Chair of Energy Systems
TUM Department of Mechanical Engineering
Technical University of Munich

Experimental Investigation of Alkali Sorption with Mineral Getter Materials for IGCC Power Plants

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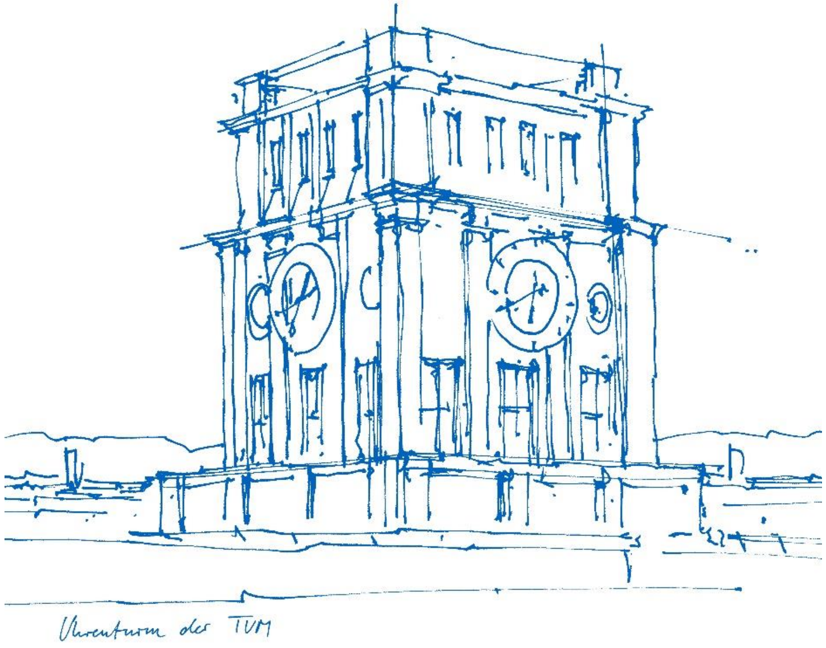
8th International Conference on

Clean Coal Technologies 2017

Cagliari, 10th May 2017

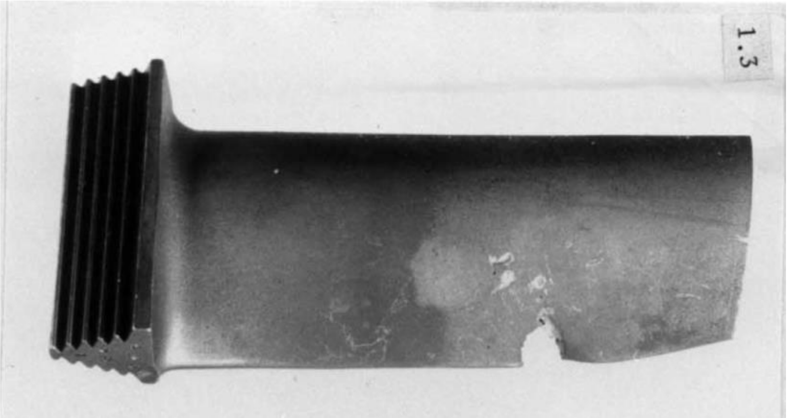


Content

- Motivation
- Gas cleaning in IGCC power plants
- Experimental
- Results
- Conclusion and Future Aspects

