Chemical Engineering 733
Coal Combustion

Ash Deposition Discussion

05/27/22

Question 1: Discuss some of the different physical mechanisms that result in deposition of mineral matter on furnace walls and boiler tubes. Also, please discuss the influence of particle size (in relative terms) on each mechanism.

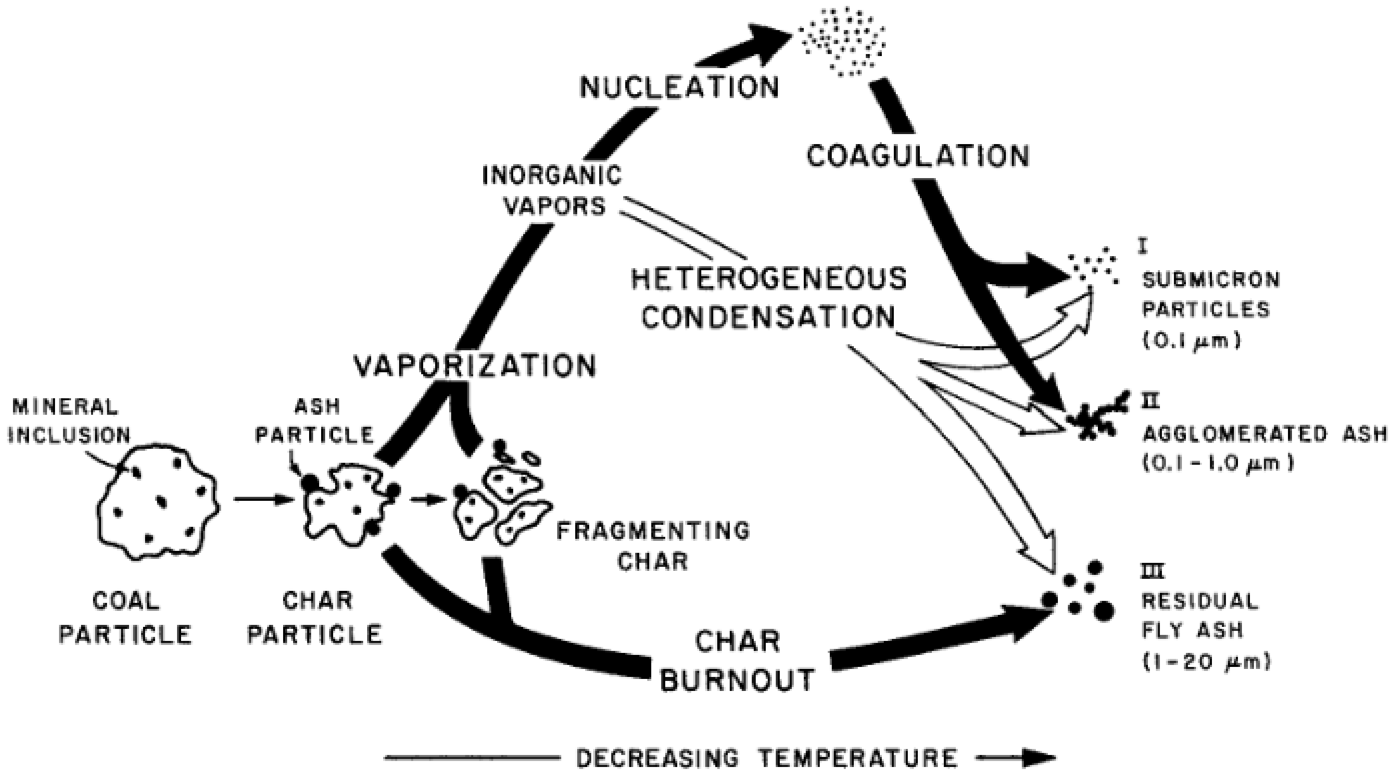

FIG. 1. Schematic of ash formation processes during coal combustion.

J. Helble, A. Sarofim., Factors Determining the Primary Particle Size of Flame-Generated Inorganic Aerosols. *Journal of Colloid and Interface Science*. 128 (2), 348 – 362

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Impaction

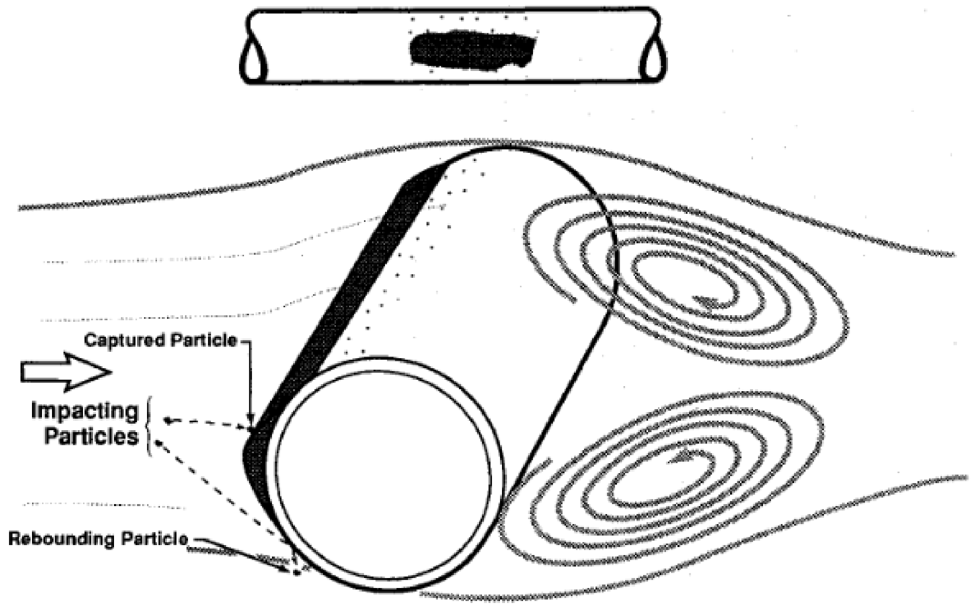

Fig. 3. Conceptual illustration of inertial impaction mechanism on a cylinder in cross flow. One rebounding and one sticking particle are also illustrated.

