On cofiring as a strategy to mitigate ash deposition during combustion of a high-alkali Xinjiang coal

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Xinjiang: Most enriched with coal

- ~2.2 trillion tonnes of coal reserves, in contrast to Wyoming (1.4 trillion)
- > 40 percent of the Chinese coal reserves
- Shallow, thick coal seams
- Surface mining: productive, cheap and safe

- ~120 million tonnes produced in 2011
- > 750 million tonnes produced in 2020; One of the 5 largest coal producers by volume
- Power transmission and railroad projects underway

(Source: China SignPost, 2005)
Importance of XJ coal utilization

- China: the largest coal consumer in the world.
- But frequently faces coal shortages.

- Xinjiang has the largest share (>50%) of Chinese coal reserves 1000 meters or less from the surface.
- The coals are cheap!!!

(Source: BP, 2013)

(Source: China SignPost, 2005)
XJ coal properties

• Sub-bituminous coal to lignite
• High moisture, low ash, middle to high volatile matter, middle heating value
• High alkali and alkaline earth metals (AAEMs, > 60 wt%), low Si and Al
  – Na$_2$O : 2.7~9.6%
  – MgO : 3.2-6.5%
  – CaO : 20~50%
  – Fe$_2$O$_3$ : 6.5~24%
  – SiO$_2$ : 7.9~23%
  – Al$_2$O$_3$ : 7.5~10.7%
Particular ash composition

XJ coals vs Chinese traditional bit. coals

XJ coals vs international low-rank coals
Challenge in XJ coal combustion

• Severe ash slagging and fouling

Deposits in high temperature superheater

Deposits in low temperature superheater

Deposits in furnace

Deposits in economizer
Strategies under development

• Removing AAEMs from XJ coals
  – Not practical due to **SEVERE** lack of water in Xinjiang Province

• Adding additives (clay/silicates, e.g. kaolin or quartz; other additives)
  – Not always efficient and may be expensive

• Developing new tube materials for mitigation of ash deposition
  – Still underway
  – Expensive

• Co-firing with less- or non-fouling coal
  – Practical and in use in MOST Xinjiang power plants
Issue with co-firing XJ coals

• How to determine an appropriate blending ratio of XJ coals during co-firing?
  – Allow maximum utilization of XJ coal
  – Not induce severe slagging/fouling for safe operation

• Current practice
  – Based on a large amount of field experience
  – Lack of scientific guidance
  – Time-consuming, not always efficient (may still cause operation problems)
Problems concerned this work

• Hami coal power plant in eastern Xinjiang
  – Mine-mouth plant near Hami coal mines
  – Capacity: 4 × 660MW

• Problem description
  – Boilers designed for co-firing high-Na XJ lignite
  – Primary fuel: high Si/Al bituminous coal
  – How to determine an appropriate blending ratio?
Objectives of this work

- To develop lab-scale methods for
  - Evaluating the effects of co-firing XJ coal on ash deposition (both slagging & fouling)
  - Determining an appropriate blending ratio of a specific XJ coal

- To find out
  - To what extent the lab results can be extrapolated to large scale power plants

Fuels
- BC coal
- XJ coal blends

Tests
- Slagging
- Fouling

Evaluation
- Performance of Hami plant

Drop tube furnace
Fuel properties

Two coals from Hami power plant in Hami region, Xinjiang
Xinjiang coal (XJ): High Na lignite; Bituminous coal (BC): High Si/Al bituminous coal

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>V</th>
<th>A</th>
<th>FC</th>
<th>C</th>
<th>H</th>
<th>S</th>
<th>N</th>
<th>O(diff.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC coal</td>
<td>3.60</td>
<td>30.04</td>
<td>36.94</td>
<td>29.43</td>
<td>39.85</td>
<td>3.66</td>
<td>0.25</td>
<td>0.54</td>
<td>15.16</td>
</tr>
<tr>
<td>XJ coal</td>
<td>5.93</td>
<td>33.61</td>
<td>10.03</td>
<td>50.43</td>
<td>59.06</td>
<td>4.34</td>
<td>0.42</td>
<td>0.69</td>
<td>19.53</td>
</tr>
</tbody>
</table>

Proximate analysis

Ultimate analysis (wt%, air dry basis)

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>K</th>
<th>Ca</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC coal</td>
<td>2.02</td>
<td>1.95</td>
<td>27.20</td>
<td>52.78</td>
<td>0.28</td>
<td>1.11</td>
<td>3.51</td>
<td>5.90</td>
<td>5.25</td>
</tr>
<tr>
<td>XJ coal</td>
<td>8.00</td>
<td>8.61</td>
<td>15.96</td>
<td>22.63</td>
<td>0.59</td>
<td>5.45</td>
<td>1.48</td>
<td>26.73</td>
<td>10.55</td>
</tr>
</tbody>
</table>

Elemental composition of low temperature ash (wt%)

![Bar chart showing elemental composition of low temperature ash for BC and XJ coals.](chart.png)
Ash properties

**Modes of occurrence of basic elements**

**Prediction of liquid phase by FACTSAGE**

**Ash fusion temperatures (°C)**

<table>
<thead>
<tr>
<th></th>
<th>DT</th>
<th>ST</th>
<th>FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>1128</td>
<td>1390</td>
<td>&gt;1400</td>
</tr>
<tr>
<td>XJ</td>
<td>1106</td>
<td>1120</td>
<td>1142</td>
</tr>
</tbody>
</table>

WS - Water soluble
AS - Ammonium acetate soluble
HS - hydrochloric acid soluble
IS - Acid insoluble
Test facility

- **High-temperature drop tube furnace (DTF)**
  - Electrically heated
  - Diameter of reactor: 56 mm
  - Length of reactor: 2m
  - Temperature range: <1450 °C

