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

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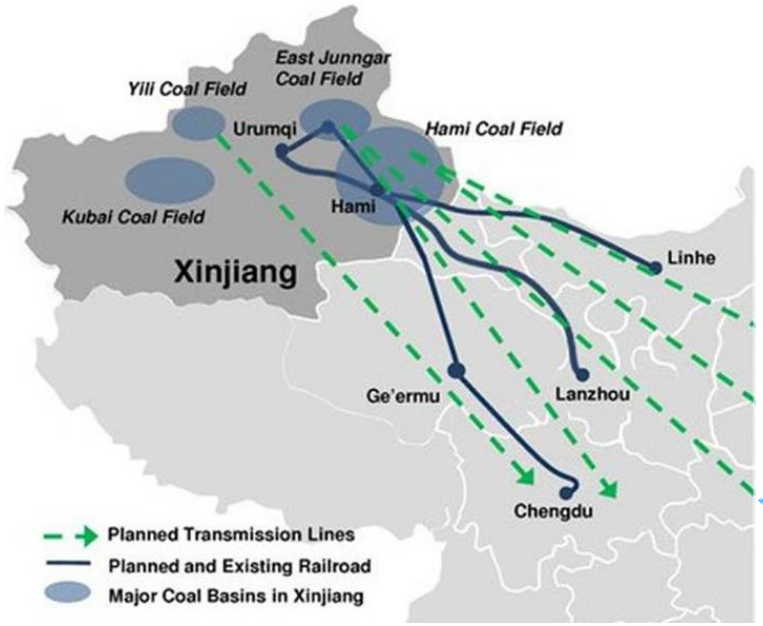
Xinjiang: Most enriched with coal



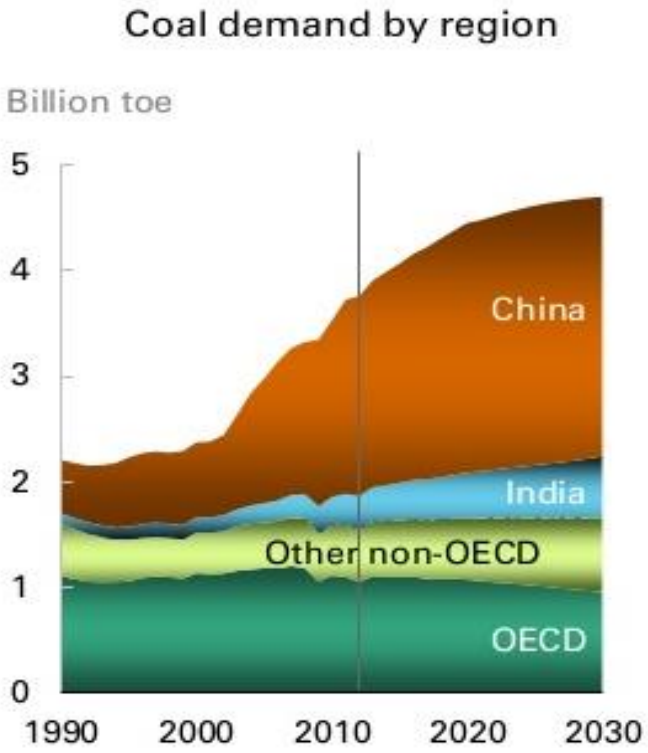
- ~2.2 trillion tonnes of coal reserves, in contrast to Wyoming (1.4 trillion)
- > 40 percent of the Chinese coal reserves
- Shallow, thick coal seams
- Surface mining: productive, cheap and safe

- ~ 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)

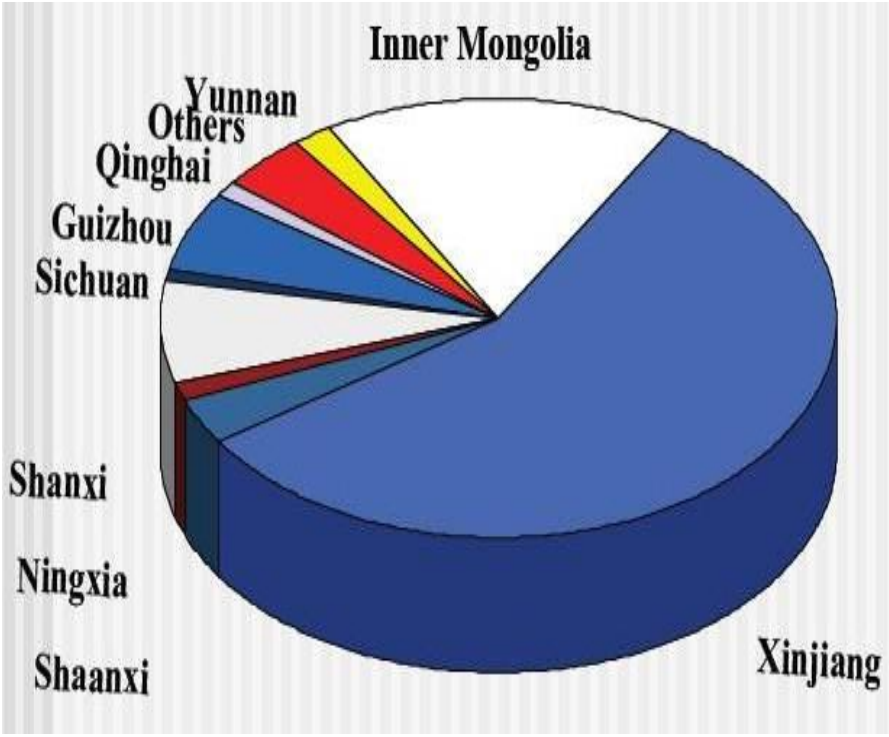
Importance of XJ coal utilization

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



(Source: BP, 2013)