Thermophoresis

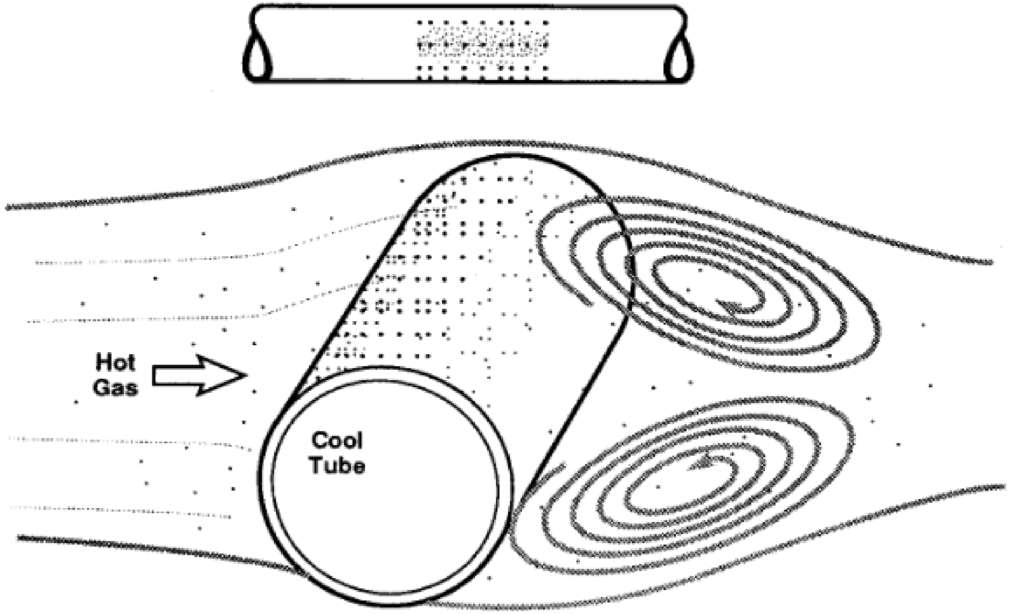

Fig. 5. Schematic illustration of thermophoretic deposition on a tube in cross flow.

L. Baxter., Ash Depostion During Biomass and Coal Combustion: A Mechanistic Approach. *Biomass and Bioenergy*. 4 (2), 85-102

Question 1: Discuss some of the different physical mechanisms that result in deposition of mineral matter on furnace walls and boiler tubes. Also, please discuss the influence of particle size (in relative terms) on each mechanism.

Condensation

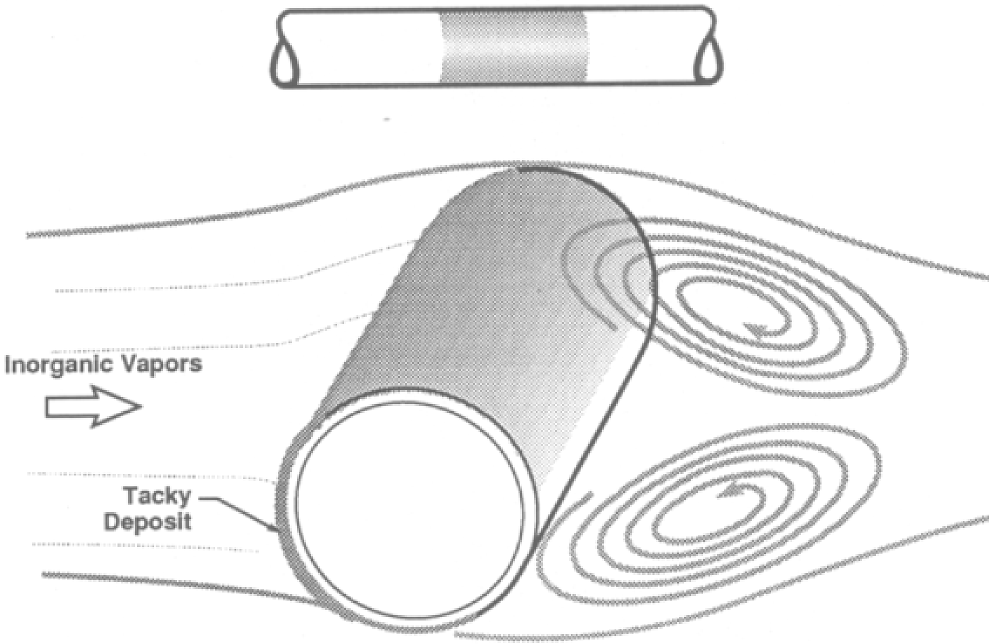

Fig. 6. Schematic illustration of condensation on a tube in cross flow.

Reaction

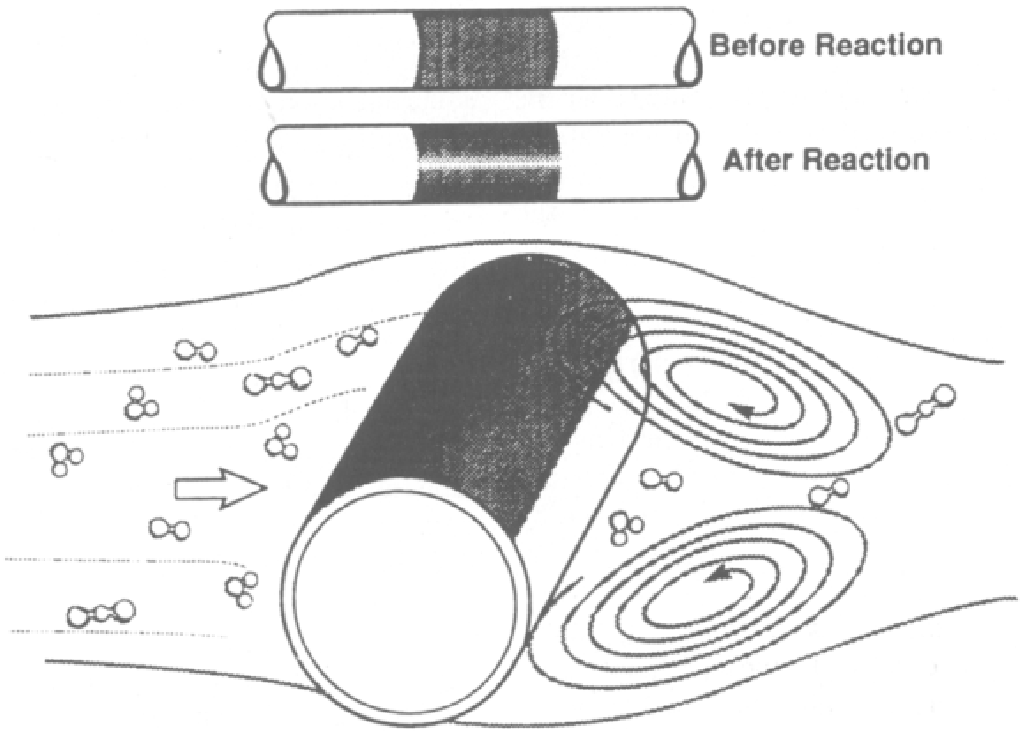

Fig. 7. Schematic illustration of chemical reaction on a tube in cross flow.

