Case studies of biomass co-firing in full-scale pulverized coal-fired (PC) power plants in China

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1. Background and motivation.

Biomass-fired power plants in China

- Actual: >16 GW (2019)
  - Half: agriculture and forest biomass
  - Half: municipal waste
Problems of biomass-fired furnace

- Ash deposition, corrosion.
- Low combustion and generating efficiency
  - UBC in ash > 35%
  - Generating efficiency < 30%

Biomass co-firing ^_^
Coal-fired power plants in China

- Total capacity: 1144 GW
- Ultra-low emissions
  - NOx < 50 mg/m³
  - SOx < 35 mg/m³
  - PM < 5 mg/m³
- Near-zero emissions
  - NOx < 25 mg/m³
  - SOx < 10 mg/m³
  - PM < 1 mg/m³
2. Current situation of biomass co-firing in pulverized coal-fired power plants in China

“Biomass co-firing” → “biomass coupling generating”
Biomass (gasification) coupling generating in large-scale PC power plants

Biomass gasifier + Coal-fired power plant
The only one case of “biomass gasification coupling”: Guodian Changyuan Jinmen Power Plant

- Biomass: 8-10 t/h.
- CFB gasifier.
- 600 MW coal-fired unit.
- Commercially operated since 2012.11.
- 0.75 RMB/kwh.
  - Other in Hubei, +0.081RMB/kwh.
Advantages and questions of “biomass gasification coupling”

Advantages:
1. Gas transporting temperature >400°C, avoid tar condensation in pipelines.
2. Able to on-line measure the gas composition, heating value, and flux, thereby obtain the feed-in subsidy price: 0.75 RMB/kwh.

Questions (2018.5):
1. Avoid coal-blending?
2. Tar in gasifier?
3. High investment: 60,000,000 RMB (8-10t/h, 10 MW).
4. Complex system, need to retrofit the coal-fired furnace.
5. Coal gasification? (effective monitoring?)
6. Inherent operating problems of CFB boilers/gasifiers.
7. Fouling in gasifier’s heat exchanger?
8. Gasification efficiency?
9. Bio-char market?
News: no subsidy for “biomass coupling generating” from the State Level-2018.6

☐ The subsidy (0.75 RMB/kwh) for the only project obtaining the subsidy from the State Level was canceled, since 2018.6.
☐ Whether subsidy or not depends on the local government.
Another mode of biomass co-firing: “Huadian Shiliquan”, the first one in China since 2005.

Coal fired furnace: 400t/h, tangential combustion.
Fuel: wheat straw and corn straw.
Designed straw capacity: 105000 t/year, accounting for 18.6% energy input.
Time: put into operation since 2005. 12.
The problems of “Huadian Shiliquan Mode” co-firing.

Technical:

1. The imported equipment for fuel treatment and combustion, huge investment >85,000,000 RMB.
2. The uncontrolled biomass price: 200 RMB/t → 500 RMB/t.
3. The equipment for fuel treatment can only cut straw.
4. Straw supplying is not enough: the actual co-firing ratio is only ~5%.

Policy:

2. Local government: obtain the additional subsidy of 0.08 RMB/kwh.
XJTU-Bao’er mode: briquette biomass co-firing

Additional benefits:

- Zero investment for power plant
- Long commercial chain, increasing job positions
- Decrease transporting cost
- Larger co-firing amount
Tested Furnace and Biomass Feeding

■ Furnace Parameters
  - 300MW, 1025t/h
  - Tangentially fired furnace
  - A-F, 6 layer combustors
  - Medium-speed roller mill
  - Direct-blow coal powder system

■ Position of Biomass Feeding
  - F bunker (standby one)
## Fuel Characteristics

<table>
<thead>
<tr>
<th>Fuel</th>
<th>( Q_{\text{net,ar}} )/MJ.Kg(^{-1} )</th>
<th>Proximate analysis</th>
<th>Ultimate analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M_{\text{ar}} )</td>
<td>( V_{\text{daf}} )</td>
<td>( A_{\text{ar}} )</td>
</tr>
<tr>
<td>Huating Coal</td>
<td>18.5</td>
<td>35.5</td>
<td>17.6</td>
</tr>
<tr>
<td>Straw pellets</td>
<td>12.6</td>
<td>79.3</td>
<td>28.3</td>
</tr>
</tbody>
</table>

