Biomass co-firing in high percentages
opportunities in conventional and advanced coal-fired plants

J.H.A. Kiel

IEA Bioenergy Task 32
workshop Increasing co-firing percentages in existing coal-fired power plants
Geertruidenberg, the Netherlands, 21 October 2008
Biomass co-firing in high percentages – opportunities in conventional and advanced coal-fired plants

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ECN Programme manager Biomass & Coal

IEA Bioenergy Task 32 workshop Increasing co-firing percentages in existing coal-fired power plants, Geertruidenberg, the Netherlands, 21 October 2008
Energy research Centre of the Netherlands
In the dunes of N-Holland - Petten

ECN develops high-level knowledge and technology for a sustainable energy system and transfers it to the market

- Independent research institute
- 650 employees
- Annual turn-over: 80 million Euro
- Activities:
  - Biomass, Solar, Wind
  - Clean fossil fuels (CCS, fuel cells)
  - Energy efficiency
  - Policy studies
Presentation overview

- Biomass co-firing options
- State-of-the-art
- R&D needs
- Examples ECN R&D
- Co-firing in advanced coal conversion
- New challenges
- Concluding remarks

Essent Amer power station
Biomass co-firing technology options

Indirect co-firing

CFB gasifier

C

F

B

M

B

M

LCOV gas

gas cooling/purification

Direct co-firing

coal

BM

BM

X

X

SCR

ESP

FGD

stack
Co-firing at Drax power station (UK)

- Coal-fired power station
- Capacity 6 x 660 MWe
- ≅ 6.5% el. needs
- 10% biomass co-firing
- = 400 MWe
- = 1.5 Mtonne/a biomass

Source: Davis Smales, Drax
10% co-firing at Drax power station (UK)

Source: Davis Smales, Drax

<table>
<thead>
<tr>
<th>Key factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass bulk storage capacity</td>
<td>36,000 m³ (≈3 days at Full Load)</td>
</tr>
<tr>
<td>Biomass buffer capacity</td>
<td>2,400 m³</td>
</tr>
<tr>
<td>Biomass firing rate</td>
<td>15 - 45 tonnes per hour per boiler</td>
</tr>
</tbody>
</table>
Biomass co-firing in high percentages – R&D needs

- Biomass upgrading technology to reduce the cost of biomass logistics and improve the compatibility of biomass as a fuel

- Better mechanistic understanding of combustion/gasification-related technical bottlenecks and translation into fuel mixing recipes, design specifications and operating guidelines

- Predictive tools for assessing the co-firing potential of biomass streams and optimising boiler design and operation for co-firing (low-cost screening, modelling)

- Advanced techniques for (on-line) process monitoring and control

- (Ash recycling strategies and) utilisation options
Biomass – a difficult energy source

- Tenacious and fibrous (grinding difficult)
- Low energy density ($\text{LHV}_{\text{ar}} = 10-17 \text{ MJ/kg}$)
- Hydrophilic
- Vulnerable to biodegradation
- Heterogeneous
Biomass upgrading – technology options

• Adapt the biomass fuel to requirements of logistic systems and conversion processes (commodity fuel or “designer fuel”)

• Technology options (a.o.):
  – Pyrolysis
  – Briqueting
  – Pelletisation
  – Torrefaction
Torrefaction for upgrading biomass

Energy densification (MJ/kg): $\frac{0.9}{0.7} = 1.3$

Process parameters:
- Temperature: 200-300°C
- Residence time: 10-30 minutes
- Particle size: < 4 cm
- Absence of oxygen
- Pressure: near atmospheric
Why torrefaction: from biomass/waste to commodity fuel

Woody biomass | Agricultural residues
---|---
Friable and less fibrous | 19 - 22 MJ/kg (LHV, ar)
Hydrophobic | Preserved
Homogeneous | Torrefaction and pulverisation

Mixed waste

Friable and less fibrous | Superior fuel properties:
10 - 17 MJ/kg (LHV, ar) | – Transport, handling, storage
Hydrophilic | – Milling, feeding
Vulnerable to biodegradation | – Gasification, combustion
Heterogeneous | – Feedstock range

Torrefaction and pulverisation

Fuel powder

Tenacious and fibrous

Fuel pellets

Pelletisation

Bulk density 700-800 kg/m³
Bulk energy density 13-17 GJ/m³
Grindability of (torrefied) woody biomass

Torrefaction leads to a dramatic decrease in required milling power and increase in milling capacity.
Torrefaction pilot-plant testing (50-100 kg/h)
BO$_2$GO demonstration plant

- Location: Delfzijl, the Netherlands
- Capacity:
  - Input: 130,000 tonne – 170,000 tonne/a
  - Output: 70,000 tonne/a
- Start-up: 2010

BioMCN methanol production
Technical bottlenecks

Many bottlenecks
ash-related

direct co-firing

catalyst
deactivation
fouling & corrosion
ESP performance
NOx emissions
ToMe emissions