L. Baxter., Ash Depostion During Biomass and Coal Combustion: A Mechanistic Approach. *Biomass and Bioenergy*. 4 (2), 85-102

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Impaction & Eddy Diffusion

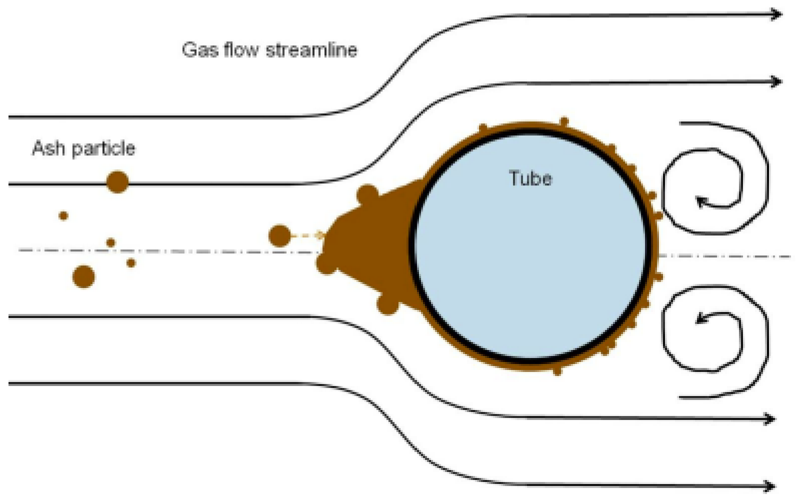


Figure 2.7: Example of deposit formation on a superheater.

B. Li., Modeling of Fireside Deposit Formation in Two Industrial Furnaces. *Doctoral Thesis, Abo Akademi, 2004*

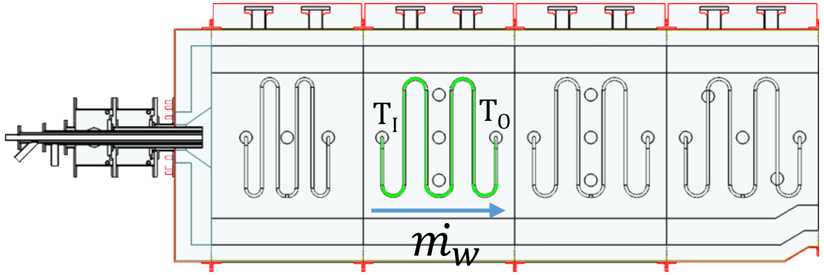
Question 2: What is the difference between slagging and fouling

Slagging – Deposition of ash particles at temperatures above the ash melting point (happens in the radiant section of the boiler)

Fouling – Deposition of ash particles at temperatures below the ash melting point (happens in the convective section of the boiler)

Question 3: What is soot blowing, and why is it important?

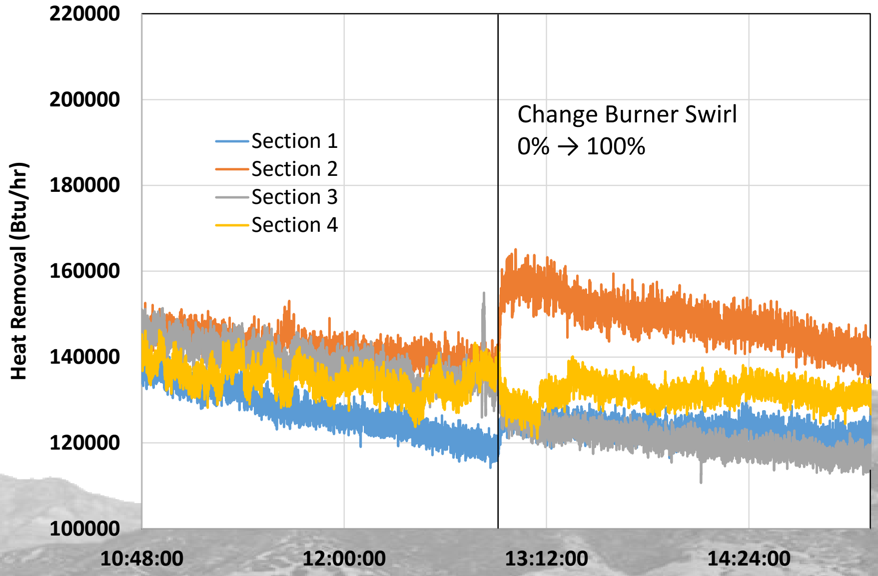
L1500 Example Data



- Cooling surfaces are necessary to provide steady state temperature profile
- Heat removal is determined by measuring the mass flow of water and the temperature of the water in and out