- The straw pellets is prepared by compressing and extruding a mixture of biomass (straw) and a binding agent (local soil).
- The mold biomass pellets are 34mm in diameter and less than 65mm in length, with a density of 1.18g/cm\(^3\).
Test Conditions

<table>
<thead>
<tr>
<th>Condition No.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Load / (MW)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Biomass Quantity / (t/h)</td>
<td>-</td>
<td>12</td>
<td>24</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Primary Air of Mill F / (m³/s)</td>
<td>-</td>
<td>21.74</td>
<td>19.37</td>
<td>15.99</td>
<td>18.70</td>
</tr>
<tr>
<td>Inlet Temperature of Mill F / (C)</td>
<td>-</td>
<td>78</td>
<td>83</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>Outlet Temperature of Mill F / (C)</td>
<td>-</td>
<td>48</td>
<td>43</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td>Ratio of Primary Air / (%)</td>
<td>25.1</td>
<td>30.7</td>
<td>30.3</td>
<td>29.2</td>
<td>32.1</td>
</tr>
<tr>
<td>Overall Furnace equivalence ratio / (1)</td>
<td>1.184</td>
<td>1.191</td>
<td>1.183</td>
<td>1.180</td>
<td>1.195</td>
</tr>
</tbody>
</table>

Target Characters

- Practicality and safety of the mill operation;
- Furnace temperature and efficiency;
- Pollutant emission;
- Ash availability in cement industry.
(1) Practicality of biomass grinding & Safety of mill operations

The roller mill can be used for pulverizing the mold biomass pellets.

- To avoid current overload and blockage of the mill.
  - Biomass feed rate should not be too high
  - Carrying airflow rate should be adequate

The following graph shows the effect of biomass feed rates and primary air flow rate.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Power Limit (KW)</th>
<th>Current Limit (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>349</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Effect of biomass feed rates & primary air flow rate
(2) Flame & Temperature profiles

No.1 12t/h  No.2 24t/h

Exhaust gas temperature vs. Furnace outlet temperature

Temperature (K)
Under the conditions of biomass co-firing, the content of unburned carbon in the fly ash is higher:
- The furnace efficiency decreases by about 0.192%, when the biomass quantity increases from 0t/h to 12t/h.
- The furnace efficiency decreases by about 0.524%, when the biomass quantity increases from 0t/h to 24t/h.

Reasons:
- Temperature of biomass feeding; feeding position of biomass.

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of biomass feed (t/h)</td>
<td>0</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Inlet temperature of upper mill (°C)</td>
<td>229</td>
<td>78</td>
<td>83</td>
</tr>
<tr>
<td>Content of unburned carbon in fly ash (%)</td>
<td>0.179</td>
<td>0.474</td>
<td>0.519</td>
</tr>
<tr>
<td>Content of carbon in slag (%)</td>
<td>1.393</td>
<td>1.438</td>
<td>1.269</td>
</tr>
<tr>
<td>Exhaust temperature (°C)</td>
<td>135.5</td>
<td>125.5</td>
<td>133</td>
</tr>
<tr>
<td>Furnace efficiency (%)</td>
<td>94.673</td>
<td>94.481</td>
<td>94.149</td>
</tr>
</tbody>
</table>
(4) Emissions of NOx

- With an increase in the biomass input, the NOx emissions are gradually reduced.
- When the quantity of the biomass feed reaches 24t/h, the NOx emissions have been reduced by about 10%.

Mainly due to much more air is feed from layer F (the same overall air ratio)
(5) Ash availability in cement industry


Key parameters of mortars:
(1) Water demand ratio; (2) Expansion; (3) Flexural strength; (4) Tensile strength at 7 days and 28 days; (5) Activity index.

<table>
<thead>
<tr>
<th>Source of fly ash</th>
<th>None (used as standard)</th>
<th>Condition 0</th>
<th>Condition 1</th>
<th>Condition 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand ratio, %</td>
<td>100</td>
<td>91.15</td>
<td>88.50</td>
<td>88.50</td>
</tr>
<tr>
<td>Expansion, mm</td>
<td>0.50</td>
<td>1.25</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>Flexural strength (7 days), MPa</td>
<td>6.40</td>
<td>4.90</td>
<td>4.95</td>
<td>5.05</td>
</tr>
<tr>
<td>Tensile strength (7 days), MPa</td>
<td>36.70</td>
<td>25.30</td>
<td>23.55</td>
<td>22.30</td>
</tr>
<tr>
<td>Flexural strength (28 days), MPa</td>
<td>8.70</td>
<td>8.95</td>
<td>8.95</td>
<td>8.60</td>
</tr>
<tr>
<td>Tensile strength (28 days), MPa</td>
<td>49.6</td>
<td>39.95</td>
<td>37.95</td>
<td>37.45</td>
</tr>
<tr>
<td>Activity index</td>
<td>100</td>
<td>80.55</td>
<td>76.50</td>
<td>75.50</td>
</tr>
</tbody>
</table>