BM
coal

burner stability
boiler performance
near-burner slagging
burnout

fly ash quality

gypsum quality
stack

milling problems
Technical bottlenecks
Ash forming elements in biomass vs. coal

- wood fuels
- straw
- coals

Graph showing the mass fraction of various elements in different fuels:
- BM1, BM2, BM3, BM4, BM5, BM6, C1, C2

Elements represented by colors:
- Pb
- Zn
- Mn
- Cl
- S
- P
- Ti
- K
- Na
- Mg
- Al
- Ca
- Fe
- Si

Label at the bottom: olive residue
Ash related issues to consider for a ‘typical’ biomass

Biomass

- low ash content
- high alkali content
- low sulphur content
- low mineral content
- high chlorine content

Deposition
Corrosion
ESP operation
Utilisation
Emissions

Answers lie in ash formation!
Lab-scale Combustion Simulator (LCS)

Realistic gas temperature and gas composition profiles, sampling 5-2500 ms
Lab-scale Combustion Simulator (LCS)

Entrained-flow reactor with integrated, premixed and multi-stage flat flame burner

- high particle heating rates
- high flame/particle temperature
- realistic gas temperature / environment history
- Controllable, long particle residence time
Full-scale probe measurements

ECN mobile heat flux & ash deposition probe

- Camera
- Water/air cooled
  O.D. 61 mm / L 3.5 m
- Heat flux sensors
- Fly ash sampling
- Deposition ring

ECN mobile heat flux & ash deposition probe
Full-scale mass-balance measurements
Ash release results – top-4 elements

Bark (spruce)  Wood chips (spruce)  Olive residue  Polish coal

Mineral calcium  Organic calcium  Potassium salt  Mineral potassium
Comparison of ash release between fuels

Release biomass very different from coal:
- total release biomass 30-55% (incl. S and Cl)
- total release coal 0.3-2.6% (excl. S and Cl) or 8-36% (incl. S and Cl)
Release behaviour in MBM co-firing

Alkali metals in MBM significantly increase risk of corrosion and fouling. Can coal non-alkaline clay minerals interact with alkalis in MBM?

- 1650-1450°C T profile, residence time (~50 µm particles) ~2.0 s
- MBM and 20% (w/w) MBM in PO56 and DGP coals

<table>
<thead>
<tr>
<th>Mineral name/content [% w/w]</th>
<th>PO56</th>
<th>DGP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ASH</td>
<td>16.6</td>
<td>14.4</td>
</tr>
<tr>
<td>Quartz</td>
<td>13.1</td>
<td>6.3</td>
</tr>
<tr>
<td>Kaolinite (non-alkaline-clay)</td>
<td>20.0</td>
<td>58.9</td>
</tr>
<tr>
<td>Montmorillonite (Mg,Na-clay)</td>
<td>19.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Illite (K-clay)</td>
<td>18.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Al-silicate (not further specified)</td>
<td>5.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Dolomite</td>
<td>5.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Pyrite</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Apatite</td>
<td>0.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Ca-Al-silicate</td>
<td>0.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Classified sum of minor fractions</td>
<td>8.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Unclassified</td>
<td>4.7</td>
<td>2.0</td>
</tr>
<tr>
<td>Total clay % of the ash</td>
<td>64%</td>
<td>65.4%</td>
</tr>
<tr>
<td>kaolinite+Al-silicate % in clay</td>
<td>39% of total clay</td>
<td>94% of total clay</td>
</tr>
</tbody>
</table>
Release behaviour in MBM co-firing

- Interactions with clays are quite significant
- Coal minerals may be used to control alkali behaviour

![Graph showing K/Na loss (mg/kg fuel)]

~ 5x reduction

 MBM sec | PO56 | PO56/MBM sec | DGP | DGP/MBM sec
---|---|---|---|---
K | 4263 | 250 | 175 | 50
Na | 2609 | 0 | 7.3 | 10
General understanding of fuel interactions

*Example potassium*

Ca/Si based aerosols (s/l)

- KCl (l/s), KOH (g), $K_2SO_4$ (s)
- KCl (g), KOH (g), $K_2SO_4$ (l)
- KCl (g), KOH (g), $K_2SO_4$ (g)

Biomass

- KCl (g), KOH (g)

Coal

- SO$_2$ (g)

Clay minerals (l/s)
Interactions demonstrated in ash deposition

- **coal**
  - minerals

- **straw**
  - KCl
  - + silicates

- **straw + coal (20/80)**
  - minerals; no KCl!
Impact deposition on heat transfer – fouling factor

<table>
<thead>
<tr>
<th>Combustion conditions</th>
<th>Fuel mass fed</th>
<th>Deposition rate</th>
<th>Deposit thickness @ 0°</th>
<th>Fraction of inorganic matter deposited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[g]</td>
<td>[g/m²s]</td>
<td>[mm]</td>
<td>% wt</td>
</tr>
<tr>
<td>full NOx</td>
<td>7.7</td>
<td>0.018</td>
<td>2.00</td>
<td>61</td>
</tr>
<tr>
<td>O₂ depleted</td>
<td>2.29</td>
<td>0.009</td>
<td>3.70</td>
<td>30</td>
</tr>
<tr>
<td>OFA</td>
<td>7.64</td>
<td>0.013</td>
<td>1.40</td>
<td>43</td>
</tr>
</tbody>
</table>