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

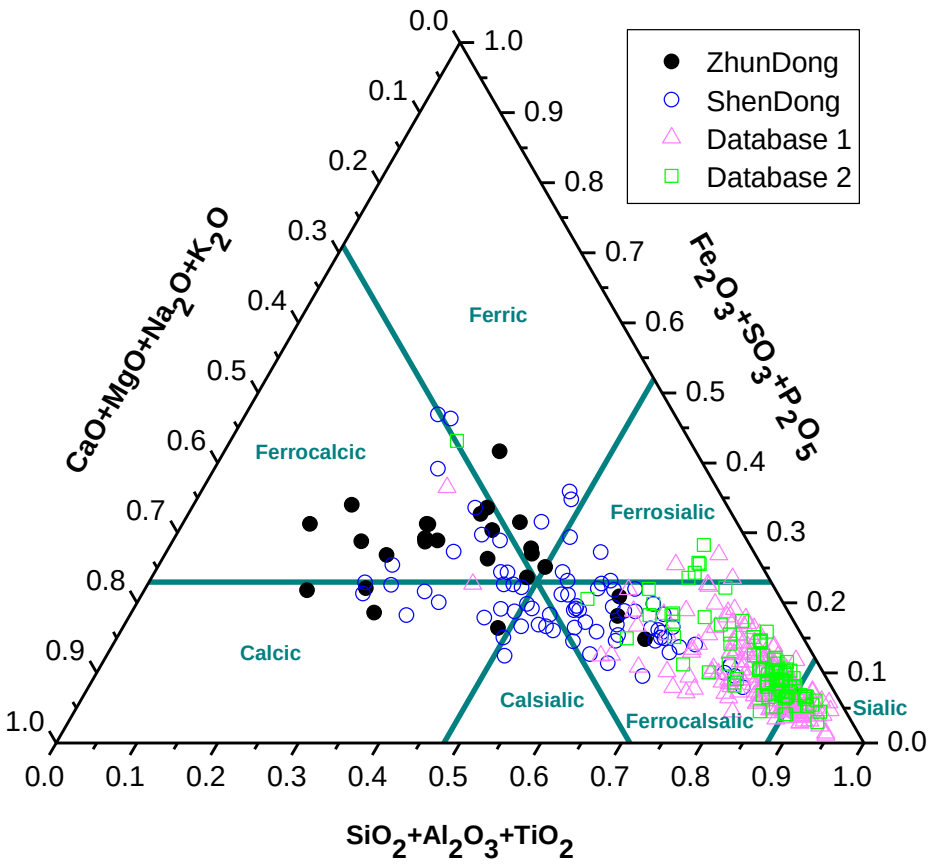


(Source: China SignPost, 2005)

XJ coal properties

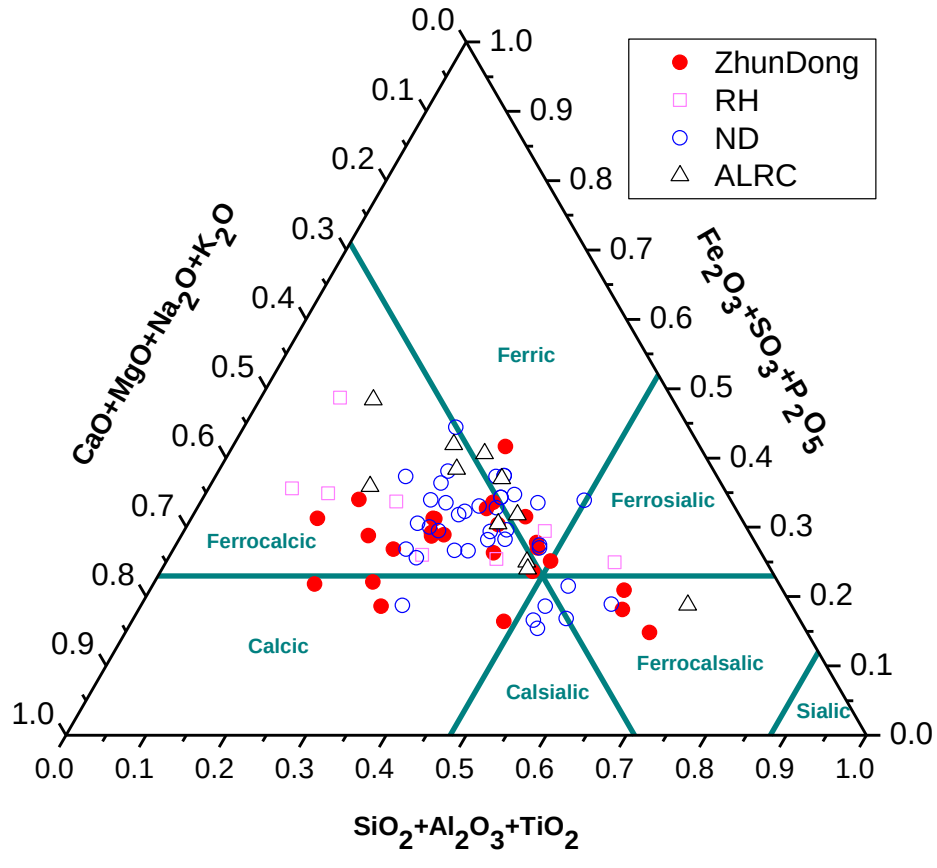
- Sub-bituminous coal to lignite
- High moisture, low ash, middle to high volatile matter, middle heating value
- High alkali and alkaline earth metals (AAEMs, > 60 wt%), low Si and Al
  - Na_2O : 2.7~9.6%
  - MgO : 3.2-6.5%
  - CaO : 20~50%
  - Fe_2O_3 : 6.5~24%
  - SiO_2 : 7.9~23%
  - Al_2O_3 : 7.5~10.7%

Particular ash composition



XJ coals vs
Chinese traditional bit. coals

RH: Rhine lignites, Germany
ND: North Dakota coals, US
ALRC: Low-rank coals, Australia



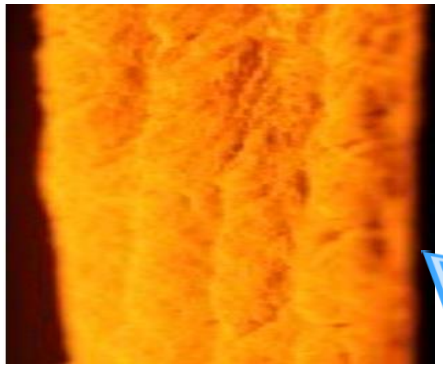
XJ coals vs
international low-rank coals

