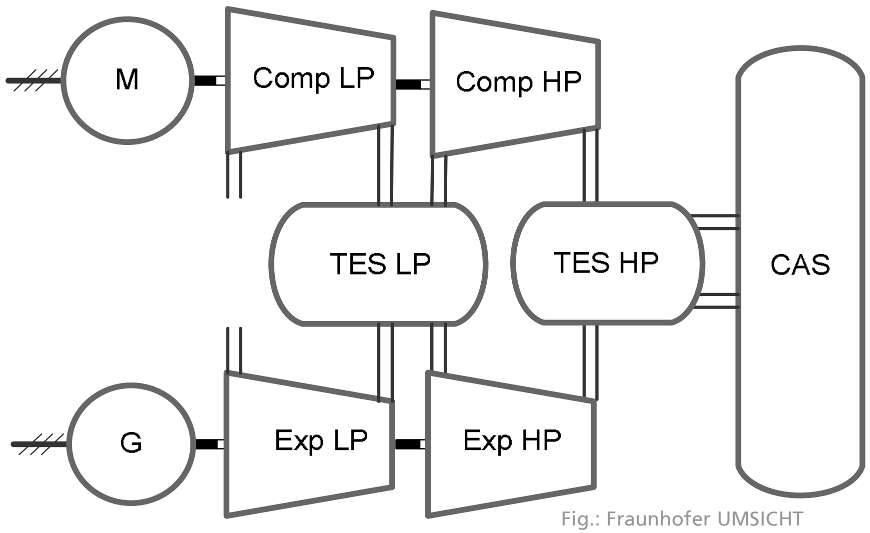
Principle 2
Influence of air humidity

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

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





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Heat management solutions

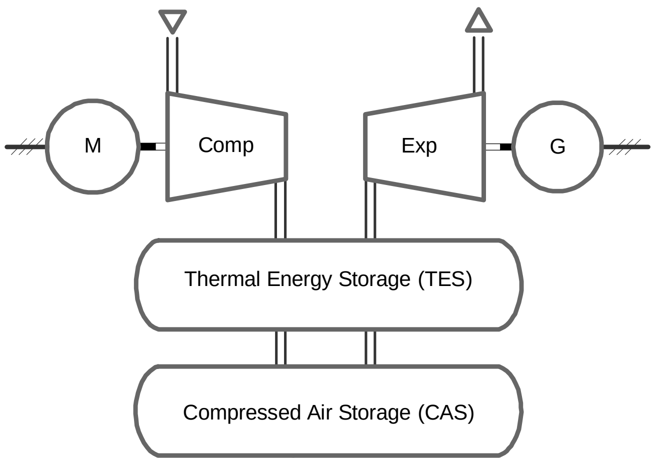
Heat management solutions for TES load balancing

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)

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-Universität Bochum

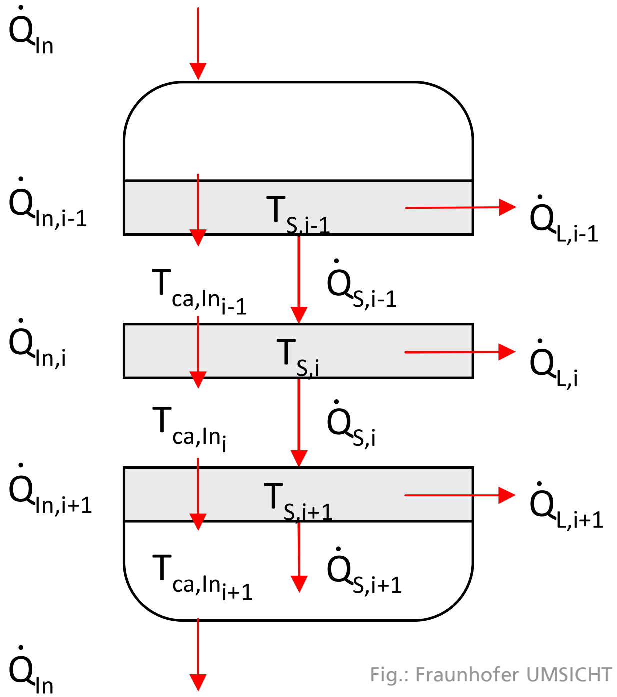

Fig.: Fraunhofer UMSICHT

- Stratified high temperature CAES-TES at laboratory of Ruhr-Universität Bochum
- Decoupled / non-pressurized storage tank
- Storage medium: molten salt at T_{max} = 500°C

- Dynamic model based on a one dimensional finite element approach
- Heat and Mass balance for each layer
- Real gas property model Predictive Soave Redlich Kwong (PSRK) for humid air