Fuel: MVC + olive residue

mass ≠ thickness ≠ fouling factor!
Predictive tools – aggregating mechanistic knowledge

- Low-cost screening
- Biofuel impact prediction (empirical modelling, esp. ash-related)
  - release, formation, properties, deposition, quality, emission
- Ash Deposition Post-Processor (CFD-based)

CFD commercial codes:
- FLUENT, CINAR

ADP: Fortran Main Program

Step 2 and 3 represent clusters of models (Fortran subroutines)
On-line deposition monitoring and control

- Membrane walls: heat flux measurement + water canons (Clyde Bergemann)
- Super-/reheaters: section-wise evaluation using cleanliness factors (ratio of actual vs theoretical heat transfer rate, e.g. ABB system)

Technology challenge: direct monitoring (and control) of super-/reheater fouling

Heat flux measurement

Water canon cleaning

Clyde Bergemann system

ABB system
Fouling under USC conditions

- Deposit bulk composition: S and Cl vs surface temperature and SO$_2$(g)
Lab-scale ash deposition (USC conditions)

Coal and coal/biomass: USC < SC
Coal/biomass > Coal (SC)
Coal/biomass ~ Coal (USC)
Sulphur: overall increase in rates
Lab-scale ash deposition (USC conditions)

- **Deposition rate [g/m²/s]**
  - **Coal**
  - **Coal + Straw**

- **Specific Fouling Fact. [K* m²/W g fuel ash]**

### Data Points
- **590**
- **590+S**
- **660**
- **660+S**
- **750**
- **750+S**
Lab-scale ash deposition (USC conditions) – initial corrosion

<table>
<thead>
<tr>
<th>Oxide layer on interface</th>
<th>C1/660 °C/0</th>
<th>C1/750 °C/0</th>
<th>C1/BM6/660 °C/0</th>
<th>C1/BM6/750 °C/0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate material</td>
<td>SS310</td>
<td>Alloy617</td>
<td>SS310</td>
<td>Alloy617</td>
</tr>
<tr>
<td>Thickness [µm]</td>
<td>5</td>
<td>1.5</td>
<td>6.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Main elements</td>
<td>Cr, Mn, Fe, Ni</td>
<td>Cr, Ni, Mo, Co</td>
<td>Cr, Mn, Fe</td>
<td>Cr, Ni, Mo, Co</td>
</tr>
<tr>
<td>Sulphur [%]</td>
<td>~4</td>
<td>&lt; d.l.</td>
<td>~2</td>
<td>~1</td>
</tr>
</tbody>
</table>
Biomass co-firing – new challenges

- Biomass should be sustainable and certified
- Biomass is scarce and costly → maximise efficiency → optimise heat utilisation
- Other biomass applications with higher added value → low quality biomass for co-firing (e.g. high alkali/chlorine content) → Low-temperature gasification (650 °C)
- Large, increasing fraction of wet biomass → need for special upgrading technology

Source: Peder Stoholm
Increasing amounts of wet biomass: TORWASH?

E.g. residues from wet/biochemical biomass processing and aquatic biomass

TORWASH = Torrefaction + Washing + Drying

- Salt removal (K, Na, Cl, SO₄)
  - better ash quality → utilisation instead of land fill

- Torrified product
  - energy densification, logistics, etc.
  - chemical conversion makes biomass water repellent

- Dry biomass
  - higher caloric value
CTORWASH (hay)

- Chlorine
- Potassium
- Sodium

10 x lower salt content

Element in mg/kg (dry material)

- Raw material, dried at 105°C
- Washed at 20°C
- Torrified at 240°C, washed at 20°C
- TORWASH 200°C
Concluding remarks

• Biomass co-firing is established technology for co-firing percentages up to 10-20% (e/e)

• Biomass co-firing at high percentages (30-50% e/e) is feasible, but needs/highly benefits from:
  – Innovative biomass upgrading technology
  – Better mechanistic understanding of technical bottlenecks
  – Better predictive tools
  – On-line monitoring and control (e.g. fouling, corrosion)

• Torrefaction + pelletisation allows cost-effective, high-efficiency production of commodity biomass fuels with superior logistic and conversion properties

• Many technical bottlenecks in biomass co-firing are ash related. Main mechanisms of ash formation and ash behaviour have been mapped. R&D focus now on quantification and incorporation of mechanistic knowledge in predictive tools

• Combination of predictive tools and on-line monitoring is key to successful management of ash behaviour

• New challenges in biomass co-firing include sustainability, heat utilisation, lower quality (“salty”) biomass, wet biomass
Thank you for your attention!

For more information, please contact:

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