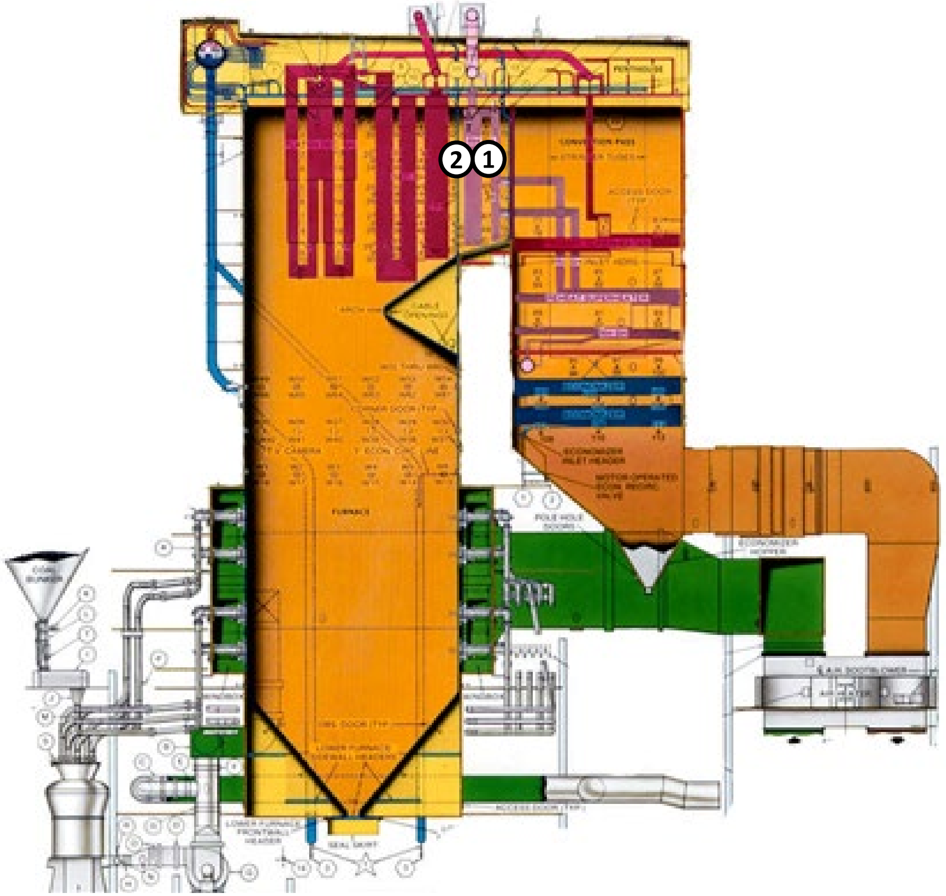
$$Q = \dot{m}_w \cdot c_p(T_O - T_I)$$

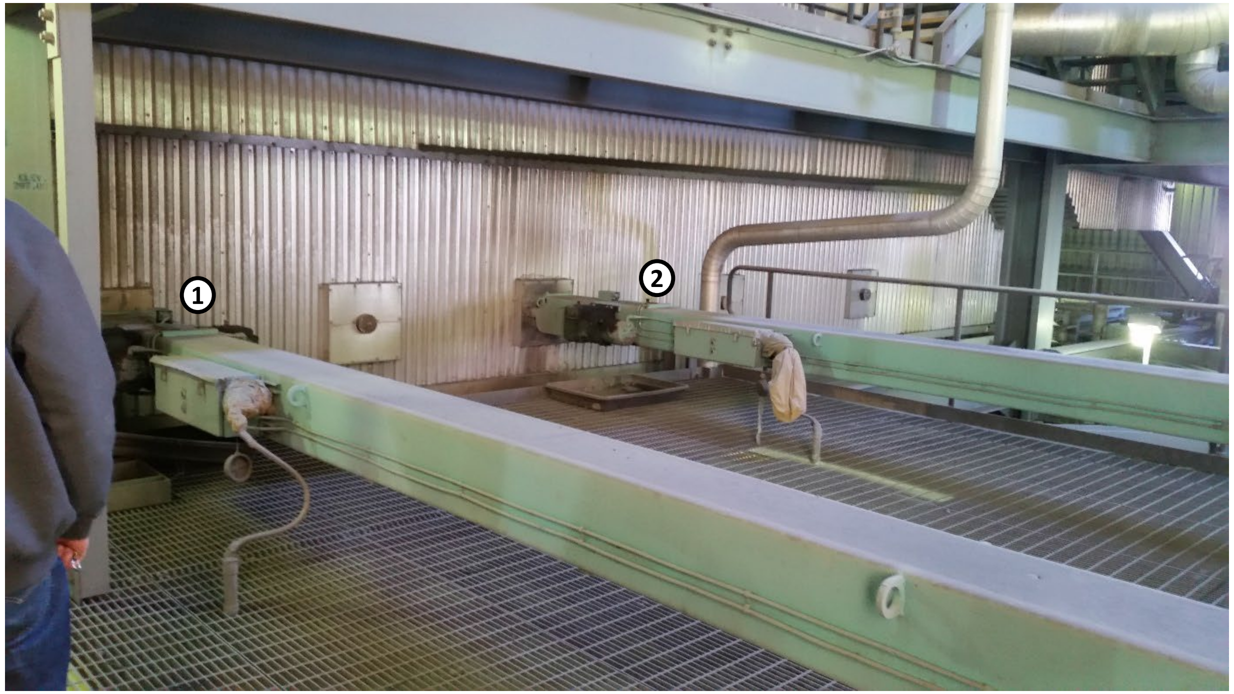
- Measurement is very sensitive to particle deposition



Question 3: What is soot blowing, and why is it important?

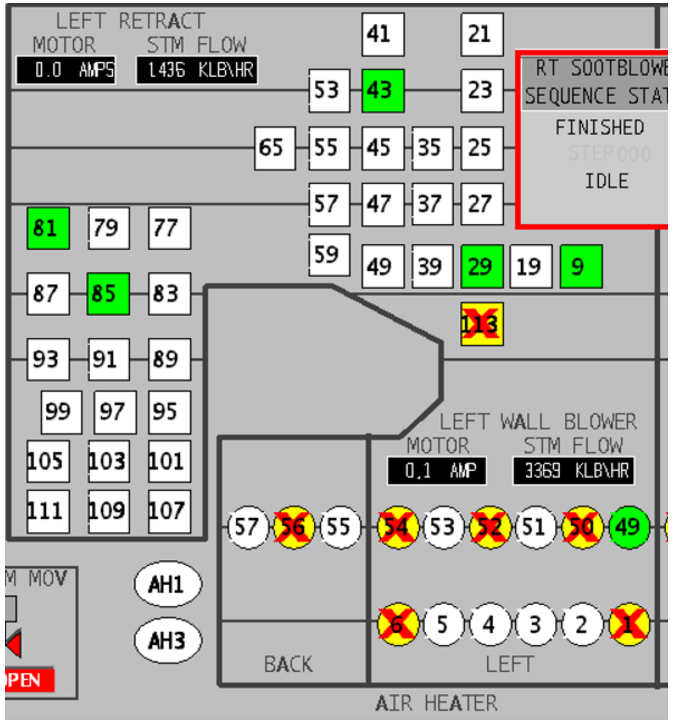
Hunter, Unit 3 Soot Blowers





Question 3: What is soot blowing, and why is it important?

Hunter, Unit 3 Soot Blower Controls, Left Wall



Question 4: How can deposition affect heat transfer in the furnace?