Motivation

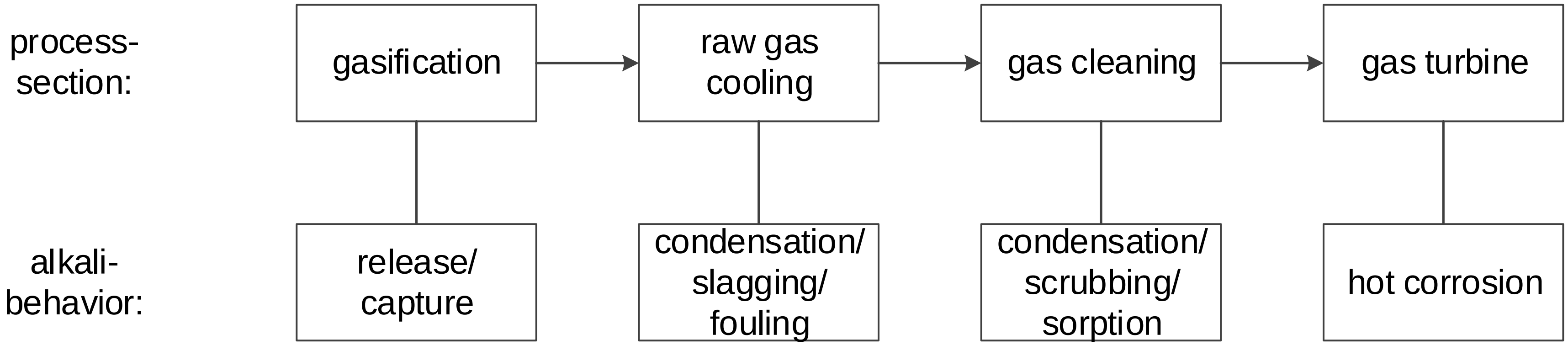
- IGCC power plants offer a higher efficiency potential compared to conventional steam power plants
- Alkali problems:
  - Slagging and fouling at the raw gas cooling
  - Hot corrosion in the gas turbine
- Knowledge of alkali behavior necessary for the design of a hot gas cleaning



(Eliaz et al., 2002)

(NCConsulting, 2016)

Gas cleaning in IGCC power plants



(Haselsteiner, 2012)

State of the art:

- Alkali-condensation at temperatures of approx. 40°C
- Separation with particle filter or scrubber

Objective: Increase of efficiency with higher temperatures of gas cleaning

- At temperatures above 500°C the saturation vapor pressure exceeds the permissible maximum vapor pressure
- Additional cleaning plant for alkali removal necessary

Gas cleaning in IGCC power plants

- Approach: Application of getter materials for the sorption of gaseous alkalis from syngas
- Retention of alkalis by physisorption and chemisorption
- Typical aluminosilicate getter materials:
  - Kaolin
  - Bauxite
  - Bentonite

Kaolin

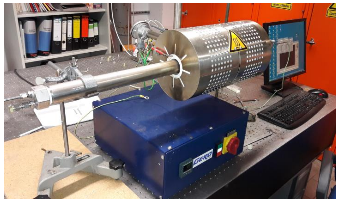
- Alkali capture with kaolinite exemplified by NaCl:

$$Al_2[Si_2O_5](OH)_4 \rightarrow Al_2O_3 \cdot 2SiO_2 + 2H_2O$$

$$Al_2O_3 \cdot 2SiO_2 + 2NaCl + H_2O \rightarrow Na_2O \cdot Al_2O_3 \cdot 2SiO_2 + 2HCl$$

Nepheline, temperature stable up to 1526°C

Experimental – Methodology



Batch reactor

- Determination of maximum getter capacities
- Comparison with equilibrium data

Getter material

Lab analysis:

- Specific surface
- Particle size distribution
- Chemical composition

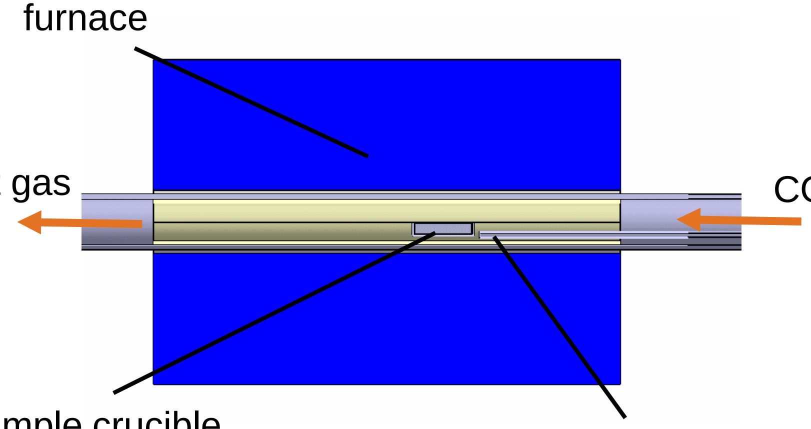
Fixed-bed reactor

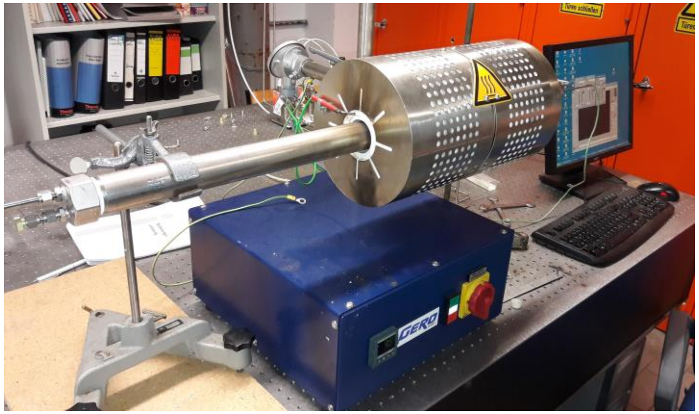
- Alkali sorption in a fixed-bed of getters
- Determination of loading and breakthrough curves

High-Pressure TGA

- Determination of kinetic data
- Influence of pressure and temperature

Experimental – Batch reactor

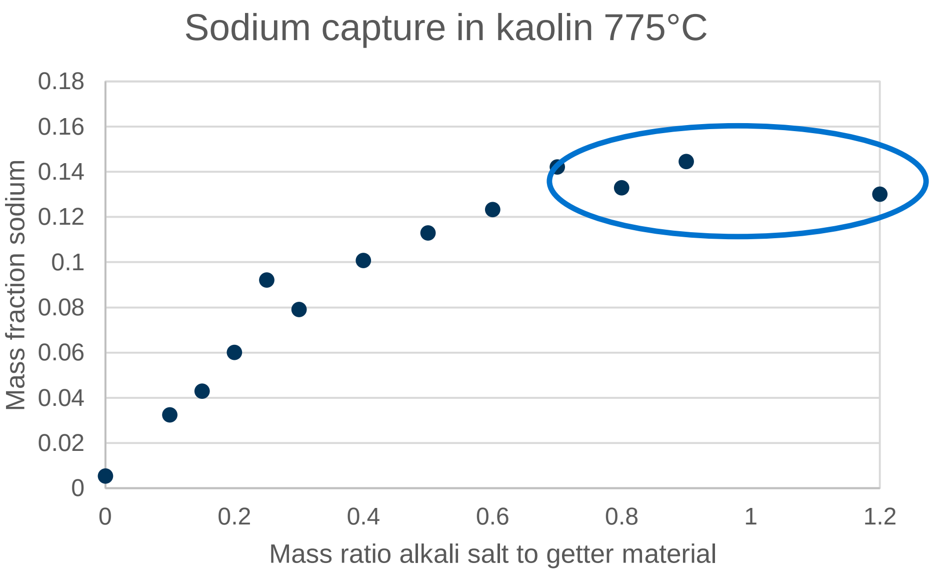




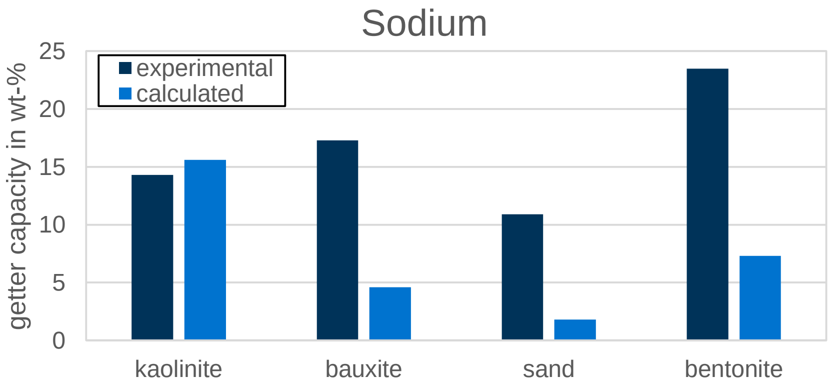
Determination of maximum getter capacities by exposition of an alkali-getter mixture in the batch reactor

