CFD modeling for parametric study on co-gasification of coal-biomass blend in a 300MW_\text{e} Shell Coal Gasification Process (SCGP) type gasifier

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Coal gasifier in Korea

- In Korea, a national project for constructing a 300MWe IGCC demonstration plant has been going on (Scheduled to finish on November, 2015).

- The Korea Western-Power Company and DOOSAN Heavy Industries & Construction Company in Korea selected a Shell coal gasification process (SCGP) type gasifier.
Shell Coal Gasification Process (SCGP) type gasifier

- High carbon conversion (nearly 99%).
- Simple mechanical design.
- Short residence time (average ~ 10 seconds)
- High operating temperature (about 1800K).
- Slag as a by-product flows out of the bottom into a water bath or slag bath.
Our group

- Carried out a 3D full scale CFD analysis of the Korea SCGP type gasifier using ANSIS Fluent.

- The results were disclosed with a paper submitted to Energy & Fuels.

- Previously, we published a paper on CFD analysis of the E-Gas gasifier.

Coal blended with biomass

❖ What are advantages of coal blended with biomass?
  • High cold gas efficiency (CGE) and high caloric value of syngas\(^1\).  
  • Free CO\(_2\) emission trading\(^2\).
  • Cost reduction of fuel.

❖ In Magnum, Netherlands, a coal-biomass co-gasifier plant has been under construction for IGCC power generation.

❖ In the Nuon Magnum IGCC power plant, SCGP type gasifier is used.

Coal/biomass co-gasifier plant

Nuon Magnum IGCC power Plant, Netherlands (SCGP)

- Feedstock: Coal, biomass and gas
  (Biomass mixing ratio: about 30%)
- Kinds of biomass
  - Waste wood: 65%
  - Sewage sludge: 25%
  - Husk of rice and coffee bean: 5%
  - Waste paper: 5%
  - Kitchen waste: Only as back-up


Detailed specific geometry of gasifier??
Our works

- The effects of amount of biomass blend on gasifier performance were numerically studied.

- In the analysis, exit temperature, species mole fractions, velocity and particle trajectories were calculated with different biomass blending ratios.

- Illinois #6 coal and pine sawdust were used in this study.
A simplified geometry of the gasifier is described in the figure.

Pulverized coal, biomass and nitrogen as transport gas were injected into the gasifier through the center hole of each burner.

At the same time, a mixture of oxygen and steam was blown through surrounding holes of the burner.
The operating conditions of the entrained bed co-gasifier for 300MWe power generation are shown in Table.

<table>
<thead>
<tr>
<th>Operating condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel feed amount (ton/day)</td>
<td>2454</td>
</tr>
<tr>
<td>Oxygen/Fuel (mass ratio)</td>
<td>0.798</td>
</tr>
<tr>
<td>Steam/Fuel (mass ratio)</td>
<td>0.103</td>
</tr>
<tr>
<td>Coal Particle Size (㎛)</td>
<td>100</td>
</tr>
<tr>
<td>Biomass particle size (㎛)</td>
<td>1000</td>
</tr>
<tr>
<td>Operating pressure (MPa)</td>
<td>4.2</td>
</tr>
<tr>
<td>Blending ratio (coal:biomass)</td>
<td>(100:0), (95:5), (90:10), (85:15), (80:20), (75:25), (70:30), (60:40), (50:50), (40:60), (30:70), (20:80), (10:90), (0:100)</td>
</tr>
<tr>
<td>→ Total 14 case</td>
<td></td>
</tr>
<tr>
<td>Inlet Temperature (K)</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>290</td>
</tr>
<tr>
<td>Oxygen</td>
<td>400</td>
</tr>
<tr>
<td>Steam</td>
<td>400</td>
</tr>
</tbody>
</table>
Result (Coal 100%)

- The velocity and particle trajectories are shown in animations.
- Gas and particle were injected from inlets, some of them headed toward the gasifier exit while others followed downward recirculation flows.
- The maximum residence time of particle was 11.18 sec.
- Local residence times of particle were about 3 ~ 6 sec.
Results (Coal 100%) – temperature

• High temperature region occurred A regions due to exothermic reactions by fuel and volatile matter with oxidant.

