Steam gasification with in-situ CO₂ capture for the production of synthetic fuels

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**Processes:**
- CFB solid fuel combustion
- Flameless combustion
- Gasification
- CCS

**Process technologies:**
- Fluidized bed systems at different scales
- Entrained flow reactors

**Fuels:**
- Solid fossil
- Solid and liquid biogenic
- Residual

**Process Modelling:**
- Process and Reactor models
- CFD simulations
- Aspen Plus®

**Measurement technologies:**
- Tar (online)
- Standard flue gas components
Fluidised bed gasification infrastructure

**Fluidised Bed Gasification**
- Air gasification
- Steam/Oxygen gasification
- Steam gasification
- Sorption enhanced reforming (SER)
- Two stage SER gasification

**Fuels**
- Biomass
- Waste
- Lignite

**Measurement techniques**
- Tar: wet chemical acc. tar protocol
- Non-condensable gases: online
- Non-condensable HC: GC
- H₂S, NH₃, HCl: wet chemical
- Online Tar analysis
Steam gasification is an atmospheric allothermal gasification process where the necessary heat for the endothermic gasification is provided by circulating bed material.

- Bed material (e.g. silica sand) acts as heat carrier.

**Steam Gasification Process**
SER (Sorption Enhanced Reforming) is an atmospheric steam gasification process with in-situ CO₂ capture.

- Limestone shifts the CO₂ from the gasifier to the regenerator.
- Limestone as a bed material leads to a CO₂ lean product gas.
In Oxy-SER process the regeneration is operated under Oxy-fuel conditions:

- High CO$_2$ output concentrations of >90 vol-%$_{\text{dry}}$ in the Regenerator can be achieved

→ Possible pre-combustion CCS technology
SER steam gasification

- Due to the chemical equilibrium, the CO$_2$-capture decreases with increasing gasification temperature.
- Limestone bed material acts as:
  - heat carrier
  - CO$_2$ carrier
  - catalyst for increasing the gas yield
  - catalyst for tar reforming

![Graph showing CO$_2$ concentration and temperature relationship.](image)

- Carbonation: CaO + CO$_2$ → CaCO$_3$
- Calcination: CaCO$_3$ → CaO + CO$_2$
- Regenerator: p = 1 bar

Temperatures range from 600°C to 900°C, and CO$_2$ concentrations range from 0.1% to 100.0% vol.-%.
**SER gasification: Application**

**Oxy-SER gasification:**
- Flexibility (feedstock, syngas composition, air/oxy operation mode)
- In-situ CO₂ capture possible

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**Steam**

Lignite

**Gasifier**

\( T = 600 - 720°C \)

- CaCO₃
- Char
- CaO

**Regenerator**

\( T = 850-950°C \)

- CO₂ / flue gas
- O₂ / Air

**steam / ORC process**

- H₂-rich syngas

**Gas Conditioning**

- Hydrogen

**Synthesis**

- Fuels
- Chemicals
- (CO₂ storage)

**Heat**

- Cement production

**Purge**

- CaO (+CaSO₄)
• **Gasifier:**
  - *bubbling* bed reactor
  - diameter: 0.33 m
  - height: 6 m

• **Regenerator:**
  - *circulating* fluidized bed
  - diameter: 0.21 m
  - height: 10 m

• **Gas analyses:**
  - **Gasifier:**
    - H₂, O₂, CO, CO₂, CH₄, C₂-C₄, tar
  - **Regenerator:**
    - CO, O₂, CO₂, SO₂, NOₓ

• **No electrical heating**
• **4 gravimetric feeders for different solid fuels and additives**
Demonstration (200 kW$_{th}$) of the Oxy-SER process

- Stable plant operation over several hours

- After ~5h the Regenerator was switched to Oxy-SER mode

→ Smooth switch of the regenerator to oxy-mode
Demonstration (200 kW_{th}) of the Oxy-SER process

**Regenerator:**
- Oxy-SER increases CO\(_2\) concentrations (up to > 80 vol.-%\(_{\text{dry}}\))
- Oxy-SER has minimal impact on regenerator temperature

**Gasifier:**
- Gasifier operation not affected by regenerator operation mode
- Temperature and gas composition in gasifier constant
In steam gasification the fuel-C is distributed between:
- C in Syngas (CO, CO₂, CH₄, C2-C4)
- C in Tars
- C in Char
- C in Carbonate (only for SER process)

SER produces a CO₂ lean product gas

→ C/H stoichiometry suitable for synthesis

Oxy-SER regenerator produces almost pure CO₂ for storage/utilization
Results of the Oxy-SER experiments

- High $\text{H}_2$-concentrations in Syngas
- No significant difference in the syngas between the two regeneration modes
- Higher $\text{H}_2\text{O}$ and $\text{CO}_2$ concentration in the fluegas due to the gas recirculation and lack of air-nitrogen
• Good agreement between model/simulation and experimental data

• C/H stoichiometry can be adjusted for synthesis or to compensate downstream fluctuations (e.g. by Gasifier temperature)
• Process model shows **high cold gas efficiencies** of >65%
• Break in efficiency trend at 680°C is caused by additional fuel in Regenerator
• Higher efficiencies can be achieved by optimised heat recovery and gas preheating
(Oxy-)SER operation process was successfully demonstrated in pilot scale

- High H\textsubscript{2} concentrations of ~70 vol.-%
- low tar concentrations due to CaO bed material
- high gas yields
  → promising production of syngas with a suitable stoichiometry for methanation or liquefaction processes

- High CO\textsubscript{2} concentrations of >90 vol.-% in the Regenerator were achieved when using oxy-fuel combustion in the Regenerator
  → promising technology for the creation of a hydrogen-rich syngas with a pre-combustion CCS

- High cold gas efficiencies of >65% can be achieved
  - higher efficiencies are possible when
    - improving the heat integrating of the system
    - using steam/ORC cycles to utilise the heat streams
Summary SER gasification

• Co-Gasification of biomass and fossil fuels possible:
  → Use of (dried) lignite as fuel is possible if sufficient biomass is not available
  → Use of seasonal biomass possible

• Due to the integration of a steam/ORC cycle, flexible co-production of el. energy and syngas possible

• The SER gasification process is a promising and efficient process for the production of storable energy out of solid fuels

more results can be found in:
• Daniel Schweitzer: Pilot-Scale Demonstration of Oxy-SER steam Gasification: Production of syngas with Pre-Combustion CO2 capture; Energy Procedia 02 (2016)
• Max Schmid: Gasification of biomass with the Oxy-SER process for syngas production with in situ CO2capture in a 200 kWth pilot plant
  In: The 6th High Temperature Solid Looping Cycles Network Meeting; Milan; 02.09.2015
Thank you for your attention

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