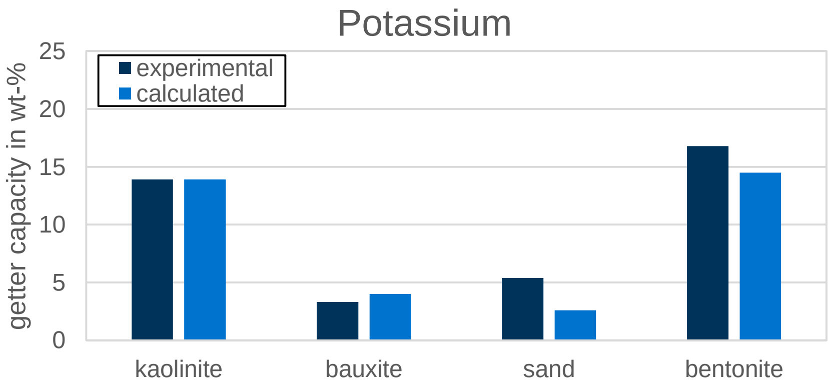
- Getter material: kaolinite, bauxite, bentonite, sand
- Alkali source: NaCl, KCl
- Temperature: 775°C
- X-ray fluorescence analyis for the alkali content

Results – Batch reactor



- Increase of captured sodium mass with higher mass ratio of NaCl in the mixture
- Comparison with thermochemical equilibrium calculations at a mass ratio of 1
- Highest capacity with bentonite
- High amount of physisorption at the sorption of NaCl by bauxite, sand and bentonite suggested