Challenge in XJ coal combustion

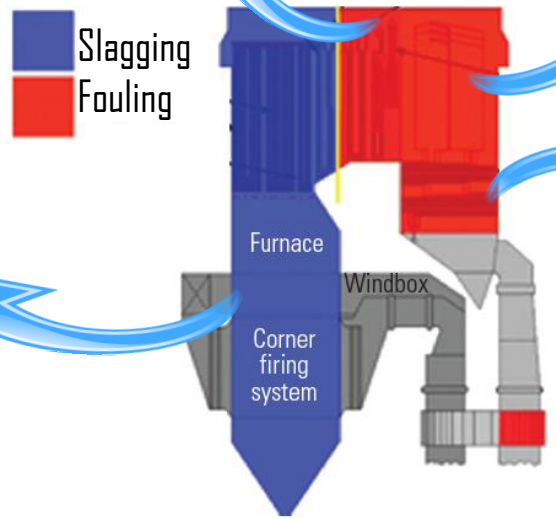
- **Severe ash slagging and fouling**

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

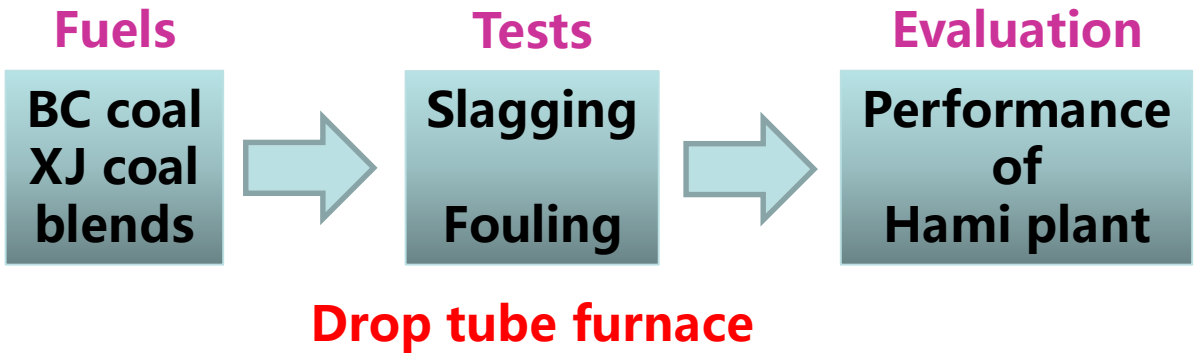
- **Hami coal power plant in eastern Xinjiang**
  - **Mine-mouth plant near Hami coal mines**
  - **Capacity: 4 × 660MW**

- **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**



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

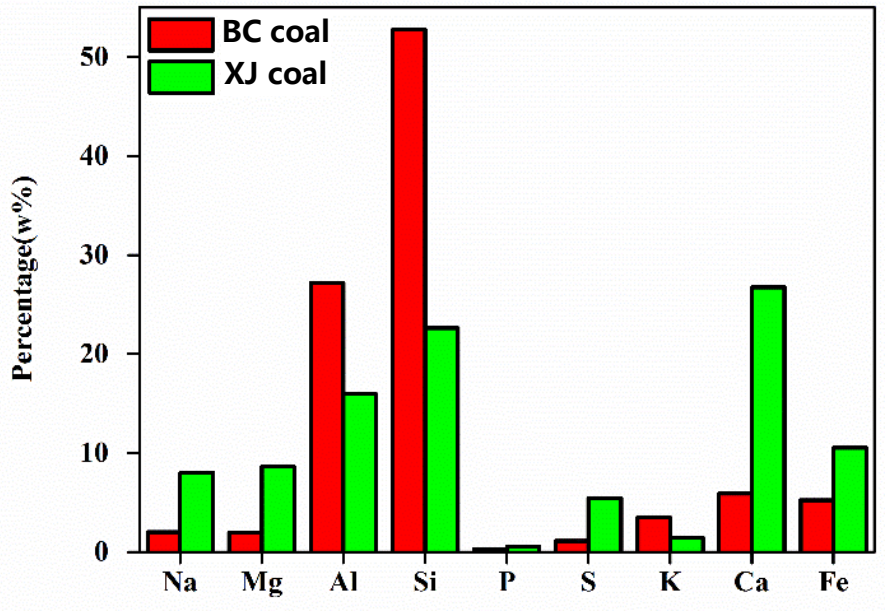
Proximate analysis

Ultimate analysis (wt%, air dry basis)

	M	V	A	FC	C	H	S	N	O(diff.)
BC coal	3.60	30.04	36.94	29.43	39.85	3.66	0.25	0.54	15.16
XJ coal	5.93	33.61	10.03	50.43	59.06	4.34	0.42	0.69	19.53

Elemental composition of low temperature ash (wt%)

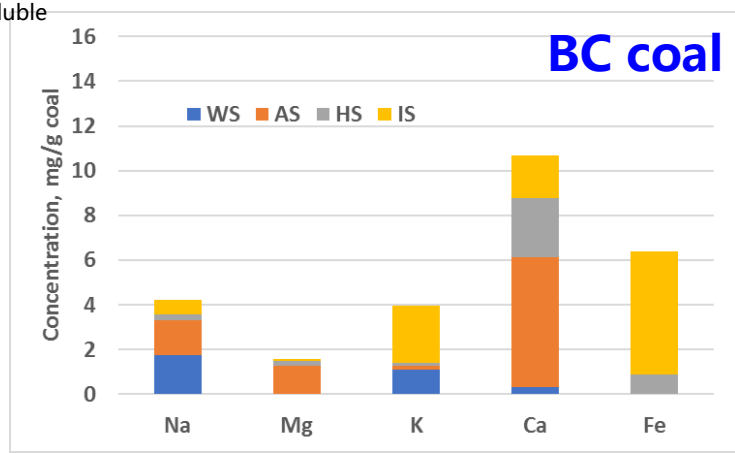
	BC coal	XJ coal
Na	2.02	8.00
Mg	1.95	8.61
Al	27.20	15.96
Si	52.78	22.63
P	0.28	0.59
S	1.11	5.45
K	3.51	1.48
Ca	5.90	26.73
Fe	5.25	10.55

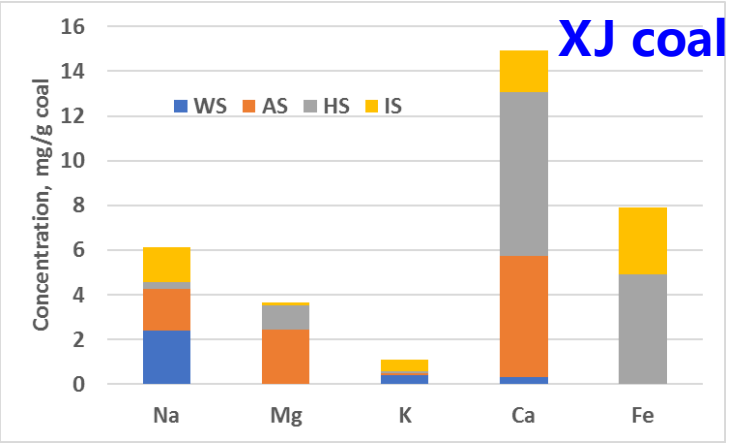


Ash properties

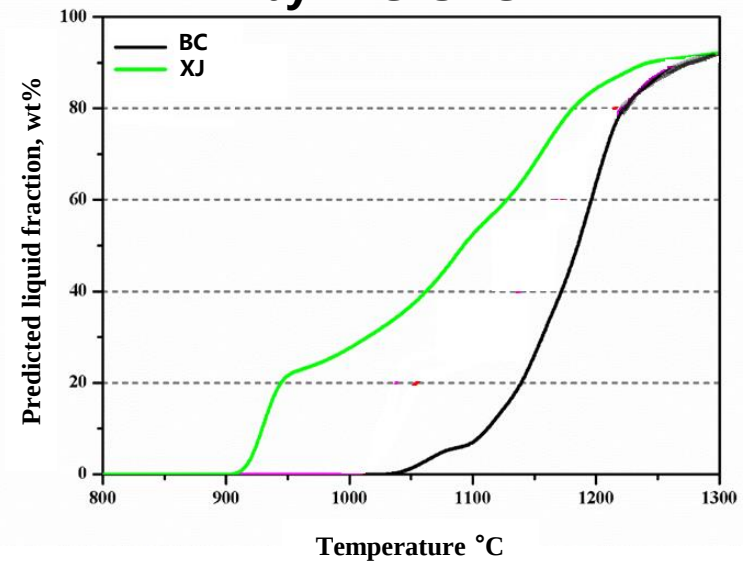
WS- Water soluble
AS - Ammonium acetate soluble
HS - hydrochloric acid soluble
IS - Acid insoluble

