Recovery Boiler Deposit Formation and Plugging Prevention

Honghi Tran
University of Toronto
Toronto, ON, Canada

TAPPI Kraft Recovery Course
Presentation Outline

- Problems with Deposits
- Deposit Formation and Properties
- Deposit Removal
- Plugging in Different Regions
- Contributing Variables
Problems with Deposits

Boiler Bank Inlet Plugging

Superheater Fouling

Superheater Corrosion
Tubes Damaged by Deposits

~500 kg
(1100 lbs)

Screen Tubes

Floor Tubes

4
Presentation Outline

- Problems with Deposits
- Deposit Formation and Properties
- Deposit Removal
- Plugging in Different Regions
- Contributing Variables
Deposit Formation

Flue Gas Vapors Carryover Dust Fume

Electrostatic Precipitator

Dust

Black Liquor

Smelt

Deposits

Vapors

10% 90%

6
Deposit Types

- **Carryover**
  - 0.01 – 3 mm molten/partially-molten smelt or partially-burned black liquor particles
  - Pink and smelt-like; formed mainly on the front side of the tube

- **Fume**
  - Submicron particles condensed from vapors of Na and K salts
  - White, powdery, and formed at the surface and on the back side of the tube
Deposit Formation at Different Locations

Screen

Superheater

Boiler Bank (back side)

Economizer

Fume

Carryover
Deposit Composition

Superheater Deposit
- Na: 33.9%
- SO₄: 40.1%
- CO₃: 20.9%
- K: 3.5%
- Cl: 1.21%
- Others: 0.4%

Boiler Bank Deposit
- Na: 31.1%
- SO₄: 56.1%
- K: 3.8%
- CO₃: 8.0%
- Cl: 1.70%
- Others: 0.4%

Economizer Deposit
- Na: 31.0%
- SO₄: 55.8%
- K: 4.0%
- CO₃: 7.0%
- Cl: 1.9%
- Others: 0.4%

Precipitator Ash
- Na: 30.6%
- SO₄: 56.9%
- K: 4.2%
- CO₃: 6.0%
- Cl: 1.94%
- Others: 0.4%
Deposit Melting Behaviour

Appearance of a Deposit Cone

Temperature (°F)

0% ~ 1%

First melting

Liquid Phase

15%

Sticky

100%

Complete melting

Slagging/flowing

Sticky Temperature Range

Temperature (°C)

0% ~ 1%
**Deposit Melting Behaviour**

- Influenced by the amount of **liquid phase** in the deposit, which is a function of deposit temperature and composition
  - Minor components: Cl, K and S (sulfide)
- Sticky temperature ($T_{\text{sticky}}$) decreases with increasing Cl, K and S contents

![Deposits at SH Entrance](image)

Pink Color

Indicative of **sulfide** present in deposit
Effects of Cl and K on Deposit Sticky Temperature

Sticky Temperature (°C) vs. Chloride Content, mole% Cl/(Na+K)

Typical Cl and K in BL or Deposits

Potassium Content mole% K/(Na+K)

- 0
- 5
- 10
- 20

Chloride Content, mole% Cl/(Na+K)
Fluffy fume particles can sinter and form hard deposits

Sintering process

- Highly temperature dependent
- Does not occur appreciably below 300°C (572°F)
- Occurs rapidly (< 1 hour) above 500°C (932°F)
Presentation Outline

- Problems with Deposits
- Deposit Formation and Properties
- Deposit Removal
- Plugging in Different Regions
- Contributing Variables
Sootblowers

- **Number of sootblowers**
  - 60 to 120 per boiler

- **Lance pressure**
  - 90 to 350 psig
  - More commonly: 200 – 300 psig

- **Steam consumption**
  - 3 to 5% of total steam production
  - Can be as high as 12%
Deposit Removal Efficiency

- Jet Peak Impact Pressure (PIP)
  - Sootblower nozzle design, steam pressure/flow rate
  - Distance between sootblower nozzle and deposit surface
    - At 1 m (3 feet) from the nozzle, the jet can retain only 10% of its initial strength

- Deposit strength
  - Composition and temperature
  - Fluid deposits are more difficult to remove than brittle deposits