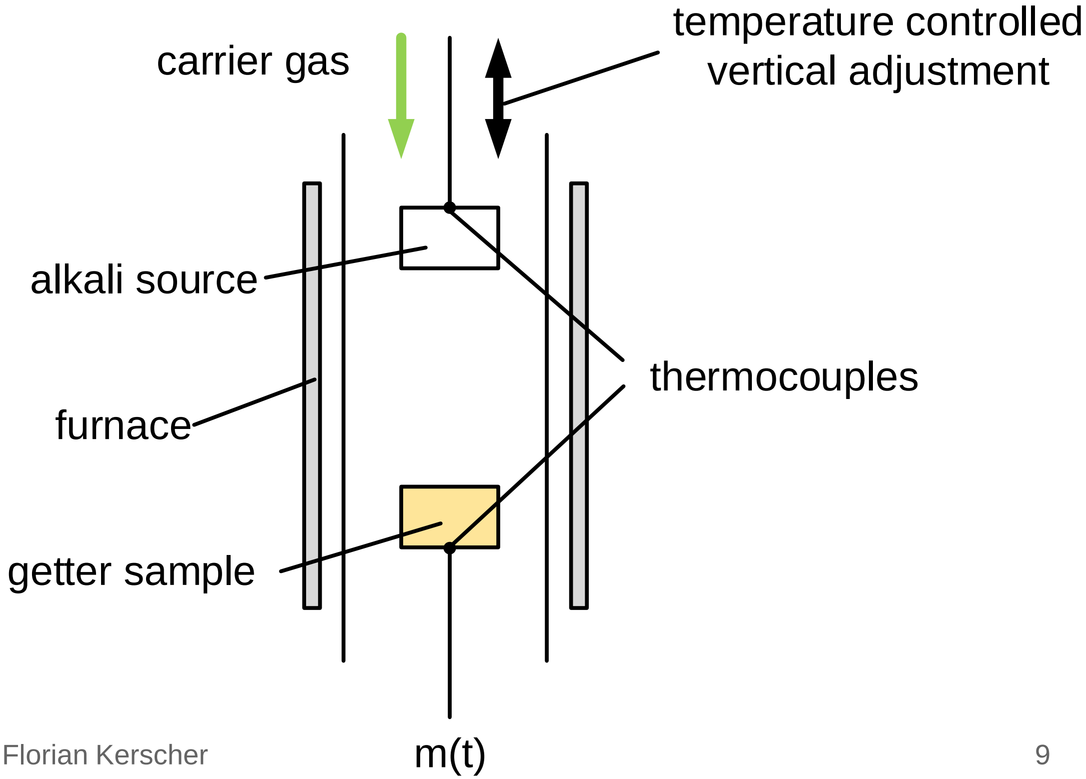




Experimental – High-Pressure TGA

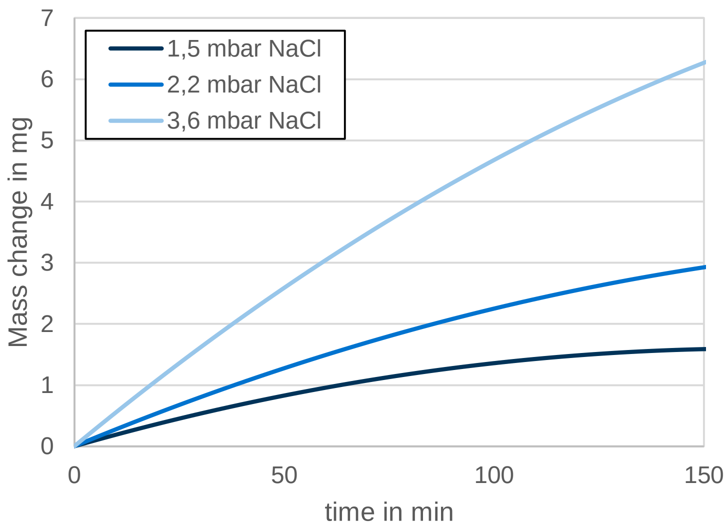
Determination of sorption kinetics

- Temperature: RT – 1800°C
- Pressure: 1 – 50 bar
- Atmosphere: N_2/Ar, CO_2, CO, H_2

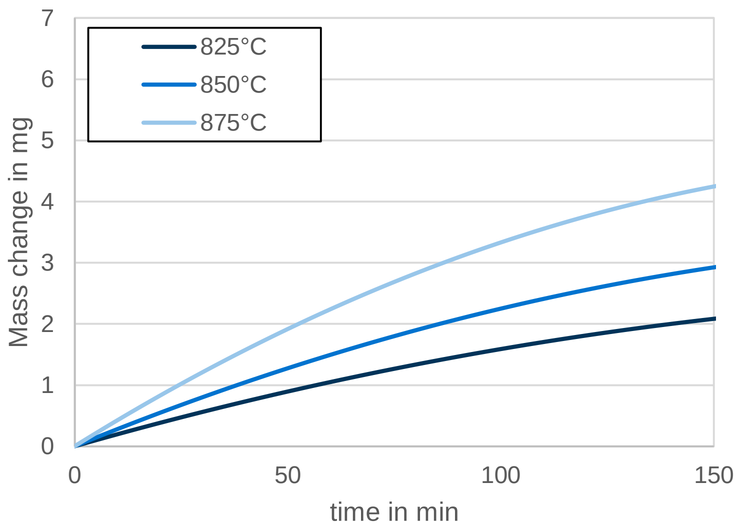


Results – High-Pressure TGA

Partial pressure influence at T = 850°C, p = 20 bar



Temperature influence at p_{NaCl} = 2.2 mbar, p = 20 bar



- Increase of sorption rate with higher partial pressure of NaCl
- Increase of sorption rate with higher temperature

→ Arrhenius approach for temperature dependency

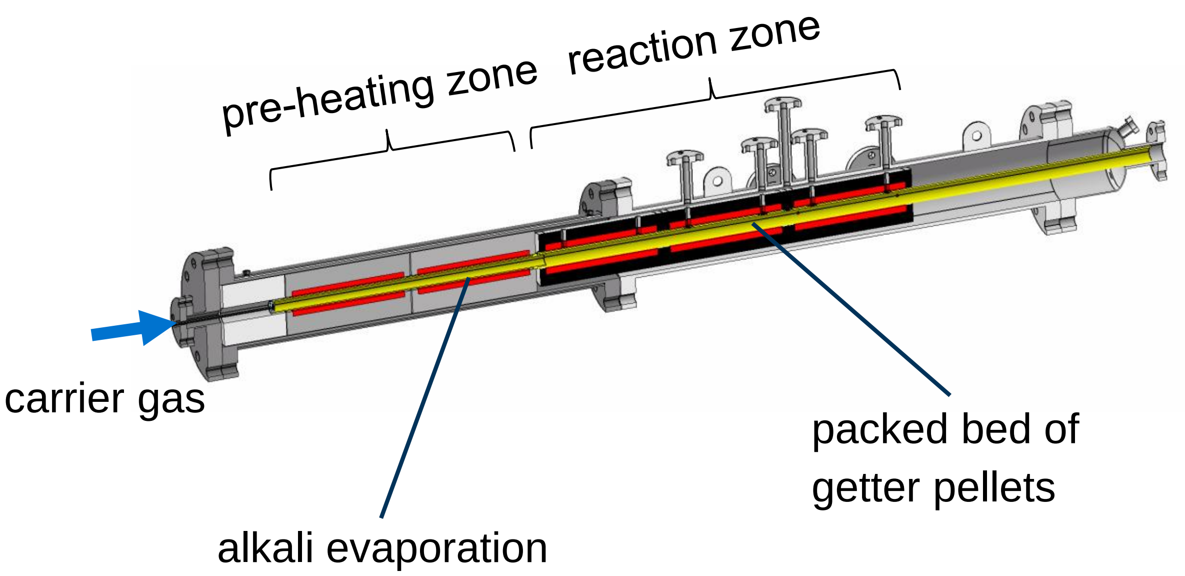
→ Power-Law model for partial pressure dependency

reaction order	pre-exponential factor k_0	activation energy E_a
1.3	$1.6 \cdot 10^6$ mg/(h·m²·mbar$^{1.3}$)	140 kJ/mol