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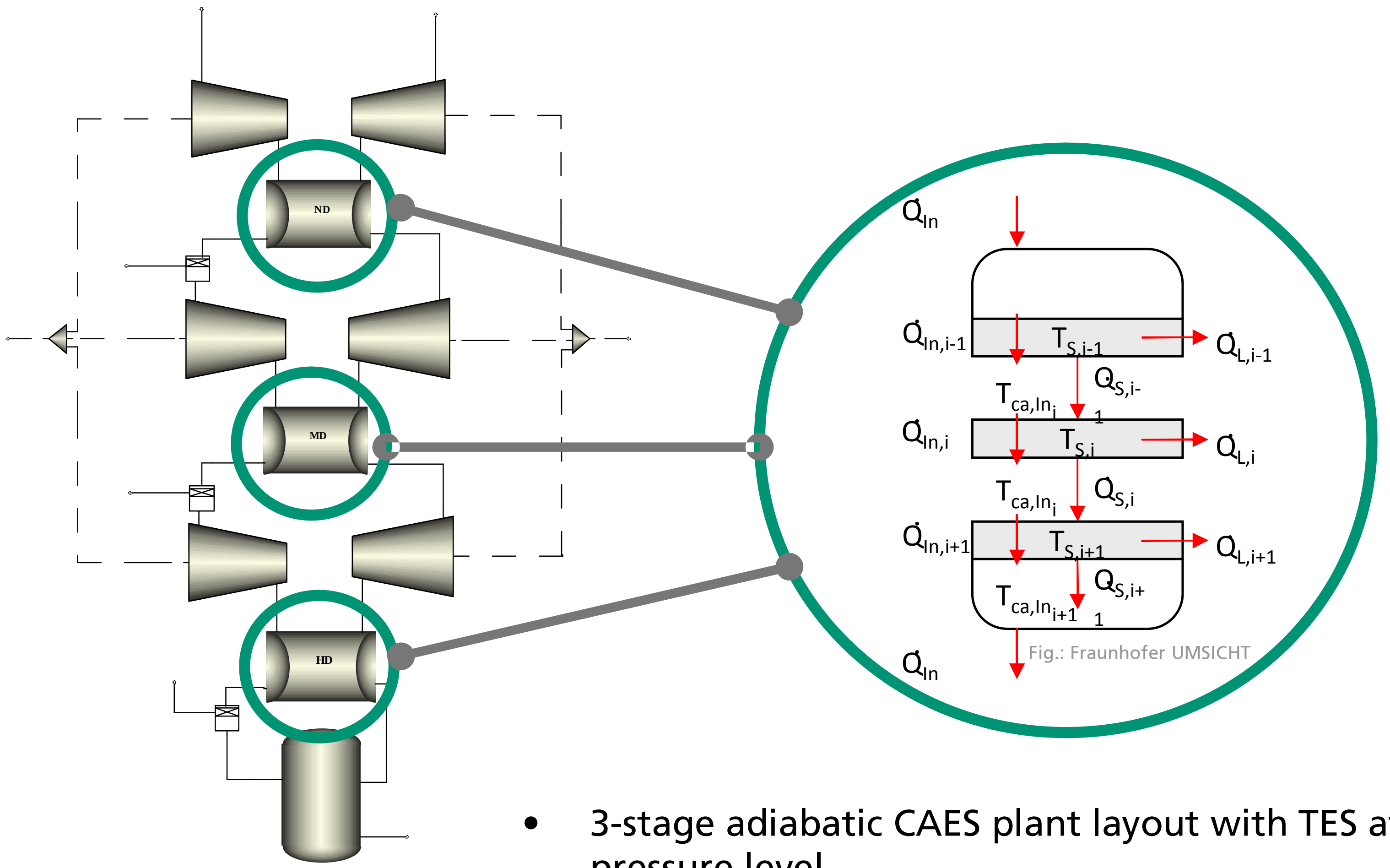
Dynamic model of adiabatic CAES with stratified TES



- 3-stage adiabatic CAES plant layout with TES at low, mid and high pressure level

