Black Liquor Evaporation
Design & Operation

Jean-Claude Patel
A.H. Lundberg Associates, Inc.
Naperville, IL

Topics

- Black Liquor Properties
  - What did we just learn?
  - What is critical for evaporator design?
- Evaporation Technologies
- Process Considerations at High Solids
- Concentration Technologies
- Multiple Effect Evaporators
What’s Black Liquor?

- Complex mixture
  - Spent pulping chemicals (Inorganic salts, caustic, etc.)
  - Organic matter (Lignin) dissolved from the wood
  - Non-Process-Elements (NPE) such as K, Cl, etc.
    - Brought in with wood, water and fresh chemicals
    - No purge points: Constantly recycled

Black Liquor Properties

- Chemical composition
  - Major role on the performance of the evaporators
    - Na₂SO₄, Na₂CO₃ co-precipitate at high solids
    - Risk of scale formation

- Critical physical properties
  - Boiling Point Rise (BPR)
  - Viscosity which impacts heat transfer
Evaporation Technologies

- Task of the evaporator
  - Take a waste stream (WBL) and turn it into fuel (SBL) for the recovery boiler
  - Condense steam (or vapors) on one side of a heating surface while boiling liquor on the other side
- Process governed by the heat transfer law
  \[ Q = U \times A \times \Delta T \]

- “Q”: Heat exchange amount which can be accomplished
- “A”: Heat transfer surface
- “\(\Delta T\)”: Temperature differential
  \[ \Delta T = \text{Sat. Vapor T In} - \text{Liquor T Out} \]
- “U”: Heat transfer coefficient, a measure of the resistance to heat transfer
  - Depends on heating surface material & cleanliness
  - Depends on liquor properties & turbulence
Rising Film Evaporator (LTV)

- Liquor film formed by generated vapors from boiling liquor at the bottom of the tubes
- Poor turndown, can't handle high viscosities, minimum $\Delta T$ requirement
- Was the workhorse of the Industry, now found only in older mills
Rising Film Evaporator (LTV)

- Low operating cost
- Low propensity for foaming
- Low liquor viscosity and high flow-rate are ideal conditions
- Only used today in WBL pre-evaporation where foaming is an issue:
  ➔ Blow Heat Recovery

Falling Film Evaporator

- Vapor (steam) inlet
- NCG vent
- Condensate outlet
- Recirculating liquor outlet
- Vapor outlet
- Liquor feed
- Liquor product
Falling Film Evaporator

- Film formed by mechanical means (Distribution plate)
- High turndown, can handle higher viscosity (Gravity helps)
- Primary technology worldwide for concentrations up to 50% TS

Plate-type FF Evaporator

- Vapor outlet
- Vapor inlet
- Distributor
- Plate heating element
- Liquor feed
- NCG vent
- Liquor product
- Condensate
Falling Film Evaporator

- Can operate at low $\Delta T$
- Flexible (High turndown)
- Good resistance to scaling
- Moderate HP consumption
- Easily automated
- Foams easily at low %TS

Process Considerations at high solids

- Precipitation of supersaturated components

![Graph showing dry solids content vs. wt-% crystals in BLS](chart.png)

- Total $\text{Na}_2\text{SO}_4 + \text{Na}_2\text{CO}_3 = 8.2$ wt-% of BLS
- Dicarbonate
- Burkeite
Process Considerations at high solids

- Precipitation of supersaturated components
  - Units > ~ 50%TS must be designed as crystallizers
    - Control the precipitation process
      - Crystals form and grow within the liquor
      - Not as scale on the heat transfer surfaces

VS.

Process Considerations at high solids

- High liquor viscosity
  - Impacts heat transfer due to low turbulence
  - Impediment to crystal growth
  - Pressurized storage or heat treatment needed?
  - Temperature becomes a critical design parameter
    - High temperatures enhance hard scaling risk
Process Considerations at high solids

- Increased corrosion tendencies
  - Stress Corrosion Cracking in 300 series SS due to
    - High temperatures to control viscosity
    - High alkalinity at high %TS
  - Duplex alloys required >75%TS

High Solids Technology

**Crystallization**
- Enhanced FC Crystallizer

**Evaporation**
- FF Crystallizer
- Switching FF Evaporator
Falling Film Concentrators

- FF heat transfer
  - Evaporation takes place at the heat transfer surface
    - High supersaturation developed within the liquor
    - Potential for excessive crystal nucleation
    - Risk of uncontrolled scale formation

1st approach: FF Crystallizer
- Keep supersaturation low
  - Minimize evaporation/tube
  - Low Heat Flux (BTU/Sq.ft.)
  - Large surface area
  - High recirculation rate
- High cost and HP usage
Falling Film Concentrators

- 2nd approach: Switching FF Evaps
  - Multiple rotating bodies with one on wash at all times
  - As long as scale washes away faster than it forms, you stay ahead
  - Complex piping arrangement

- High turndown capability
- Moderate HP consumption
- Easily automated
- On-line washing (switching type designs)
Falling Film Concentrators

- Highly sensitive performance
  - Liquor chemistry changes
  - Soap and fiber
- Poor operation at high viscosity
  - Distribution and heat transfer
  - Operation at high temperatures (Calcium scaling)
  - Liquor Heat Treatment (Expensive)
- Product %TS swings (Switching type designs)
- High risk of plugging (Non-switching designs)