Experimental – Fixed-bed reactor

Investigation of hot gas cleaning in a pressurized plug flow reactor with a fixed-bed of getter pellets under industry-oriented conditions

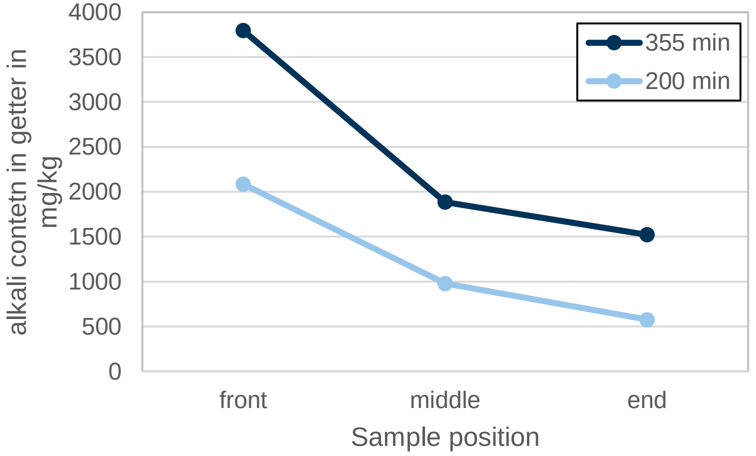
- Temperature: RT – 1300°C
- Pressure: 1 – 40 bar
- Atmosphere: N_2/Ar, CO_2, CO, H_2



kaolin pellets

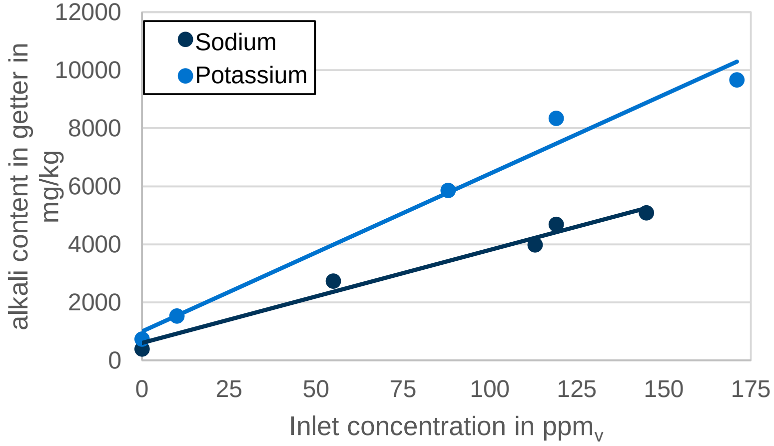
Results – Fixed-bed reactor

T = 800°C, c_{NaCl} = 100ppm$_V$, t = 3h, L = 0,03m



- Decrease of alkali concentration in getter material with lenght of packed-bed
- Increase of alkali concentration with higher experimental time

T = 800°C, t = 3h, L = 0,03m



- Linear relation between inlet concentration and getter loading
- No saturation effect observed

Conclusion and Future Aspects

Conclusion

- Determination of maximum getter capacities in a batch reactor
- Determination of sorption kinetics in a high-pressure TGA
- Sorption analysis in a fixed-bed reactor under industry-oriented conditions

  → Determination of data relevant for the design and construction of an alkali hot gas cleaning unit in IGCC power plants

Future Aspects

- Modelling of the alkali sorption in a fixed-bed of getter material
- Validation with experimental data of the fixed-bed reactor
- Scale-up of hot gas cleaning process to large-scale processes

Thank you for your attention!