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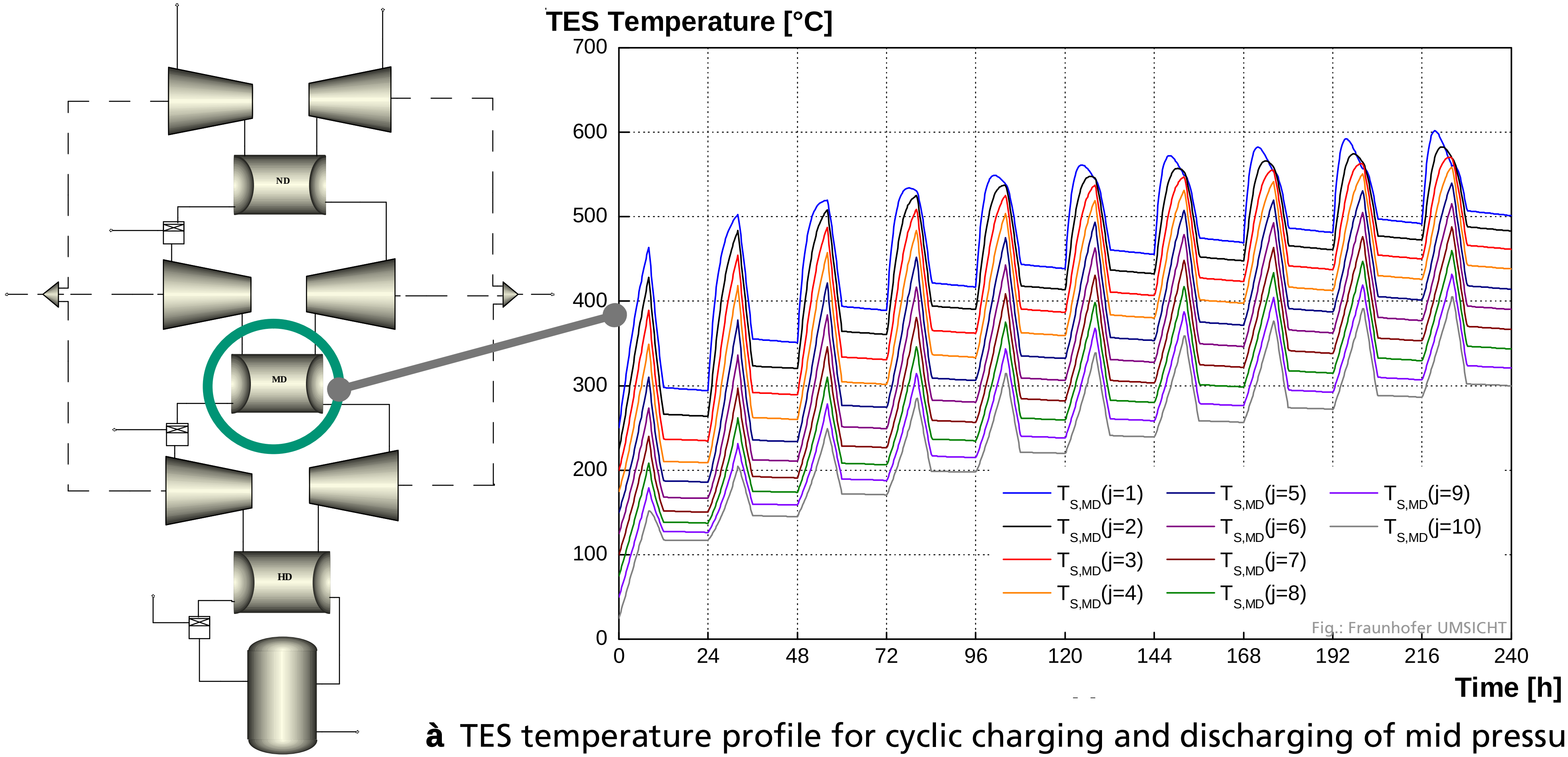
Preliminary model results I



à TES temperature profile for cyclic charging and discharging of mid pressure TES in a 3-stage CAES plant without any heat management measures