Modes of occurrence of basic elements





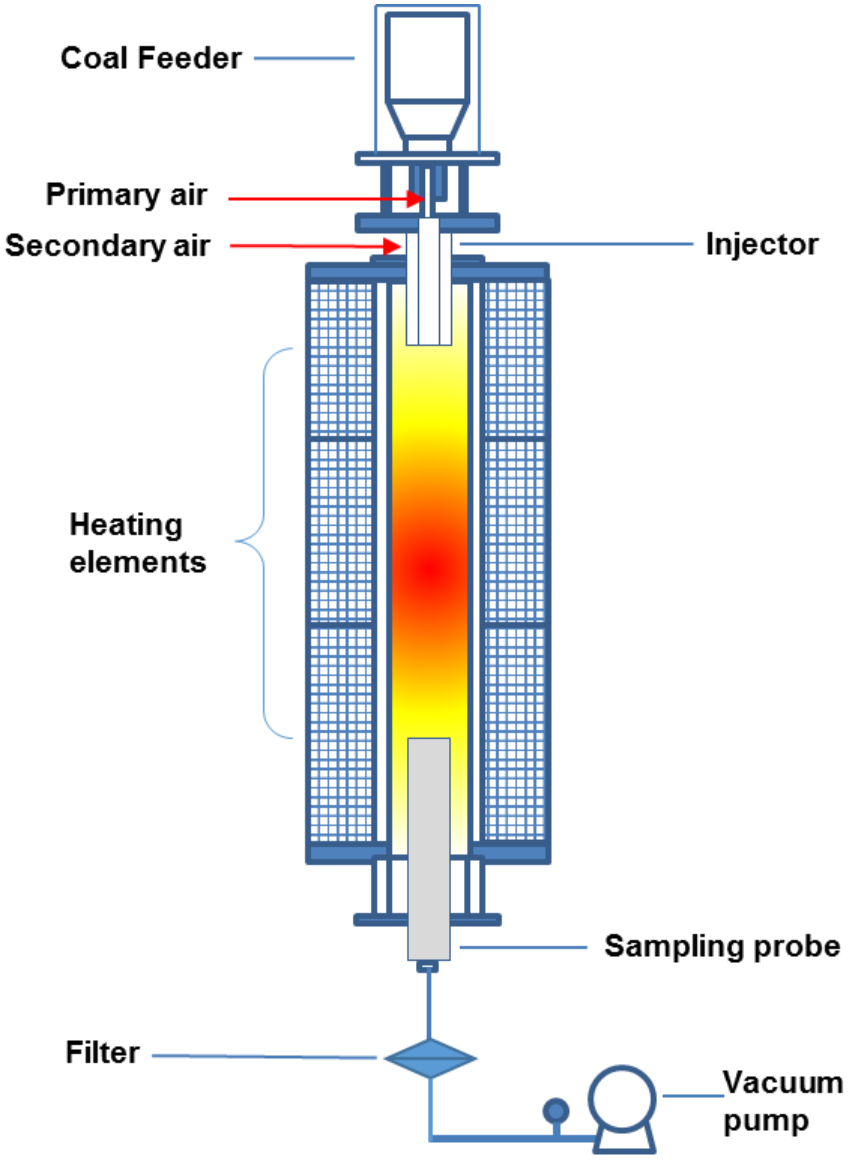
Prediction of liquid phase by FACTSAGE



Ash fusion temperatures (℃)

	DT	ST	FT
BC	1128	1390	>1400
XJ	1106	1120	1142

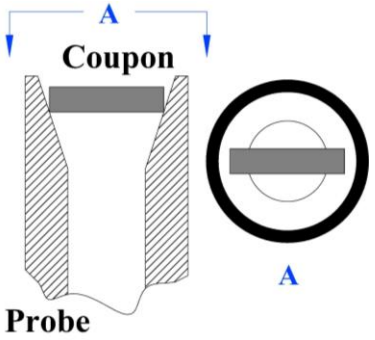
Test facility



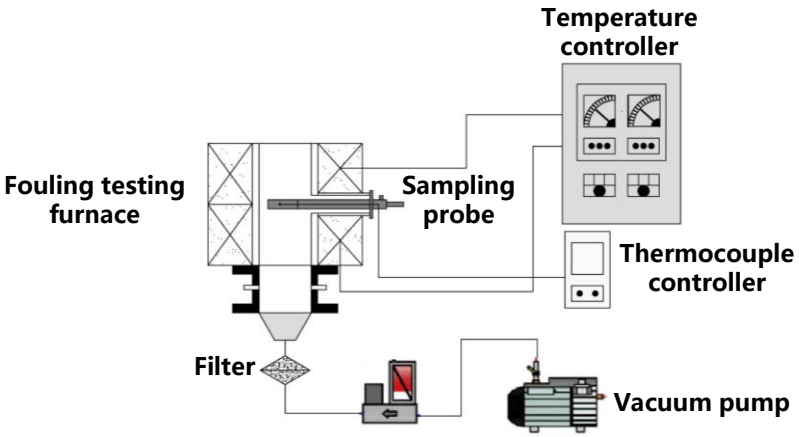
- **High-temperature drop tube furnace (DTF)**
  - Electrically heated
  - Diameter of reactor: 56 mm
  - Length of reactor: 2m
  - Temperature range: <1450 °C
- **Coal feeder**
  - Sankyo Piotech Micro Feeder (Model MFEV-10)
  - Feeding rate adjustable: >= 0.1 g/min
- **Advantages**
  - Much inexpensive 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

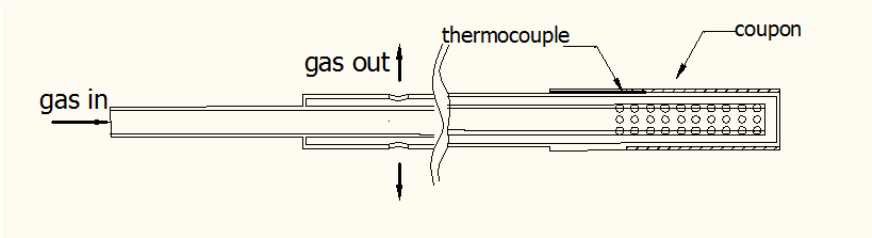
- **Slagging test method**
  - Uncooled mullite coupon for deposit collection
  - Coupon situated on the sampling probe
  - Probe positioned at a location with desired temperature
  - Mimic high-temperature slagging in full-scale combustors