Heat transfer model

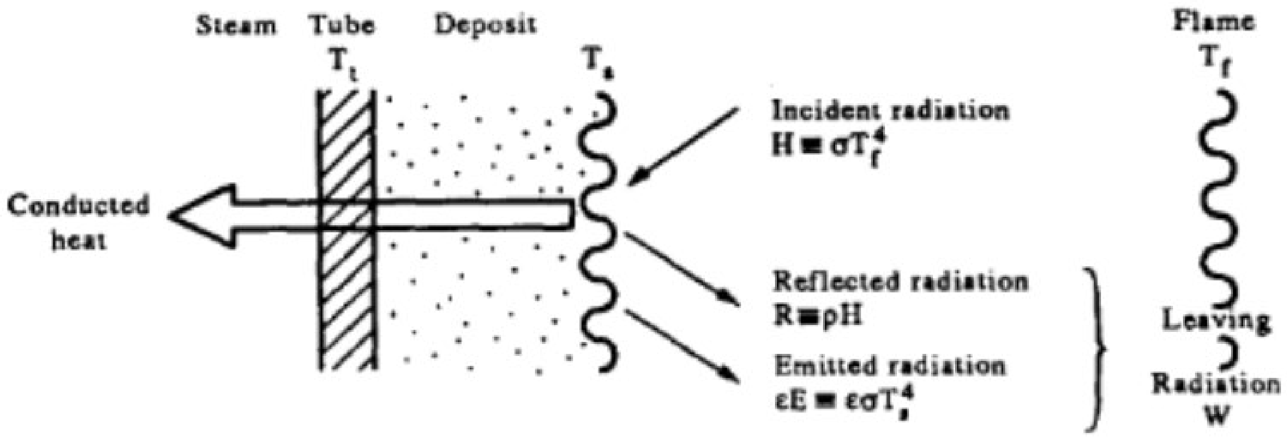


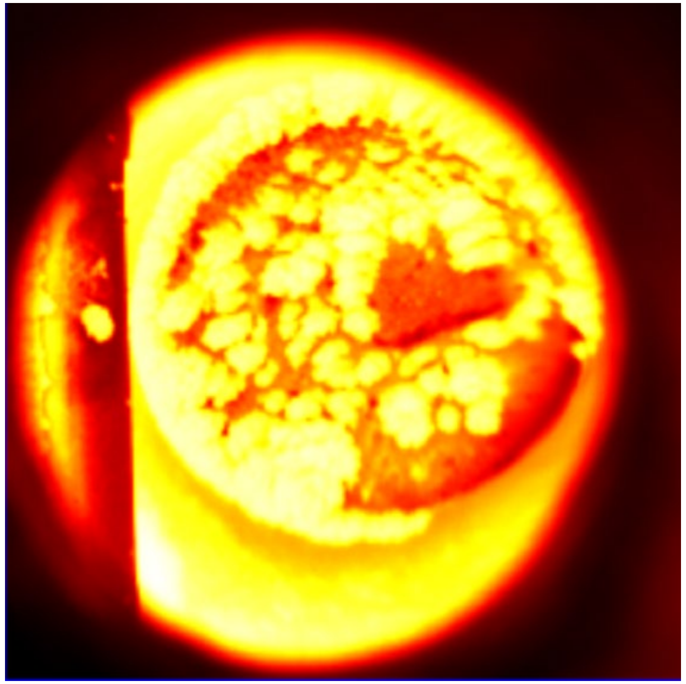
FIG. 1. Outline of the heat transfer mechanisms to and through deposits, from Wall *et al.*[1]

- Resistance
  - Thermal conductivity
    - Steel 45 W/mK
    - Coal Ash 0.29 – 0.58 W/mK
- Radiation
  - Emissivity
    - Steel 0.79 – 0.85
    - Bituminous ash 0.6 – 0.9
    - Subbituminous ash 0.4 – 0.8

T. Wall, S. Bhattacharya, D. Zhang, R. Gupta, X. He., The properties and thermal effects of ash deposits in coal-fired furnaces. *Prog. Energy Combust. Sci, 19, 487 - 504*

Question 4: How can deposition affect heat transfer in the furnace?

Water cooled cold target in a hot furnace



Question 5: Why would the deposit on the upstream surface of a steam tube be different than the deposit on the downstream side?

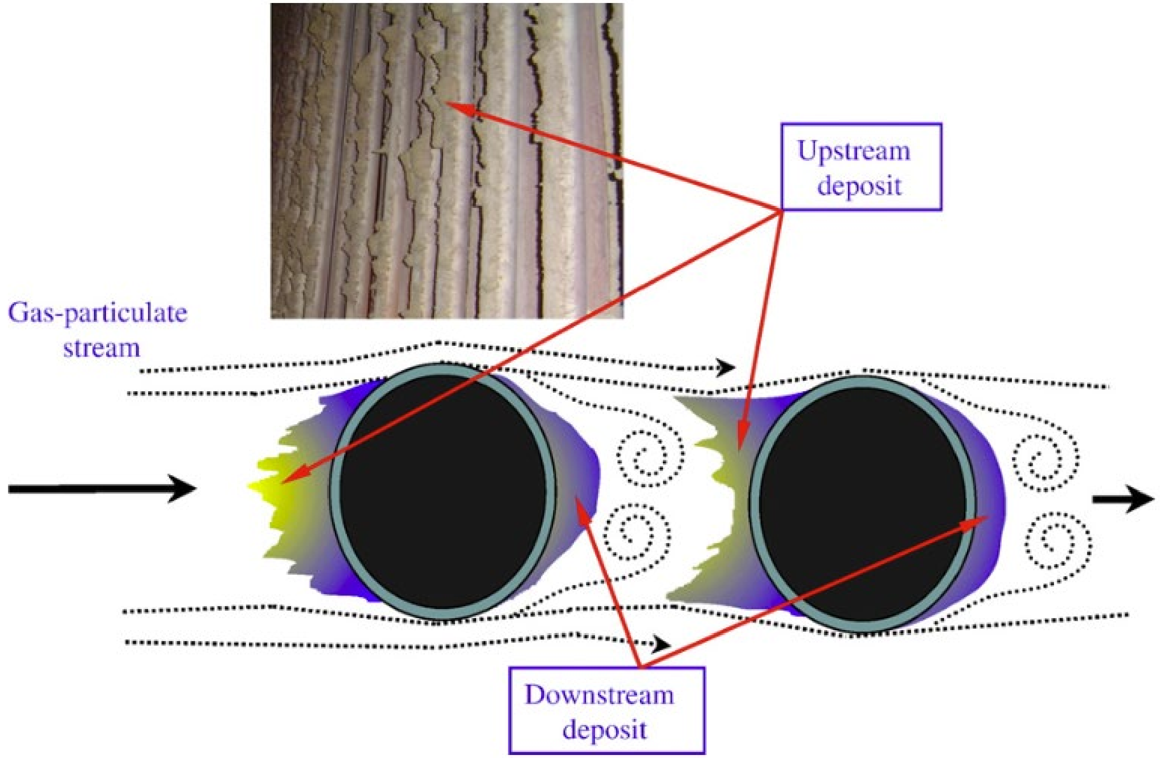


Fig. 11. Fouling deposit on tubes in convective pass.

Z. Ma, F. Iman, P. Lu, R. Sears, L. King, A, Rokanuzzman, D. McCollor, S. Benson., A comprehensive slagging and fouling prediction tool for coal-firedboilers and its validation/application. *Fuel Processing Technology, 88, 1035 - 1043*

Question 6: Please describe some of the factors that affect deposit strength?

Deposit Strength $\longrightarrow$ Densification / Sintering $\longrightarrow$ f(Temperature)

Question 7: Summarize some of the main deposition problems when co-firing biomass with coal.