Forced Circulation Crystallizer
Reynolds Enhanced Crystallizer (REX)

- Spiral tube inserts disrupts the boundary layer at the tube wall, highest resistance to heat transfer
- Apparent Reynolds number in the turbulent region even at high liquor viscosities
  - High U coefficient
  - Lower tube velocities
  - Lower HP

Forced Circulation Crystallizer

- Boiling suppression
  - No evaporation during heat transfer \(\Rightarrow\) very low supersaturation levels developed
  - Crystallization point is never exceeded within the heater \(\Rightarrow\) Eliminates uncontrolled scale formation
- Liquor viscosity
  - Not as much an issue: No film, no distribution device
  - Can be operated at lower temperatures \(\Rightarrow\) Lower risk for liquor decomposition and hard scale formation
Forced Circulation Crystallizer

- Excellent resistance to scaling
- Very infrequent washing needed, if any
- High tolerance to liquor chemistry swings
- High turndown capability
- Moderate HP consumption
- Easily automated
- Simple and robust

Multiple Effect Evaporation

- 100,000 lbs of steam will evaporate only 100,000 lbs of water from the liquor, if heat content is used only once

- Economic operation dictates the *multiple effective* use of the heat content of the steam used for evaporation

- Venting, radiation and other losses prevent from ever attaining full theoretical efficiency
Single Effect Operation

116k lb/hr steam
45k lb/hr SBL 50% TS

116k lb/hr condensate
150k lb/hr WBL 15% TS

Steam Economy = \( \frac{\text{water evaporated}}{\text{steam supplied}} \) = \( \frac{105}{116} \) = 0.9

Two-Effect Operation

57k lb/hr steam
45k lb/hr 50% BL

51k lb/hr vapor
99k lb/hr 23% BL

111k lb/hr condensate
150k lb/hr 15% BL

Steam Economy = \( \frac{105}{57} \) = 1.8
Multiple Effect Evaporation

- Operating conditions in the MEE are set
  - Available live steam pressure (typ. 60 psig or less)
  - Vacuum in last effect and SC (typ. around 25” Hg)
- Defines overall $\Delta T$ available
- Actual $\Delta T$ much lower due to BPR

Cumulative BPR Impact on $\Delta T$

<table>
<thead>
<tr>
<th></th>
<th>Temp., °F</th>
<th>Temp., °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam temperature</td>
<td>274</td>
<td>134</td>
</tr>
<tr>
<td>Condenser temp.</td>
<td>132</td>
<td>56</td>
</tr>
<tr>
<td>$\Delta T$ maximum</td>
<td>142</td>
<td>79</td>
</tr>
<tr>
<td>Sum of BPR's</td>
<td>43.7</td>
<td>24.3</td>
</tr>
<tr>
<td>$\Delta T$ actual</td>
<td>98.3</td>
<td>54.6</td>
</tr>
<tr>
<td>Capacity loss</td>
<td>31%</td>
<td>31%</td>
</tr>
</tbody>
</table>
Multiple Effect Evaporation

- Available $\Delta T$ per effect
  - Six effect train: $98.3/6 = 16.4^\circ F$
  - Seven effect train: $98.3/7 = 14.0^\circ F$
  - Eight effect train: $98.3/8 = 12.3^\circ F$

- Minimum $\Delta T$ required with LTV Evaporators
  - Below 13-15$^\circ F$, LTV effects “stall” and behave poorly

Why the $\Delta T$/effect limit with LTVs?

- Need to go back to $Q = U \times A \times \Delta T$
  - Low $\Delta T$ implies large area $A$ (i.e. many tubes)
    - Low evaporation per tube
  - Vapor generation per tube becomes too low for film formation & for making it rise to the top
    - Some tubes flood and “burp” at random
    - Others percolate returning liquor to the bottom liquor box (i.e. Mr. Coffee)
Rising Film (LTV) Multiple Effect Evaporation

- $\Delta T$/effect limit
  - Sets number of LTV bodies which fit within overall $\Delta T$
  - Sets steam economy

- LTV trains
  - Six effects maximum
  - Few 7 effect trains around
    - Unstable & very “twitchy”

Rising Film (LTV) Multiple Effect Evaporation

- Little turndown capability
  - At low capacities, $\Delta T$ drops below $\Delta T$/effect limit
  - Minimum operation
    - $\sim$ 70% of design rate

- Older mills rely on several LTV sets for flexibility.
Falling Film (FF) Multiple Effect Evaporation

- Film created by mechanical means
  - Liquor recirculation and distribution device
  - No minimum ΔT issues
- Higher efficiencies achievable

Several 7 and 8 effect FF trains in USA, Asia, Brazil and Europe

- High turndown
  - ~ 20% of design rate
- Modern mills can rely on a single line of FF evaporators
  - Easily matches evaporation demand from production
Multiple Effect Evaporation

- Integration of several evaporators ("effects")
  - Vapors from one effect drive the next one

- Entire train performance depends on the operation of each single effect and surface condenser

"The weak link governs"

- Optimizing performance will require working on one weak link and then the next one, etc.