- **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



Sampling probe used in fouling tests



Test conditions

Test samples with different blending ratios (wt%)

Samples	XJ00	XJ20	XJ40	XJ60	XJ80	XJ100
XJ	0	20	40	60	80	100
BC	100	80	60	40	20	0

Slagging testing conditions

DTF temp. (℃)	Coupon surface temp. (℃)	Fuel feeding rate (g/min)
1300	1300	0.3

Fouling testing conditions

DTF temp. (℃)	Fouling furnace temp. (℃)	Coupon surface temp. (℃)	Fuel feeding rate (g/min)
1300	900	500	0.3

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

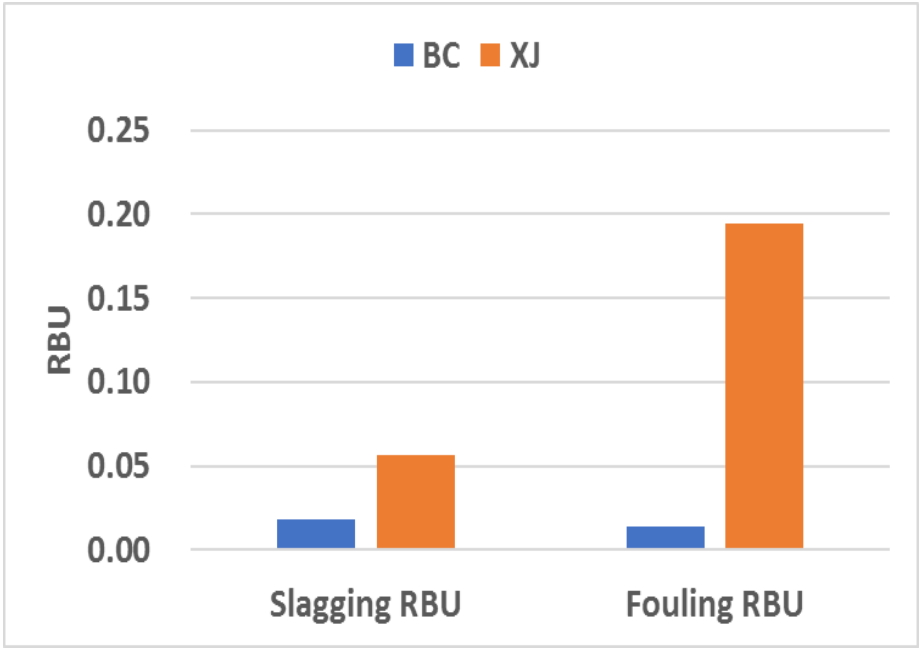
- **Rate of buildup (RBU) of deposits has been widely used to reflect ash deposition tendency.**

$$RBU = \frac{\text{Mass of deposits on coupon}}{\text{Mass of ash entering the projected area of coupon in the same exposure time}}$$

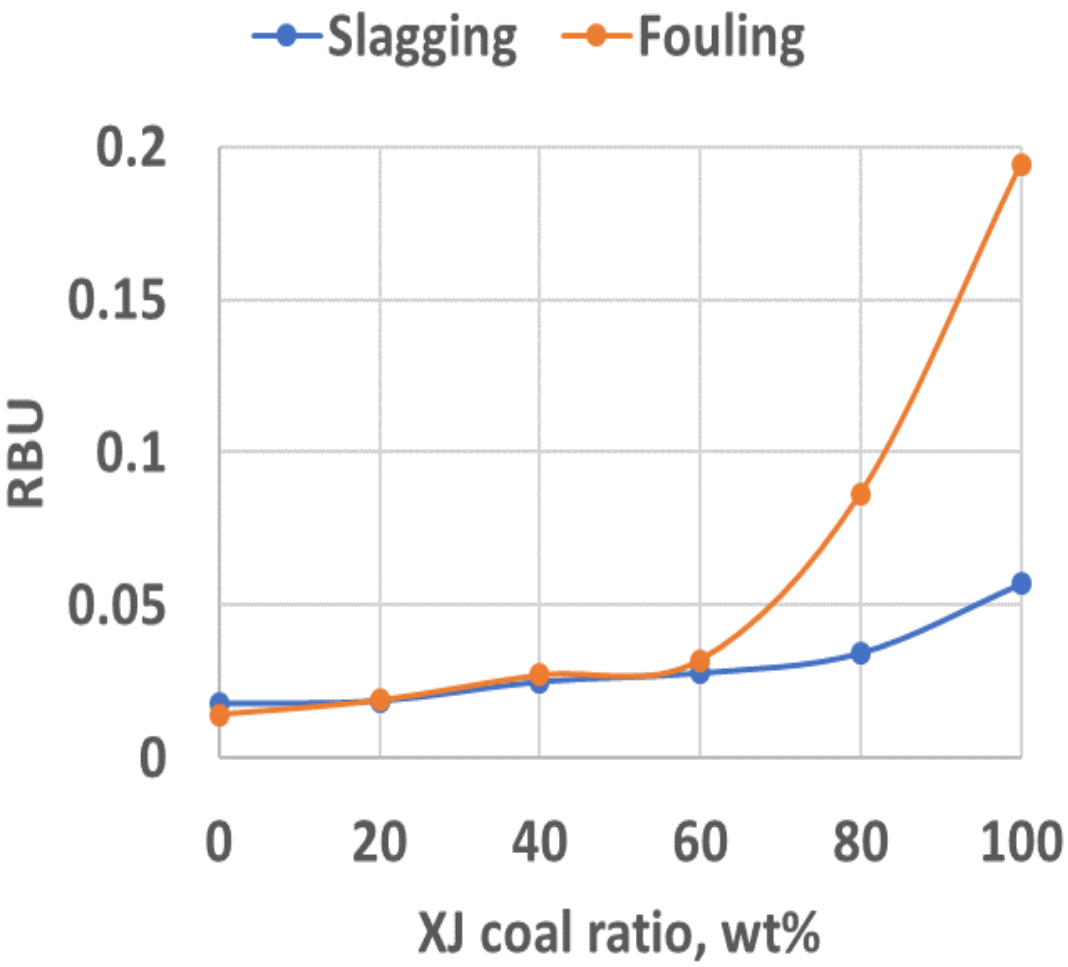
Results for individual coals

- 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

	BC	XJ
Slagging RBU	0.02	0.06
Fouling RBU	0.01	0.19
Fouling RBU/Slagging RBU	0.79	3.42