Table 7.3: *The major mineral transformations that occur in the flame when firing coal and biomass materials.*

a. Coal mineral transformations

Constituent	Mineral transformation
SiO_2	partial melting, cracking, rounding of edges
Clay minerals	dehydroxylation, melting in some cases
Pyrite (FeS_2)	decomposition to pyrrhotite (FeS) and iron oxides
Calcite/dolomite	decarboxylation to CaO and mixed Ca/Mg oxides
Na compounds	decomposition, release of Na species into the vapour phase

b. Biomass mineral transformations

Constituent	Mineral transformation
SiO_2	partial melting
K/Na salts	decomposition and release of K/Na species into the vapour phase
Ca salts	decomposition to CaO

- Biomass has less ash than coal
- Biomass has more alkali and alkaline earth metals
  - Organically associated
  - Vaporize in the flame and condense later
- Synergistic effects with coal
- Are all biomass created equal?

Question 7: Summarize some of the main deposition problems when co-firing biomass with coal.

Table 4. Percent Elemental Ash Composition of Different Biomass Materials

Sample	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	TiO_2	Reference
Poplar bark	1.86	77.31	8.93	2.48	0.62	2.36	0.74	0.74	4.84	0.12	Kang *et al.* 2014
Willow	6.1	46.09	23.40	13.01	1.96	4.03	0.74	3.00	1.61	0.06	Kang *et al.* 2014
Hybrid poplar	5.90	49.92	9.64	1.34	0.84	18.40	1.40	2.04	0.13	0.30	Jenkins *et al.* 1998
Wood residue	53.15	11.66	4.85	1.37	12.64	3.06	6.24	1.99	4.47	0.57	Kang *et al.* 2014
Wood pellets (Pine)	4.30	55.90	16.80	3.90	1.30	8.50	1.50	-	0.60	-	Roy 2017
Bamboo whole	9.92	4.46	53.38	20.33	0.67	6.57	0.67	3.68	0.31	0.01	Kang *et al.* 2014
Miscanthus	56.42	10.77	19.75	5.54	0.79	3.01	0.94	2.28	0.47	0.03	Kang *et al.* 2014
Sorghum grass	73.21	7.02	8.97	4.43	1.83	2.21	0.95	1.11	0.25	0.02	Kang *et al.* 2014
Switchgrass	66.25	10.21	9.64	3.92	2.22	4.71	1.36	0.83	0.58	0.28	Kang *et al.* 2014
Bana grass	38.59	4.09	49.08	3.14	0.92	1.96	0.73	-	0.44	-	Roy 2017
Corn stover	51.99	8.99	26.38	2.79	0.28	6.09	1.12	2.20	0.08	0.01	Gresham 2012
Cotton gin trash	41.80	10.80	10.50	2.60	3.10	3.30	0.70	5.90	0.60	-	Capareda 2014
Wheat straw	50.35	8.21	24.89	3.54	1.54	2.74	0.88	4.24	3.52	0.09	Kang *et al.* 2014
Rice husks	94.48	0.97	2.29	0.54	0.21	0.19	0.22	0.92	0.16	0.02	Kang *et al.* 2014
Sugarcane bagasse	46.79	4.91	6.95	3.87	14.60	4.56	11.12	3.57	1.61	2.02	Kang *et al.* 2014
Sunflower husks	23.66	15.31	28.53	7.13	8.75	7.33	4.27	4.07	0.80	0.15	Kang *et al.* 2014
Chicken litter	5.77	56.85	12.19	15.40	1.01	4.11	0.45	3.59	0.60	0.03	Kang *et al.* 2014
Mixed waste paper	28.62	7.63	0.16	0.20	53.53	2.40	0.82	1.73	0.54	4.37	Kang *et al.* 2014
RDF	38.67	26.81	0.23	0.77	14.54	6.45	6.26	3.01	1.36	1.90	Kang *et al.* 2014
Sewage sludge	33.28	13.04	1.60	15.88	12.91	2.49	15.70	2.05	2.25	0.80	Kang *et al.* 2014
Wood yard waste	60.10	23.92	2.98	1.98	3.08	2.17	1.98	2.46	1.01	0.32	Kang *et al.* 2014

L. Nelson, S. Park, M. Hubbe., Thermal Depolymerization of Biomass with Emphasis on Gasifier Design and Best Method for Catalytic Hot Gas Conditioning. *BioResources, 13 (2), 4630 - 4727*

Question 8: Suppose we knew everything about mineral matter deposition, including all of the chemistry, particle sizes, velocity patterns, and temperature distributions. What could we do with this information to make money?

Measurement Methods for Deposits

- CCSEM – Computer Controlled Scanning Electron Microscopy
- XRD – X-ray Diffraction
- ToF SIMS – Time Of Flight Secondary Ion Mass Spectrometry
- SMPS – Scanning Mobility Particle Sizer
- APS – Aerodynamic Particle Sizer
- ELPI – Electrical Low-pressure Impactor
- BLPI – Berner Low Pressure Impactor
- Deposition Probes
  - Coupons
  - Real Time Mass Measurement
- Corrosion Probes
  - Coupons
  - EN – Electrochemical Noise

CCSEM

- How might this be different for deposits than for coal

XRD

X-ray diffraction (XRD) is a highly versatile technique that provides chemical information for elemental analysis as well as for phase analysis. Besides chemical characterization, XRD is extremely useful for stress measurements as well as for texture analysis. Samples to be analyzed using XRD must be crystalline however the technique can provide the degree of crystallinity in polymers

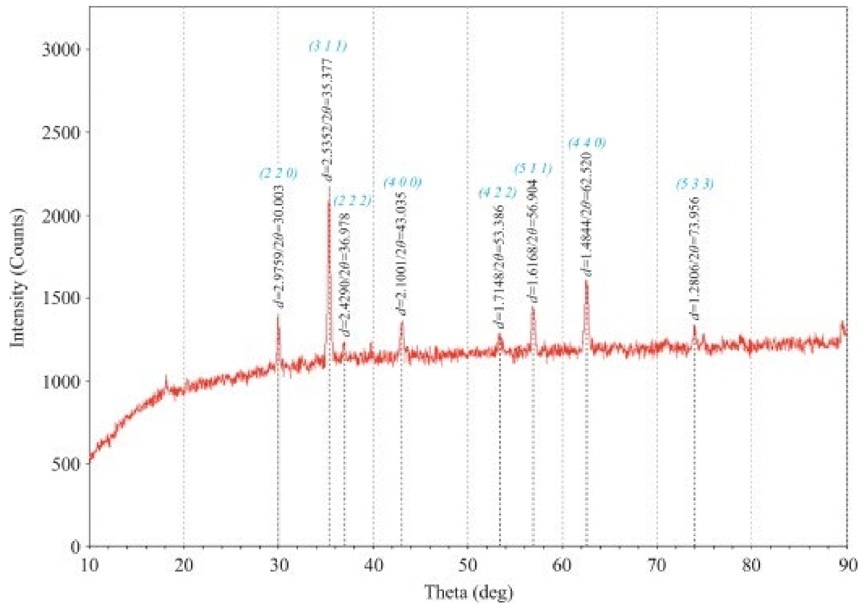
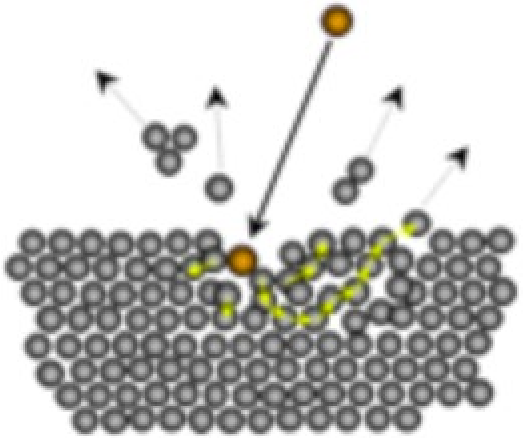