- Blowing frequency
Presentation Outline

- Problems with Deposits
- Deposit Formation and Properties
- Deposit Removal
- Plugging in Different Regions
- Contributing Variables
Plugging at Superheater Entrance near Furnace Roof

- Deposits are made mainly of carryover
  - High gas temperature
  - Sticky carryover

- Not made of fume
  - High gas temperature
  - No/little fume can form
In severe cases, carryover deposits are so massive that they can completely block the spacing between superheater platens.
Plugging at the Boiler Bank inlet

- **Narrow tube spacing**
  - 2” (50 cm)

- **Sticky carryover**
  - High flue gas temperatures as a result of heavy deposit buildup in the superheater region

- **Fume deposition**
  - Large amount of fume
  - Captured by deposit rough surface
  - Fume sintering
Plugging at the Boiler Bank Inlet

Sticky deposit zone

Clean → Fouled → Plugged

Time → Plugging
Plugging in the Generating Bank

- Narrow tube spacing and sticky carryover
- Insufficient sootblowing
  - Jets can be obstructed by boiler tubes
Plugging in the Boiler Bank
(Bi-drum Boiler)
Plugging in the Boiler Bank
(Single-drum Boiler)
Plugging in the Economizer (Bi-Drum Boilers)

- Economizer Inlet and Baffles
  - Overloaded
  - Insufficient sootblowing

- Sticky fume
  - Mixture of mainly Na$_2$SO$_4$ and NaHSO$_4$

- NaHSO$_4$ Formation Reaction
  - Na$_2$SO$_4$ + SO$_2$ +½ O$_2$ +H$_2$O = 2 NaHSO$_4$
  - High sulphidity black liquor
  - Low bed temperature
Plugging in the Economizer (Single-drum Boilers)

- **Parallel Flow Design**
  - Fume particles flow vertically along tubes; they do not accumulate much
  - Plugging is usually not an issue

- **Plugging may occur near ash hoppers**
  - Large pieces of deposits falling from above
  - Abrupt change in flue gas flow direction causing particles to impinge and accumulate on ash hopper wall
Presentation Outline

- Problems with Deposits
- Deposit Formation and Properties
- Deposit Removal
- Plugging in Different Regions
- Contributing Variables
Contributing Variables

- Many variables
  - Boiler designs, firing loads, air flow rates, air distributions, black liquor properties, spray patterns, sootblowing strategies, etc.

- Often interact with one another; difficult to single out one or two variables

- Variables can be classified into three main groups

  - Particle Quantity
  - Particle Stickiness
  - Sootblowing Efficiency
More particles, but not sticky $\Rightarrow$ No/little deposition

Sticky, but fewer particles $\Rightarrow$ No/little deposition
More and stickier particles $\Rightarrow$ Larger overlapping area $\Rightarrow$ More severe deposition
Particle Quantity

Particle Stickiness

Deposition

More Particles → Sootblowing Efficiency → Stickier Particles

Fouling/Plugging

Poor Efficiency

Group Interaction
**Variables Contributing To:**

**More Particles**
- Firing Load $\uparrow$
  - Pulp production
  - Wood species
  - EA to wood ratio
  - Liquor inventory
  - Process changes
  - Process upsets

**Gas Velocity $\uparrow$**
- Firing load
  - Air flow rate
  - Air distribution
  - Air port design
  - Air port pressure
  - % excess $O_2$
  - ID fan speed

**Particle Size and Density $\downarrow$**
- Particle type
  - BL temperature
  - BL pressure
  - BL org./inorganic ratio
  - BL residual EA
  - BL swelling properties

**Others**
- Nozzle design
- Nozzle position
- Spray angle

**££££ More Particles**

**Stickier Particles**
- Chloride Content $\uparrow$
  - Mill location
  - Makeup chemicals
  - Degree of mill closure
  - Liquor sulfidity
  - Char bed temperature

- Potassium Content $\uparrow$
  - % hardwood
  - Degree of mill closure

**Sulfide Content $\uparrow$**
- Firing load
  - Air flow rate
  - Air distribution
  - Liquor sulfidity

**Particle Temperature $\uparrow$**
- Firing load
  - Air flow rate
  - BL heating value
  - Flue gas temperature
  - Retention time