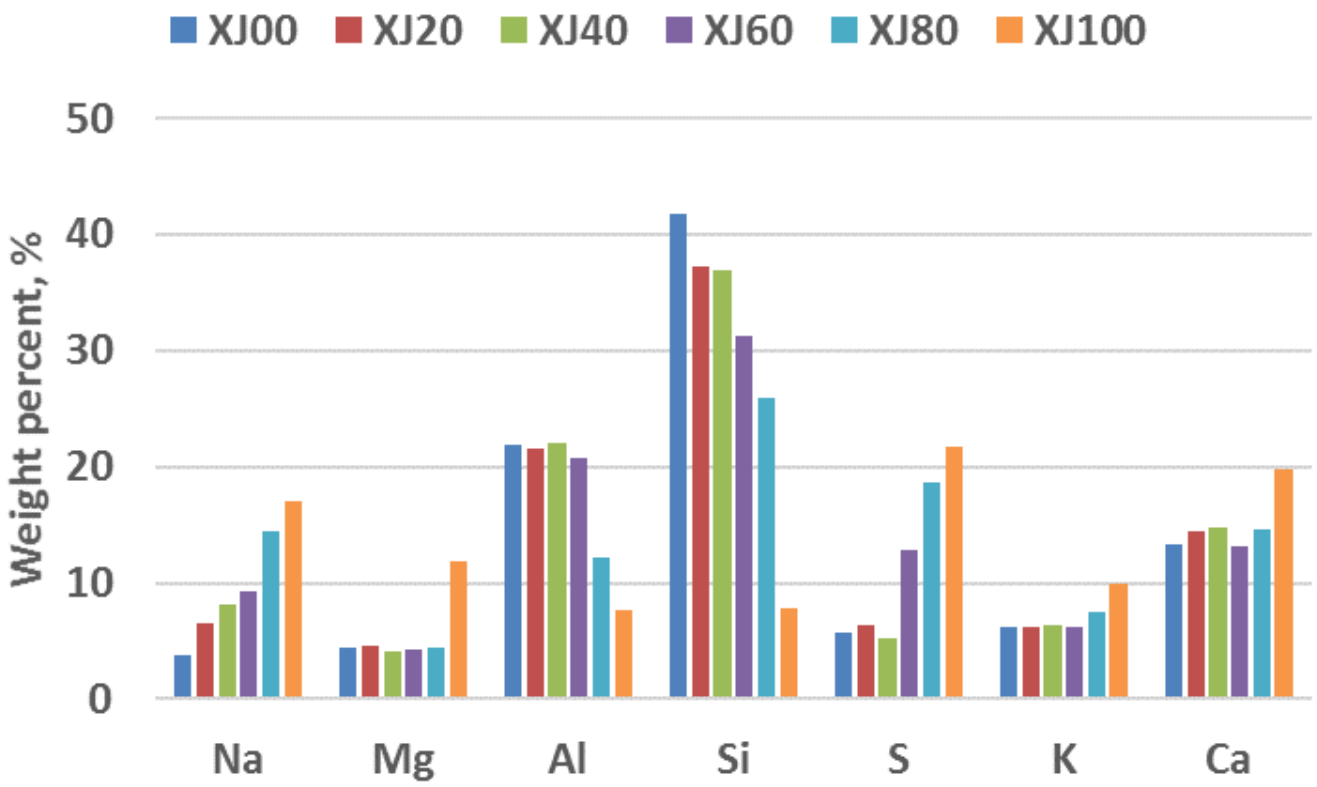


Results for coal blends



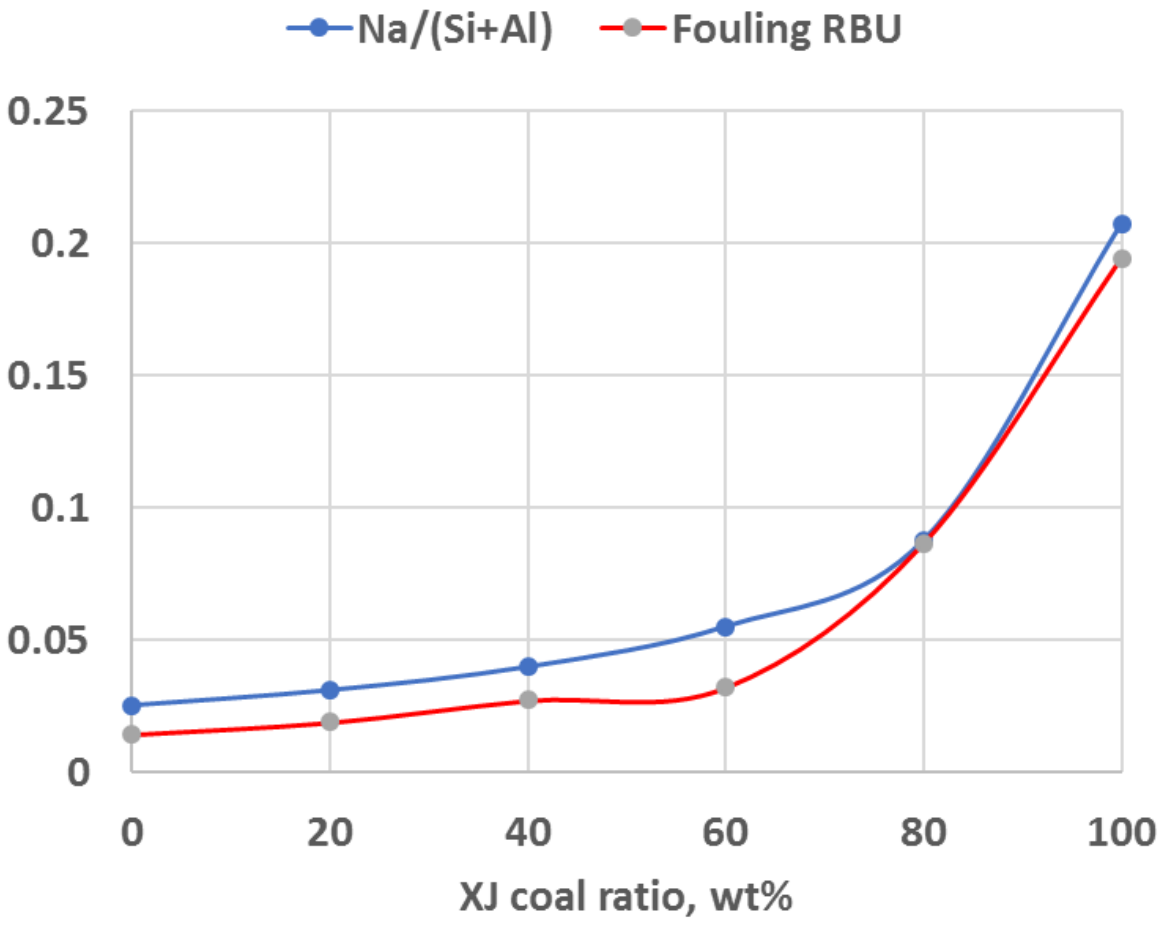
- XJ coal ratio ≤ 60%
  - No significant increase in RBU of slagging & fouling
- XJ coal ratio > 60%
  - Significant increase in RBU, especially for fouling
- Implications
  - <60% of XJ coal may be appropriate for co-firing in full-scale boilers