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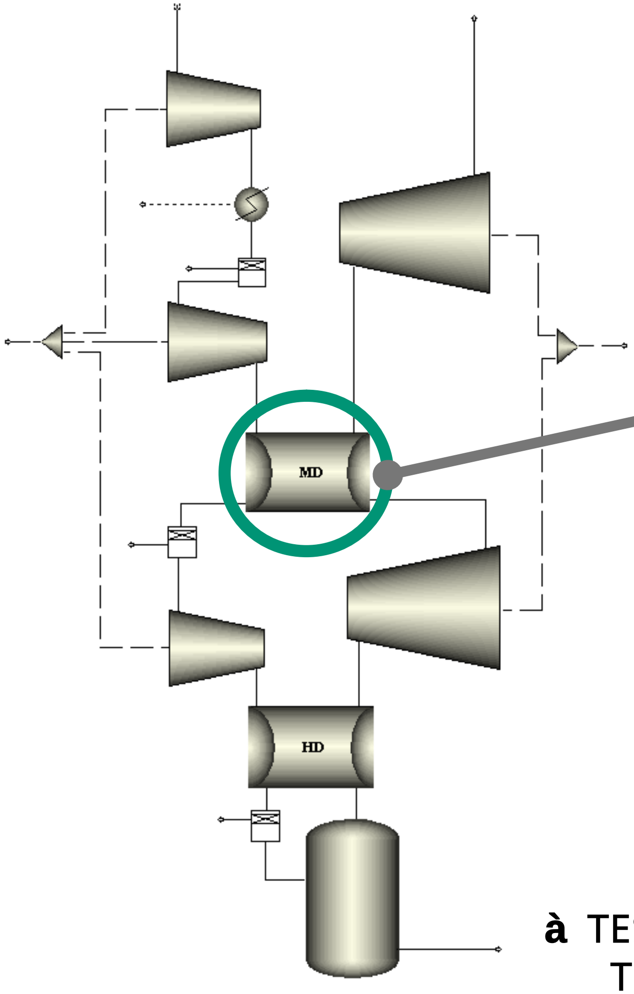
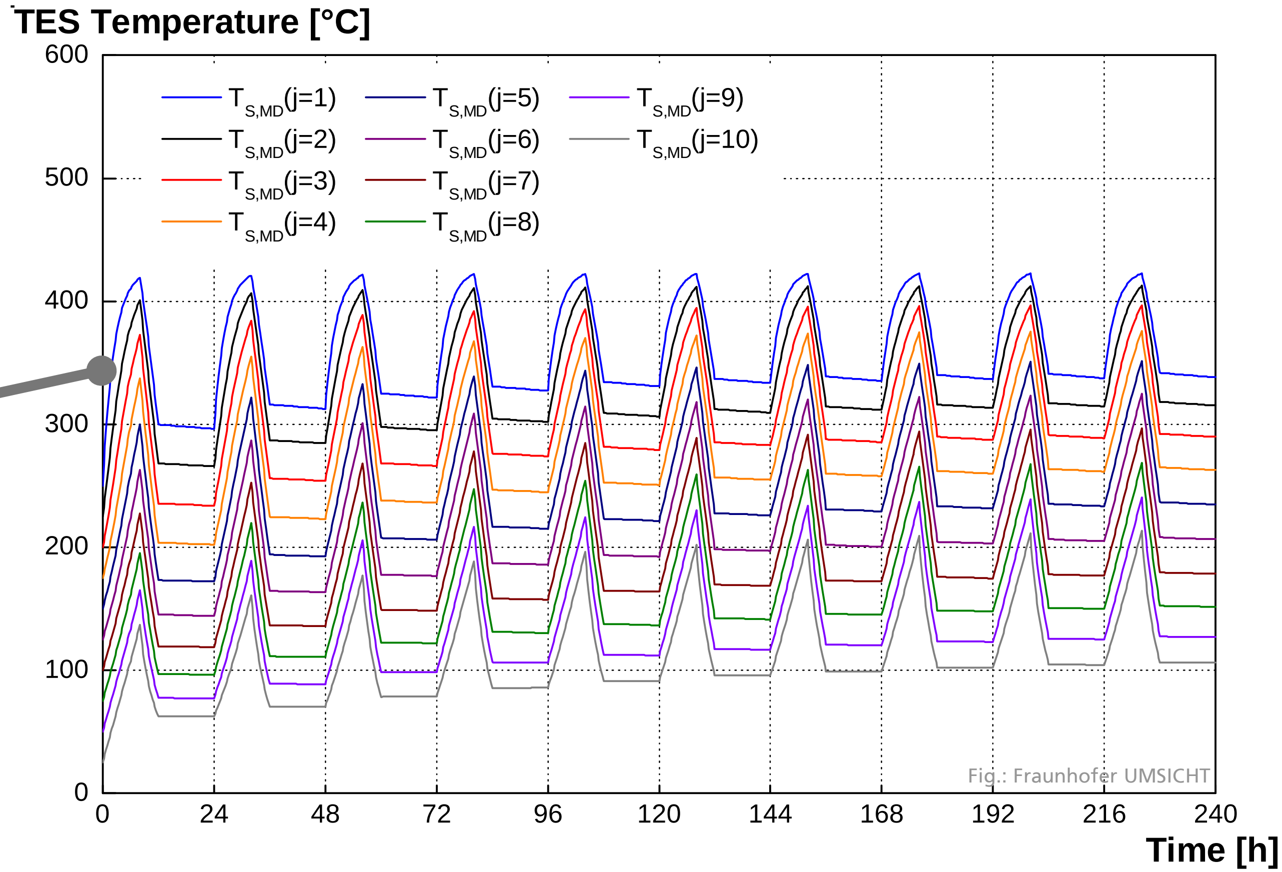
Preliminary model results II





à TES temperature profile for cyclic charging and discharging of mid pressure TES in a 3-stage CAES plant with re-cooling after the first stage and adapted turbine expansion ratios

Conclusion

Conclusion

- There is excess heat in the TES of an adiabatic CAES plant
  - § Excess heat due to non-isentropic compression and expansion
  - § Condensation of the air humidity

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 TES model was developed and applied within a CAES plant model
- Proof-of-concept successful !

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Thank you for your attention!

Any questions?

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