**Jet PIP (Force) $\downarrow$**
- Nozzle design
  - Steam flow rate
  - Steam pressure
  - Distance to deposits
  - Tube arrangement

**Deposit Strength $\uparrow$**
- Firing Load
  - Particle stickiness
  - Tube temperature
  - Deposit thickness
  - Thermal shock/shedding

**Sootblowing Frequency $\downarrow$**
- Number of sootblowers
  - Sootblower speed
  - Blowing sequence

**£££££ Poor Sootblowing Efficiency**
Variables Contributing to More Particles

- Pulp production
- Wood species
- EA to wood ratio
- Liquor inventory
- Process changes
- Process upsets

- Firing load
- Air flow rate
- Air distribution
- Air port design
- Air port pressure
- % excess O₂
- ID fan speed

- BL droplet size
- BL solids content
- BL org./inorg. ratio
- BL temperature
- BL pressure
- BL residual EA
- BL swelling properties

- BL nozzle design
- BL gun position
- BL spray angle
Variables Contributing to Stickier Particles

- Mill location
- Makeup chemicals
- Degree of mill closure
- Liquor sulfidity
- Bed temperature

- % hardwood
- Degree of mill closure

- Firing load
- Air flow rate
- Air distribution
- Liquor sulfidity
- Retention time

- Firing load
- Air flow rate
- BL heating value
- Flue gas temperature
Variables Contributing to Poor SB Efficiency

- Nozzle design
- Steam flow rate
- Steam pressure
- Distance to deposits
- Tube arrangement

- Firing Load
- Particle stickiness
- Tube temperature
- Deposit thickness
- Thermal shock/shedding

- Number of sootblowers
- Sootblower speed
- Blowing sequence

Jet PIP (Force) ↓
Deposit Strength ↑
Sootblowing Frequency ↓
An Example of Variable Interaction – Firing Load

More Particles
- Firing load
- Particle size
- Particle density
- Gas velocity

Stickier Particles
- Chloride content
- Potassium content
- Sulfide content
- Temperature

Poor Sootblowing Efficiency
- Jet PIP (force)
- Deposit strength
- Blowing frequency
Firing Load

- The most important variable affecting deposit formation and plugging.

- But burning more liquor is also important to mill productivity.
  
  ▶ Reducing liquor firing rate is NOT an option.

- Must find other ways to minimize deposit formation and prevent plugging from occurring.
Options/Actions

Fewer Particles
- Firing Load ↓
  - Pulp production
  - Wood species
  - EA to wood ratio
  - Liquor inventory
  - Process changes
  - Process upsets
- Gas Velocity ↓
  - Firing load
  - Air flow rate
  - Air distribution
  - Air port design
  - Air port pressure
  - % excess O₂
  - ID fan speed
- Particle Size and Density ↑
  - Particle type
  - BL temperature
  - BL pressure
  - BL org./inorganic ratio
  - BL residual EA
  - BL swelling properties

Less Stickier Particles
- Chloride Content ↓
  - Mill location
  - Makeup chemicals
  - Degree of mill closure
  - Liquor sulfidity
  - Char bed temperature
- Potassium Content ↓
  - % hardwood
  - Degree of mill closure
- Sulfide Content ↓
  - Firing load
  - Air flow rate
  - Air distribution
  - Liquor sulfidity
- Particle Temperature ↓
  - Firing load
  - Air flow rate
  - BL heating value
  - Flue gas temperature
  - Retention time

High Sootblowing Efficiency
- Jet PIP (Force) ↑
  - Nozzle design
  - Steam flow rate
  - Steam pressure
  - Distance to deposits
  - Tube arrangement
- Deposit Strength ↓
  - Firing Load
  - Particle stickiness
  - Tube temperature
  - Deposit thickness
  - Thermal shock/shedding
- Sootblowing Frequency ↑
  - Number of sootblowers
  - Sootblower speed
  - Blowing sequence
Summary

- Deposits cause many problems in recovery boiler operation
  - Lower steam production
  - Plug gas passages
  - Corrode tubes
  - Damage sootblowers, screen tubes and floor tubes

- Deposit formation and properties vary greatly with location within a boiler, and from boiler to boiler

- Important to identify the problem and the main operating variables causing it in order to devise appropriate solutions