Composition of fouling deposits



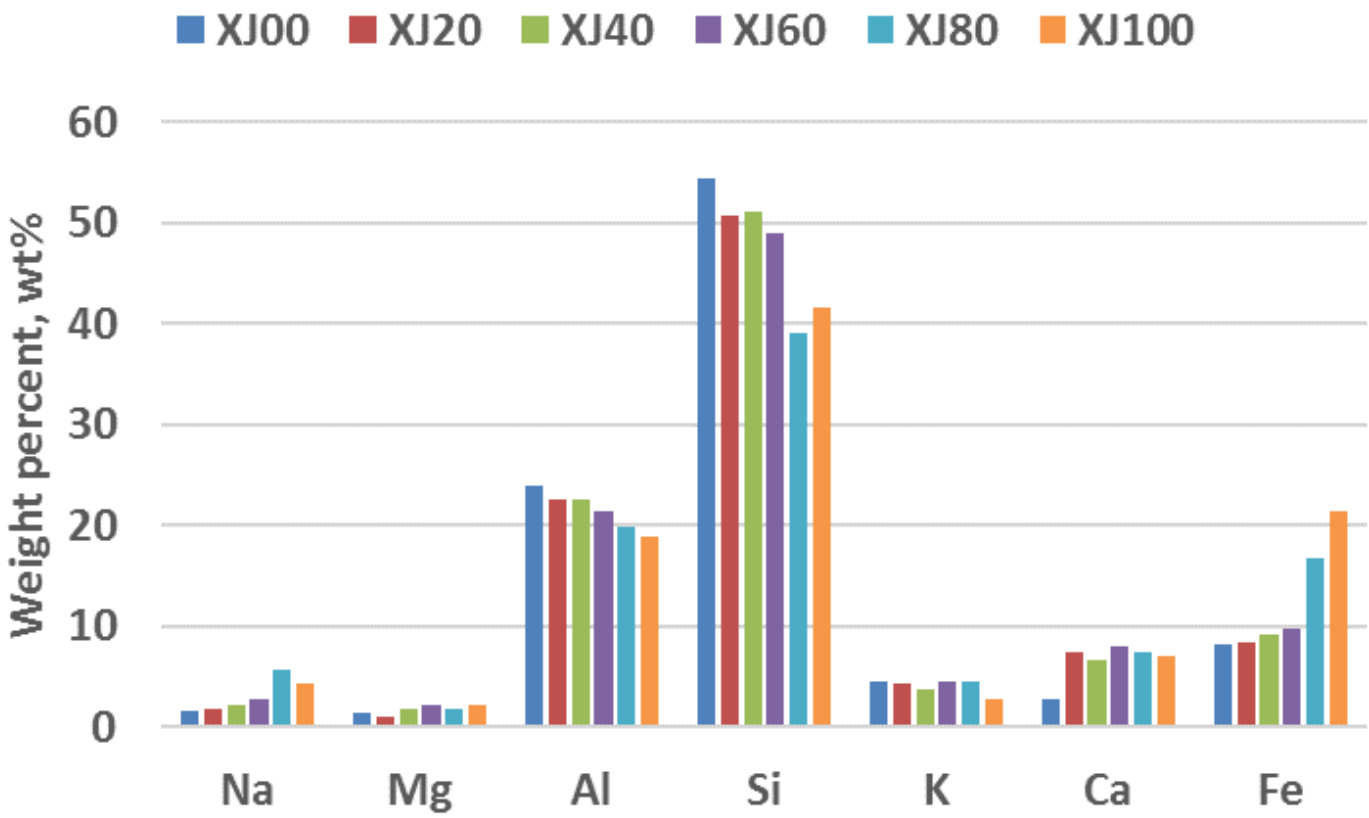
- **Na increases significantly when XJ coal >60%**
- **Mg, K, Ca remain constant except case of XJ coal (XJ100)**
- **Conclusion: Na in the blends is the critical factor affecting fouling propensity**

Fouling propensity vs Na/(Si+Al)



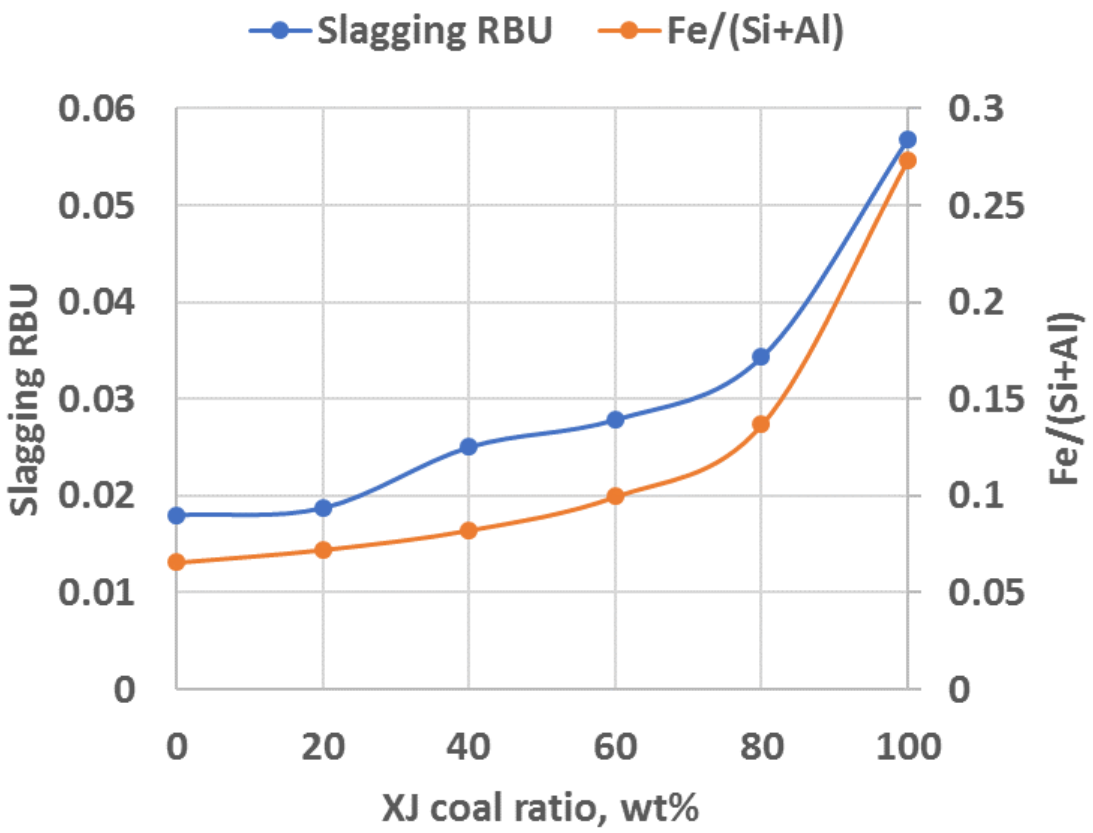
- A good correlation found
- Index of Na/(Si+Al)
  - <0.05 negligible fouling
  - >0.05 significant or severe fouling