>75% √
The commercial operating of “XJTU-Bao’er mode”

1. Power plant fostered some fuel suppliers (FSs).
2. The crushed biomass was dried and then briquetted in briquetting station.
3. 0.8-1 t/h, per equipment, moister content <25%.
4. FSs “buy one machine, get one machine”.
5. We have built 19 briquetting stations with 50 briquetting, machines.
6. Year-2011: 10,000 ton biomass were burned.

341 RMB/t = 213 (raw fuel) + 50 (transport) + 78 (process)
4. XJTU-Baishui mode: biomass powder co-firing in a 55 MW PC furnace.

- 100KM: 4.25 million tons.
- 50KM: 1.53 million tons.
- 40-50% is fruit branches.

- Three biomass-fired unit planded.
- None running.
- Enough fuels.
Biomass powder pretreatment
Co-firing experiment (2018.6)

Symbol note:
- CO sampling
- Temperature measure
- Fuel powder sample
- Primary air
- Secondary air
- Tertiary air
Co-firing experiment (2018.6)
Safety of biomass powder milling and storage

CO concentration in milling system (ppm)

- Mill outlet
- Powder storehouse

100% coal: 0 ppm
5% biomass: 0 ppm
10% biomass: 2 ppm
20% biomass: 6 ppm
Safety of biomass powder transport in primary air pipe
Temperatures in storage house and primary air pipe

Temperature in the powder house

Primary air pipes
**Particle size distribution, unburned carbon (UBC), and efficiency**

<table>
<thead>
<tr>
<th>Cases</th>
<th>Qnet (MJ/kg)</th>
<th>UBC in ash (%)</th>
<th>UBC in slag (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure coal</td>
<td>22.67</td>
<td>4.706</td>
<td>11.479</td>
<td>90.88</td>
</tr>
<tr>
<td>5% biomass</td>
<td>22.370</td>
<td>4.676</td>
<td>14.063</td>
<td>90.82</td>
</tr>
<tr>
<td>10% biomass</td>
<td>22.069</td>
<td>5.769</td>
<td>15.960</td>
<td>90.09</td>
</tr>
<tr>
<td>20% biomass</td>
<td>21.468</td>
<td>5.161</td>
<td>15.992</td>
<td>90.11</td>
</tr>
</tbody>
</table>
NOx emission and De-NOx efficiency

- NOx emission
- De-NOx efficiency
Economic analysis for 2×55 MW unit

- One-time investment: 3,350,000 RMB
  - Field storing biomass 1,900,000 RMB
  - Controlled transport and weight system 450,000 RMB
  - Powder machine 1,000,000 RMB

- Fuel price (15 MJ/kg): 397 RMB/ton (can be lower)
  - Raw fuel 350 RMB/ton
  - Electricity 10 RMB/ton
  - Labor 25 RMB/ton
  - Depreciation 12 RMB/ton

- Low sulfur coal price (21.8MJ/kg): 510 RMB/ton
- High sulfur coal price (18.9MJ/kg): 300 RMB/ton
- Cost reduction in De-NOx and De-SOx
5. Summary

1. Biomass co-firing is promptly developed in China.
2. “Biomass gasification coupling co-firing” is under demo-stage, and there are concerning problems in technical and economics.
3. Biomass direct co-firing in PC power plants: (1) “Shiliquan”, (2) “XJTU-Bao’er” and (3) “XJTU-baishui”.
4. Direct co-firing:
   - Approved safety of system and powder transport system.
   - Slight decrease in efficiency, because of moisture and primary air temperature.
   - Lower NOx emission and higher De-NOx efficiency.
   - Ash availability in concrete industry.
5. Economic analysis: biomass direct co-firing can be competitive at a comparatively higher coal price, like now.