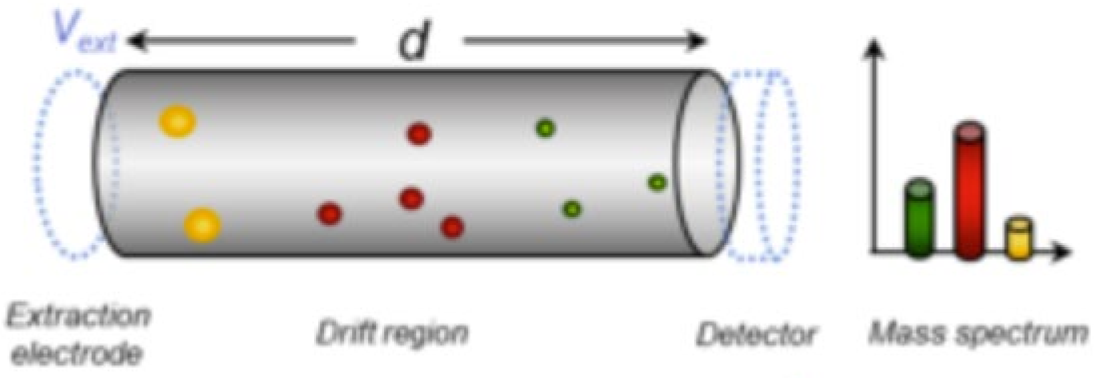
Figure 2.8. XRD pattern of a corroded low carbon steel pipe damaged through flow-accelerated corrosion

S. Nasrazadani, S. Hassani., Modern analytical techniques in failure analysis of aerospace, chemical, and oil and gas industries. *Handbook of Materials Failure Analysis with Case Studies from the Oil and Gas Industry, 2016.*

ToF SIMS

ToF-SIMS is an imaging mass spectrometry (MS) technique that allows us to obtain isotopic, elemental, and molecular information from the surface of solid samples. A pulsed, energetic “primary” ion beam bombards the surface and induces a collision cascade, liberating “secondary” ions that are then sent to a time-of-flight mass analyzer for detection



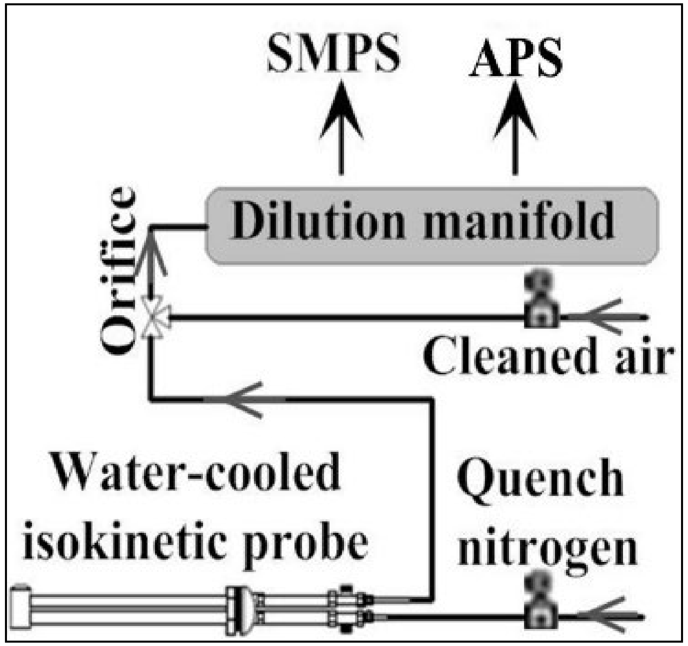


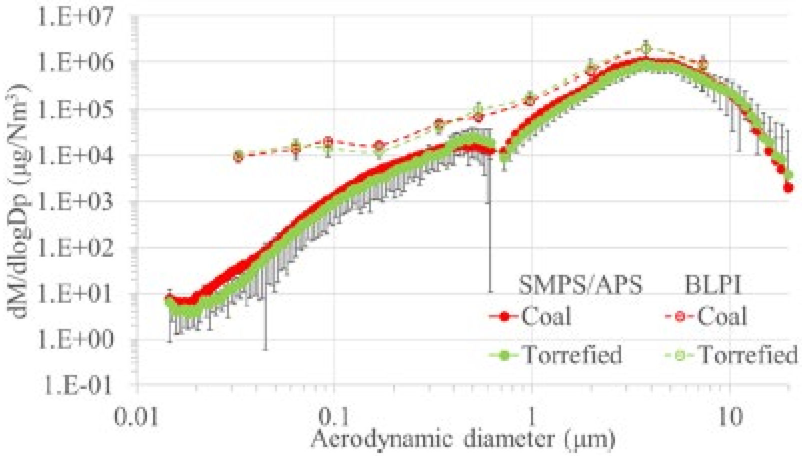
$$E = qV_{ext} = \frac{1}{2}mv^2$$

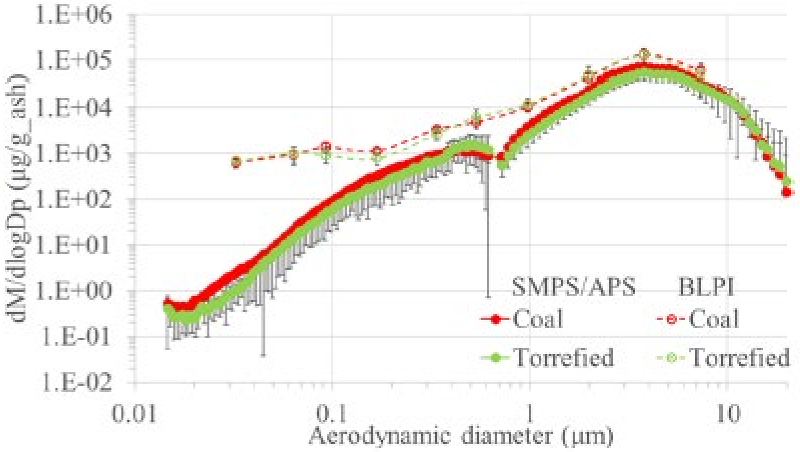
$$t = d\left(\frac{m}{2qV}\right)^{1/2} \propto m^{1/2}$$

https://www.nist.gov/programs-projects/time-flight-secondary-ion-mass-spectrometry

