Solid Fuel Gasification: an Old Technology with Modern Challenges

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Outline

• What is solid fuel gasification?

• Gasification through History

• Which are the Challenges?

• Which role will this technology play in the future?

• Activities at the chair of energy systems
What is solid fuel gasification?

- It is a chemical process which converts a solid feedstock in an energetic gas stream (or Syngas) mainly composed by Hydrogen and Carbon Monoxide.

- Boudouard:
  \[ C(s) + CO_2(g) \leftrightarrow 2CO(g) \]  \( \Delta H^0 < 0 \)

- Water gas reaction:
  \[ C(s) + H_2O(g) \leftrightarrow H_2(g) + CO(g) \]  \( \Delta H^0 < 0 \)

- CO shift reaction:
  \[ CO(g) + H_2O(g) \leftrightarrow H_2(g) + CO_2(g) \]  \( \Delta H^0 < 0 \)

High temperature process!!
Gasification through History

Charcoal Production is known since centuries: Pyrolysis of biomass (wood) to obtain a carbon rich fuel

First and second Industrial revolution in the 19th century: town gas was produced from coal to supply fuel for street lights, domestic heating and cooking

During the World War 2, shortage of oil (especially in Germany) drove the development of integrated gasification systems on Vehicles (charcoal or coal).
The Fischer-Tropsch process to produce hydrocarbons (Diesel, Lubricants etc.) from syngas sped up the industrialization on a large scale of this technology.

During the second half of the 20th century, solid fuel gasification has been mostly used for the chemical industry: ammonia, methanol and SNG (substitute natural gas) syntheses.

Only during the last 30 years, the interest arose to apply this technology for power production:

**Integrated Gasification Combined Cycle (IGCC)**
Modern Challenges: IGCC Power Plant

- **AIR SEPARATION UNIT**
  - Produce O₂ for the gasification process

- **GASIFIER**
  - Conversion of solid feedstock into raw syngas

- **ACID GAS REMOVAL**
  - Remove acid components from syngas: H₂S, HCN, HCl, etc.

- **GAS TURBINE COMBINED CYCLE**
  - Produce electric power combining gas and steam turbines
Modern Challenges: IGCC Power Plant

Advantages:

• High efficiency $\epsilon \leq 45\%$ (NG Combined Cycle $\epsilon \leq 58\%$)
• Effective pollutants removal in the gas stream
• $CO_2$ capture

Disadvantages:

• High investment costs (25% more respect to conventional systems)
• High level of integration leads to:
  • the need for an accurate control system
  • low flexibility (base load)
Modern Challenges: IGCC Power Plant

Increase the efficiency:

• Hot gas cleaning system (1200°C instead of 300-400°C)
• Increase integration

CO₂ separation and storage (CCS)

• Design of membrane shift reactor in which Hydrogen and Carbon Dioxide are produced and simultaneously separated
• Integrated CCS affects greatly the overall efficiency

Versatility of the feedstock

• Every Feedstock has different gasification behavior
• Optimization of the gasification chemistry
Which role will this technology play in the future?

Different Scenarios in Germany for the year 2050

- Massive presence of Renewables in all the scenarios
- Shut down of nuclear power plants in 2020
- Reduction of CO₂ emissions

<table>
<thead>
<tr>
<th>Capacity</th>
<th>in 2010</th>
<th>in 2050*</th>
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<tbody>
<tr>
<td>Renewables</td>
<td>60 GW</td>
<td>~170 GW</td>
</tr>
<tr>
<td>Wind</td>
<td>27 GW</td>
<td>50-110 GW</td>
</tr>
</tbody>
</table>

*average and ranges for different scenarios

Source: DLR, BMU, BMWi
Which role will this technology play in the future?

Need for the future to follow the demand and to cope with the variability of the renewable sources!

Increase storage capacity!

CAES
Compressed air in geological cavities

Pumped-storage Hydroelectricity (PSH)

Battery Clusters

Chemical synthesis

Thermal Energy Storage
Which role will this technology play in the future?

Solid Feedstock → Renewable Power → Electrolysis → Chemical Synthesis → Storage

- Methanol
- SNG
- FT liquids

Flexible power production with combined cycles

CO₂, H₂ → Syngas → Gasifier

Infracstrutures already present for SNG and FT fuels.
Activity at the Chair

- Investigation of gasification kinetics
- Study on the cooling behavior of trace elements in syngas (alkali)
- CFD simulations for IGCC power plant (Gasifier, Syngas cooler, membrane reactors)
- Overall process flowsheet simulation and economics
Conclusion

- Alternative Technology to use solid/fossil fuels for power production
- The technology can meet low emission standards
- Concrete possibility to capture and store CO$_2$
- With increasing share of renewable energy, the design offers high flexibility through the integration of electrolysis and chemical synthesis
- No commercial power plants in operation until now
- Economically not competitive until the price of energy rises and CO$_2$ trade emission market grows
Thank you for your attention!