- **Coal feeder**
  - Sankyo Piotech Micro Feeder (Model MFEV-10)
  - Feeding rate adjustable: >= 0.1 g/min

- **Advantages**
  - Much inexpensive relative to pilot or field tests
  - Multiple data sets in a very short time
  - Mimic key parameters in full-scale combustion: temperature, residence time, excess air, gas-cooling rates, and deposit surface substrate temperatures
  - Produce results similar to those observed in a full-scale boiler
  - Good for fly ash formation, ash deposition, and reactivity, etc
Slagging/fouling test methods

- **Slagging test method**
  - Uncooled mullite coupon for deposit collection
  - Coupon situated on the sampling probe
  - Probe positioned at a location with desired temperature
  - Mimic high-temperature slagging in full-scale combustors

- **Fouling test method**
  - Fouling testing furnace (temperature adjustable) connected directly to DTF
  - Stainless steel coupon on air-cooled deposition probe
  - Surface temperature of coupon well-controlled
  - Mimic low-temperature fouling in full-scale combustors

Diagram showing:
- Fouling testing furnace
- Sampling probe
- Thermocouple
- Filter
- Vacuum pump
- Temperature controller
- Sampling probe used in fouling tests
# Test conditions

## Test samples with different blending ratios (wt%)

<table>
<thead>
<tr>
<th>Samples</th>
<th>XJ00</th>
<th>XJ20</th>
<th>XJ40</th>
<th>XJ60</th>
<th>XJ80</th>
<th>XJ100</th>
</tr>
</thead>
<tbody>
<tr>
<td>XJ</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>BC</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

## Slagging testing conditions

<table>
<thead>
<tr>
<th>DTF temp. (℃)</th>
<th>Coupon surface temp. (℃)</th>
<th>Fuel feeding rate (g/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>1300</td>
<td>0.3</td>
</tr>
</tbody>
</table>

## Fouling testing conditions

<table>
<thead>
<tr>
<th>DTF temp. (℃)</th>
<th>Fouling furnace temp. (℃)</th>
<th>Coupon surface temp. (℃)</th>
<th>Fuel feeding rate (g/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>900</td>
<td>500</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Samples and analyses

• Samples
  – Bulk ashes
  – Deposits at high temperatures (slagging)
  – Deposits at low temperatures (fouling)

• Analysis techniques
  – SEM + EDS, XRF, XRD
  – Particle sizer, CCSEM
  – FACTSAGE
Deposition tendency assessment

- Rate of buildup (RBU) of deposits has been widely used to reflect ash deposition tendency.

\[
RBU = \frac{\text{Mass of deposits on coupon}}{\text{Mass of ash entering the projected area of coupon in the same exposure time}}
\]
Results for individual coals

- XJ coal has a much higher ash deposition propensity (slagging & fouling) than BC coal
- For XJ coal, fouling is a TOP priority
- For BC coal, slagging is a priority if any

<table>
<thead>
<tr>
<th></th>
<th>BC</th>
<th>XJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slagging RBU</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Fouling RBU</td>
<td>0.01</td>
<td>0.19</td>
</tr>
<tr>
<td>Fouling RBU/Slagging RBU</td>
<td>0.79</td>
<td>3.42</td>
</tr>
</tbody>
</table>
Results for coal blends

- XJ coal ratio $\leq 60$
  - No significant increase in RBU of slagging & fouling
- XJ coal ratio $> 60$
  - Significant increase in RBU, especially for fouling

Implications
- <60% of XJ coal may be appropriate for co-firing in full-scale boilers
Composition of fouling deposits

• Na increases significantly when XJ coal >60%
• Mg, K, Ca remain constant except case of XJ coal (XJ100)
• Conclusion: Na in the blends is the critical factor affecting fouling propensity
Fouling propensity vs Na/(Si+Al)

- A good correlation found

- Index of Na/(Si+Al)
  - <0.05 negligible fouling
  - >0.05 significant or severe fouling
Composition of slagging deposits

- Fe increases significantly when XJ coal >60%  
- Other basic elements seldom affected  
- Implication: Fe in the blends is the critical factor affecting slagging propensity
Slagging propensity vs Fe/(Si+Al)

- A good correlation found
- Index of Fe/(Si+Al)
  - <0.02 negligible slagging
  - >0.02 increased slagging
Extrapolation of lab results

• Lab results
  – 60% may be a safe ratio for co-firing XJ coal
  – Used for guides to Hami power plant operation

• Field results
  – No problem with a ratio < 40% of XJ coal
  – Slight slagging with 40-60% XJ coal, depending on thermal load
  – Significantly Increased fouling and slagging when the ratio >60%

Relatively good consistency between lab and field results
Deposits at 40-60% XJ coal

Slagging deposits: windward side deposits on primary superheater tubes

- Fe decreases in deposit growth direction
- Fe-induced slagging
- Attributed to De-NOx combustion

Fouling deposits: negligible
Conclusions

• Developed systematic methods for evaluating effects of co-firing a XJ coal on BOTH slagging & fouling
  – XJ coal has a much higher ash deposition propensity than BC coal
  – For XJ coal, fouling is a TOP priority
  – For BC coal, slagging is a priority
  – Na/(Si+Al) correlates with fouling
  – Fe/(Si+Al) correlates with slagging
  – <60% of XJ coal may be appropriate for co-firing in full-scale boilers

• Lab results can be a useful guide to full-scale operation
  – Field results: consistent with lab results except slight slagging at ratios >40%
  – Slight slagging is Fe-slagging due to De-NOx combustion

• Future work: May need to consider effects of De-NOx combustion
Acknowledgements

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Thanks
Questions?
Contact Dunxi Yu at yudunxi@hust.edu.cn
Boiler configurations

- Tower Type Super-critical Boiler