SMPS / APS



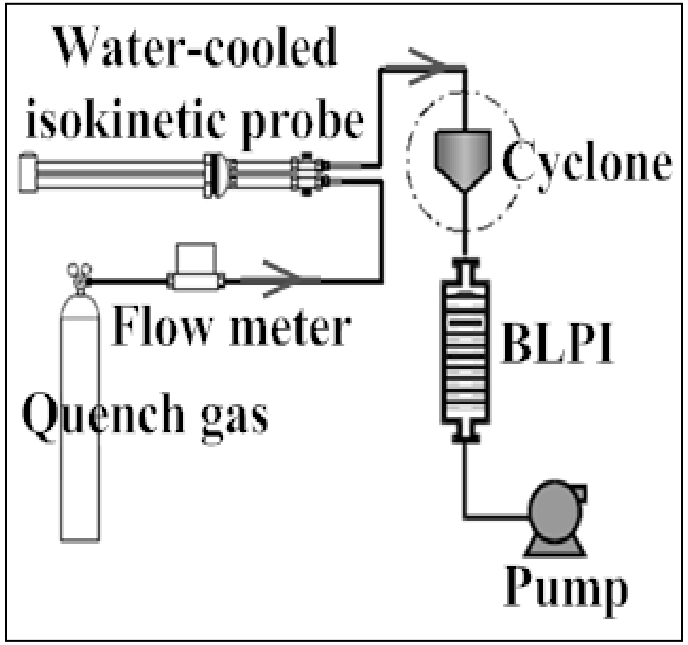




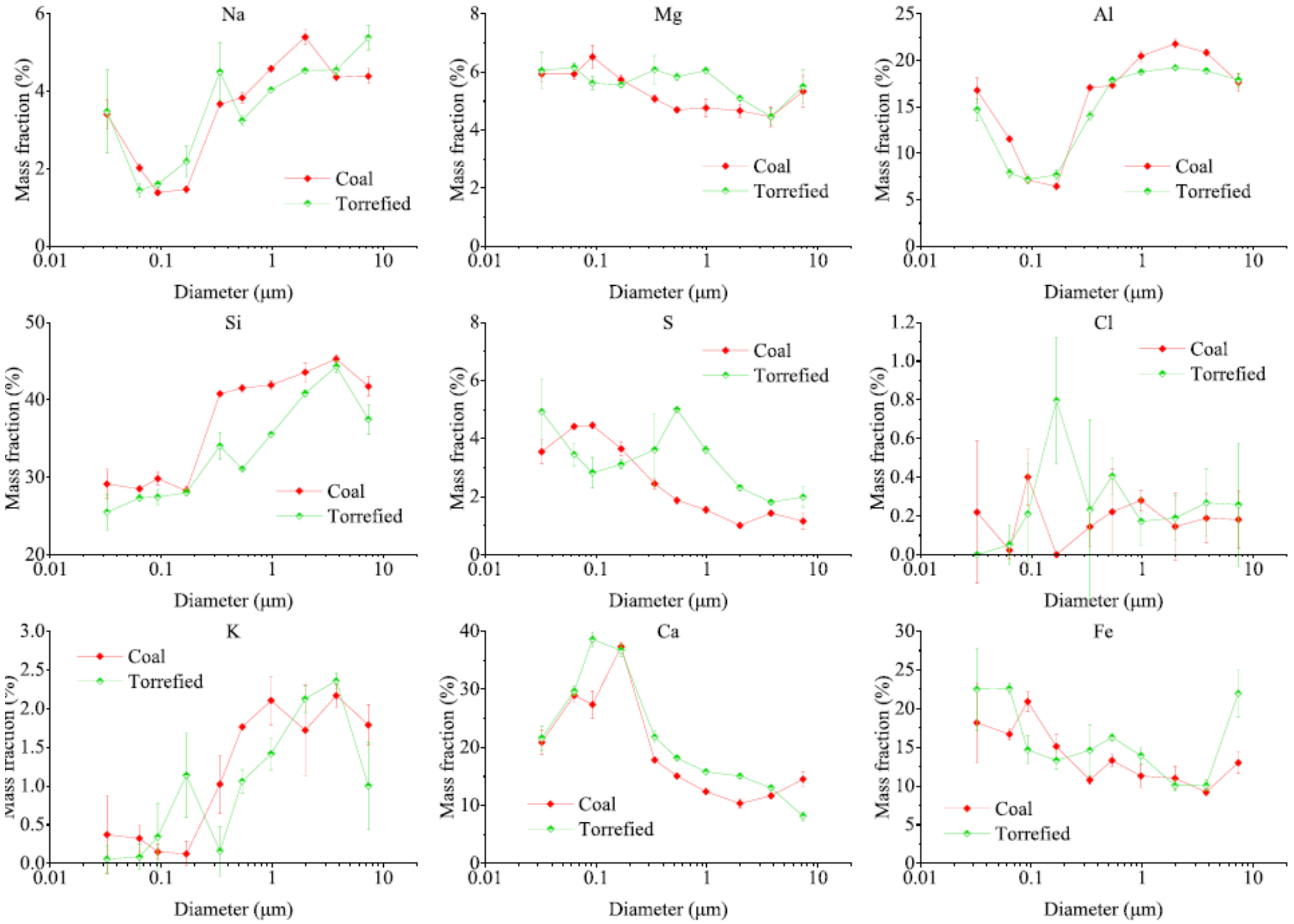
SMPS: 0.0143 – 0.6732 µm
APS: 0.532 – 20 µm

X. Li, S. Fakourian, B. Moyer, J. Wendt, A. Fry., Ash Aserosol and Deposit Formation from Combustion of Coal and It's Blend with Woody Biomass a Two Combustion Scales: Part 2 – Tests on a 471 MWe Full-scale Boiler. *Energy Fuels 2022, 36,. 565-574.*

BLPI



BLPI: 0.0324 – 15.7 µm



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