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

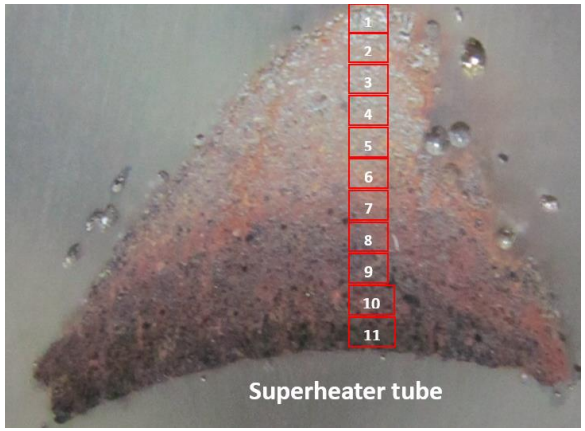
Extrapolation of lab results

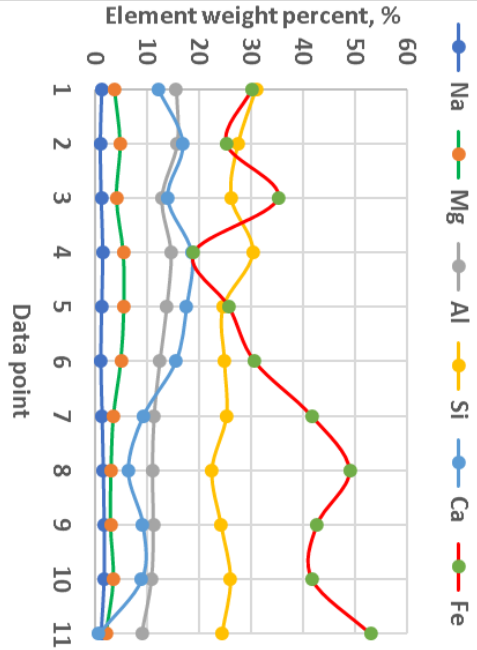
- **Lab results**
  - 60% may be a safe ratio for co-firing XJ coal
  - Used for guides to Hami power plant operation
- **Field results**
  - No problem with a ratio < 40% of XJ coal
  - Slight slagging with 40-60% XJ coal, depending on thermal load
  - Significantly Increased fouling and slagging when the ratio >60%

Relatively good consistency between lab and field results

Deposits at 40-60% XJ coal

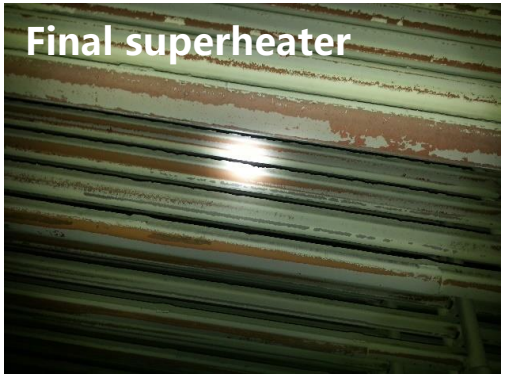
Slagging deposits: windward side deposits on primary superheater tubes





- 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?

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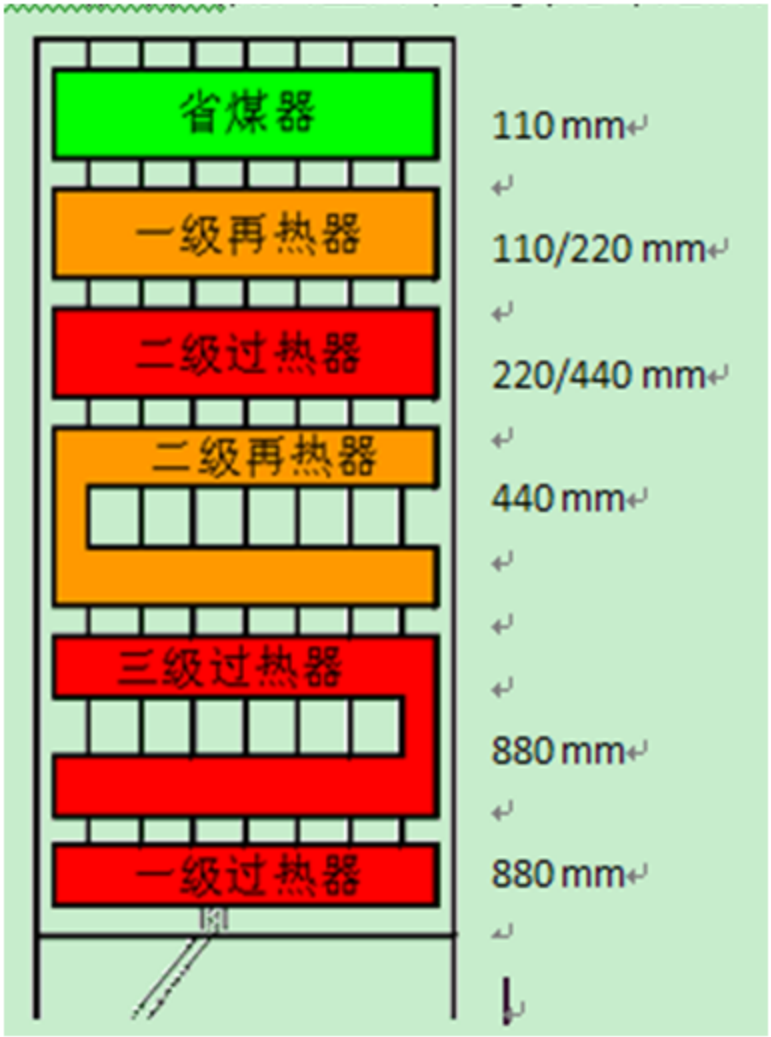
Boiler configurations

- **Tower Type Super-critical Boiler**