• Whereas, in the B regions, the temperature decreased due to endothermic reactions by char gasification with O₂, H₂O, and CO₂ under the oxidant exhausted condition.
The CO mole fraction is lower in A region, while that is higher in B regions and C region.

This phenomenon A region can be accounted for CO$_2$ formation by exothermic reactions with oxygen injected, while the char gasification with O$_2$, H$_2$O, and CO$_2$ may also contribute to this phenomenon in B regions and C regions.
• Low H₂ mole fraction shown in the A regions, while a high H₂ mole fraction shown in the B regions.
• In the B regions, reactions of forward water gas shift reaction and methane steam reforming reaction dominated by H₂O.
• Whereas, reverse reaction of the water gas shift reaction occurred in the A regions.
Results – Validation of our simulation

- Our CFD analysis results were compared with operating data obtained from a demonstration plant in Buggenum, Netherlands (coal 100%).

<table>
<thead>
<tr>
<th>Contents</th>
<th>Numerical study (Our works)</th>
<th>Actual IGCC Plant (SCGP gasifier)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mole Fraction of CO</td>
<td>0.5712</td>
<td>0.5797</td>
</tr>
<tr>
<td>Mole Fraction of H₂</td>
<td>0.2905</td>
<td>0.3006</td>
</tr>
<tr>
<td>Mole Fraction of CO₂</td>
<td>0.0193</td>
<td>0.0143</td>
</tr>
<tr>
<td>Exit Temperature [K]</td>
<td>1845.31</td>
<td>1850.15</td>
</tr>
<tr>
<td>Carbon Conversion Efficiency [%]</td>
<td>96.3</td>
<td>99.5</td>
</tr>
</tbody>
</table>

- Table shows that our CFD analysis results agree well with the actual operating data.

Comparison – temperature

BR = 0
(Coal 100%)

BR = 0.2
(Coal 100% : Biomass 20%)

• When BR 0.2, temperature distribution in gasifier is higher than BR 0.
• This result can be accounted as exothermic reaction by oxygen in biomass.
Comparison – mole fraction of CO

BR = 0  
(Coal 100%)

BR = 0.2  
(Coal 100% : Biomass 20%)

- When BR 0.2, CO mole fraction distribution in gasifier is lower than BR 0.
- This result can be accounted as CO2 generation reaction by oxygen in biomass.
• For BR 0.2, H2 mole fraction distribution in gasifier is higher than BR 0.
• This result can be accounted as water gas shift reaction.
**Result – product gases**

- **Species mole fractions at gasifier exit**

  \[ BR = \frac{\text{Biomass}}{\text{Coal + Biomass}} \]

  - The mole fraction of \( \text{H}_2 \) was increased with increasing BR. It may be due to **hydrogen** in biomass.
  - Also, the mole fraction of \( \text{CO}_2 \) was increased with increasing BR. It may be due to **oxygen** in biomass.
  - The hydrogen and oxygen is higher biomass than coal.
  - On the other hand, the mole fraction of CO was decreased with increasing BR. It may be due to increasing \( \text{CO}_2 \) in biomass.
Results – temperature, CCE and CGE

- Temperature, CCE, and CGE at gasifier exit

- The exit temperature of gasifier increased with increasing BR since the increasing biomass amount led to increase the exothermic reaction by oxygen in biomass.
- The CCE gradually increased with increasing BR from 0 to 0.3 and then reached about 98.0% with BR ratios higher than.
- The CGE increased with increasing BR. This result of CGE can be explained with the results of H2 mole fraction.
The CFD modeling results on gasification performance in an one-stage entrained bed coal gasifier (Korea SCGP gasifier) was performed for parametric studies with various blending ratios.

Illinois #6 coal and pine sawdust were used for CFD modeling.

Carbon conversion and cold gas efficiencies, temperature and species mole fractions at the gasifier exit were calculated as well as spatial distributions of temperature and species concentrations.

Optimal conditions of blending ratio for the Korea SCGP gasifier were found to be 0.2, for selected operating conditions.
THANKS FOR YOUR ATTENTION