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This work is part of a project supported by the German Federal Ministry for Economic Affairs and Energy and industrial partners (Air Liquide, RWE) und contract number: 0327773I

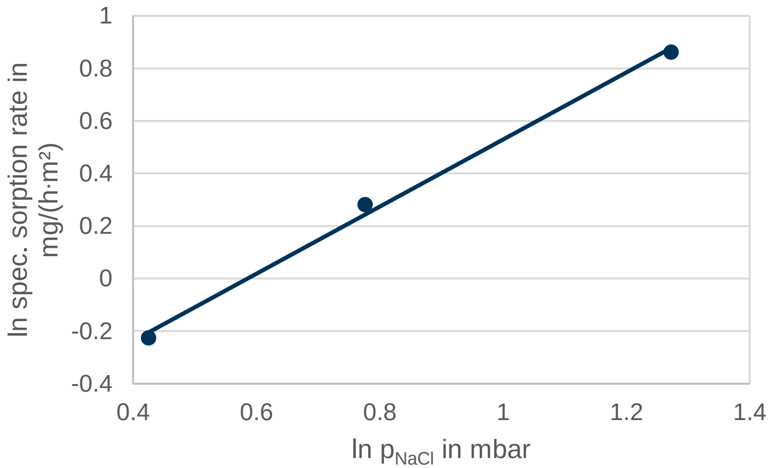
Supported by:

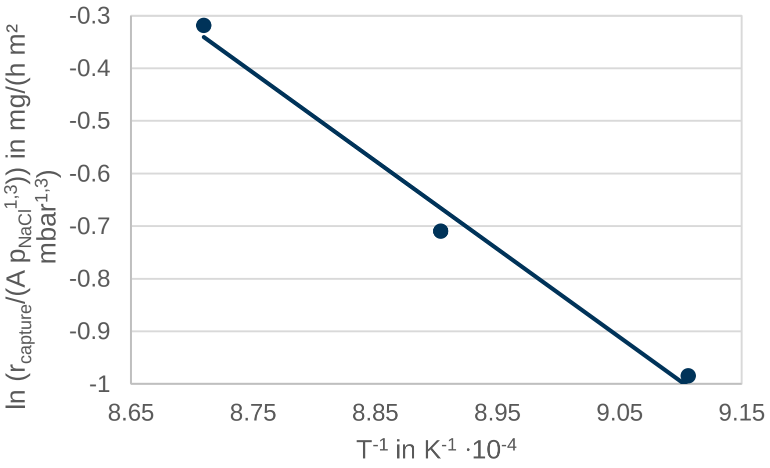
Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

Results – High-pressure TGA

$$r_{capture} = k_0 \cdot e^{-\frac{E_a}{R \cdot T}} \cdot A \cdot p_{NaCl}^n$$





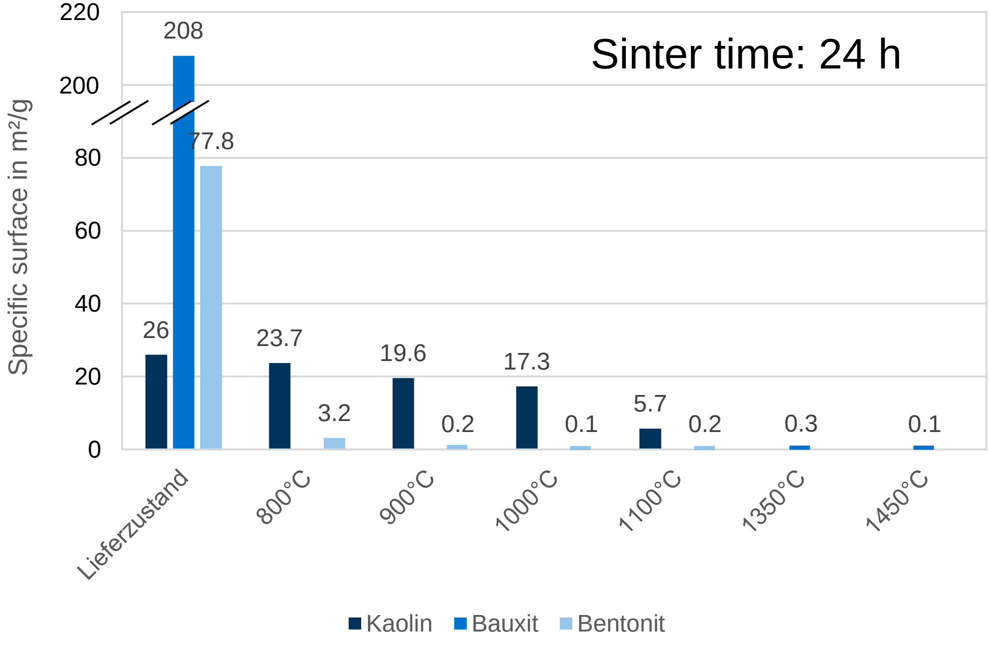
Kinetic parameters:

reaction order	pre-exponential factor k_0	activation energy E_a
1.3	1.6 · 10^6 mg/(h·m²·$mbar^{1,3}$)	140 kJ/mol

Results – Fixed-bed reactor

Getter insertion in form of pellets → pellet production by sintering in furnace

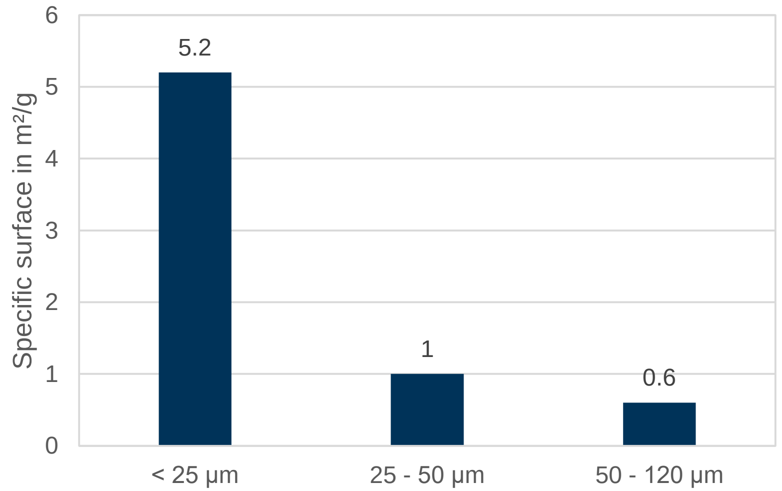
Influence of sinter temperature on specific pellet surface

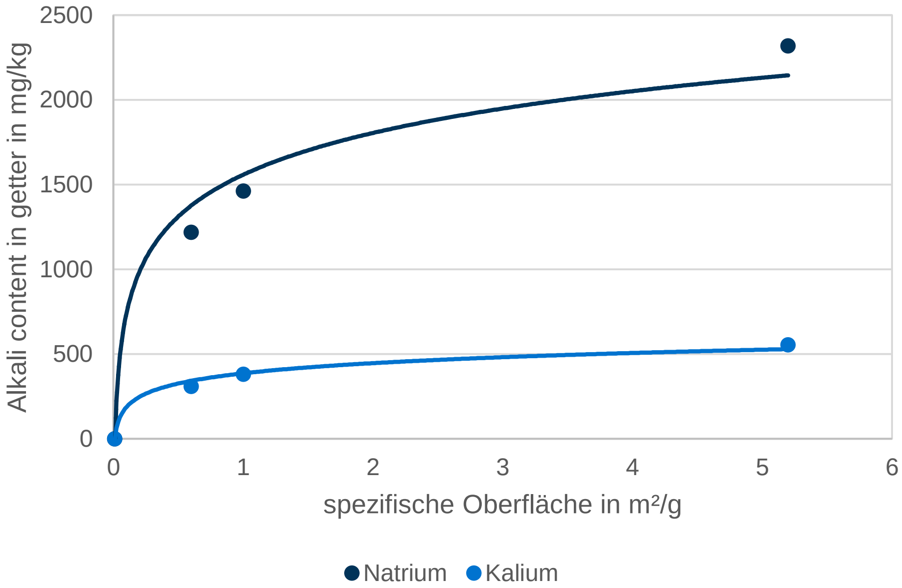


- Decrease of specific surface with higher sinter temperature
  → Decrease of sorption rate
- Increase in mechanical stability with higher sinter temperature
- Highest sorption rate expected with kaolin as getter material

Results – Fixed-bed reactor

Dependence of alkali sorption on particle size





Bentonite powder, sieved

Sinter temperature: 800°C

T = 800°C, p = 1 bar, t = 3h, L = 0,03m

Decrease of specific surface with higher particle size

→ Decrease of sorption rate

→ Lower getter loading