Black Liquor Evaporation
Design & Operation

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

1

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

2

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

3

Black Liquor Properties

- Chemical composition
  - Major role on the performance of the evaporators
    - Na_2SO_4, Na_2CO_3 co-precipitate at high solids
    - Risk of scale formation
- Critical physical properties
  - Boiling Point Rise (BPR)
  - Viscosity which impacts heat transfer

4

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

$$Q = U \times A \times \Delta T$$

5

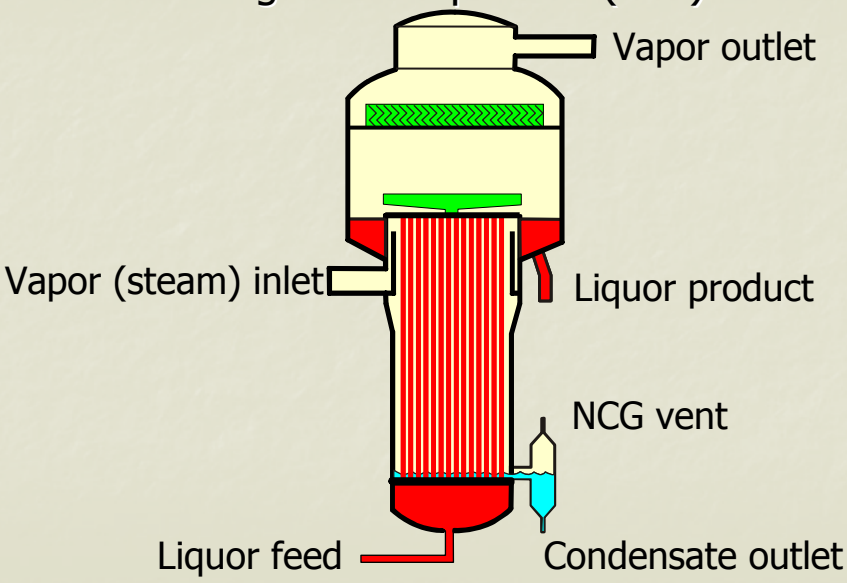
Evaporation Technologies

- "Q": Heat exchange amount which can be accomplished
- "A": Heat transfer surface
- "ΔT": Temperature differential

  ΔT = Sat. Vapor T In – 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

6

Rising Film Evaporator (LTV)



7

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 ΔT requirement
- Was the workhorse of the Industry, now found only in older mills

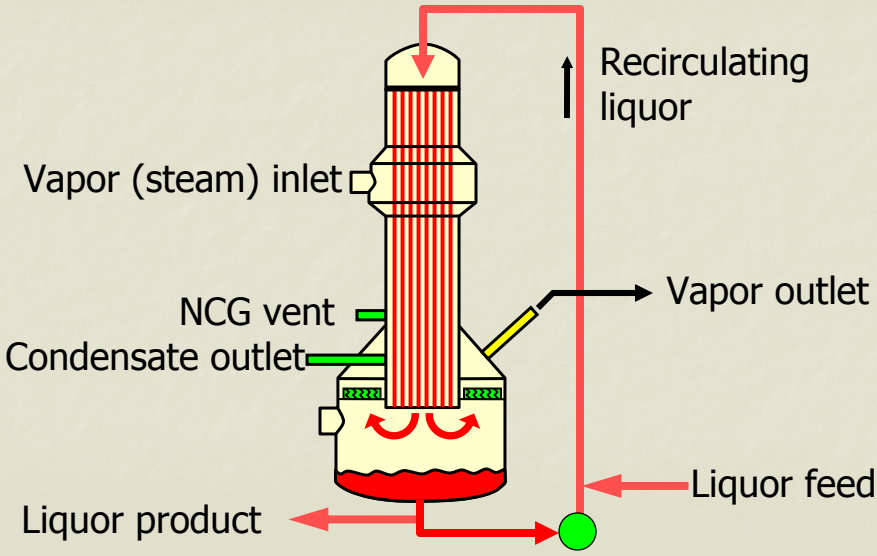
8

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

9

Falling Film Evaporator



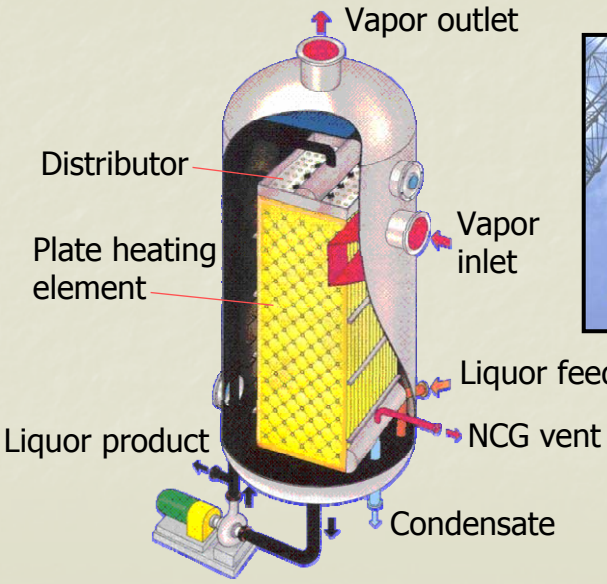
10

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

11

Plate-type FF Evaporator



12

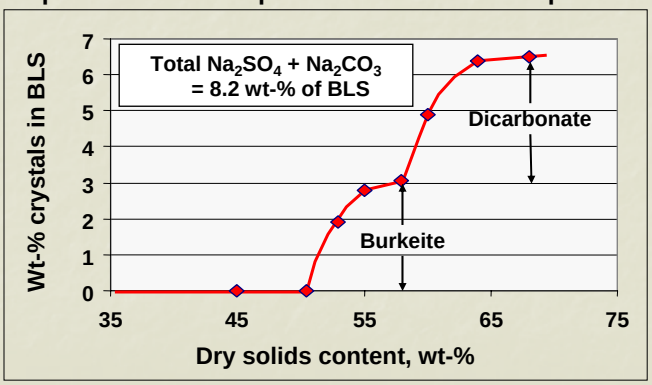
Falling Film Evaporator

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

13

Process Considerations at high solids

- Precipitation of supersaturated components



14

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.

15

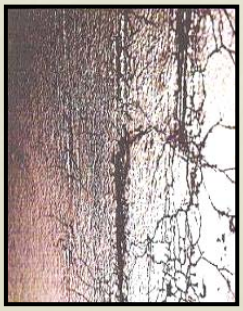
Process Considerations at high solids

- 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

16

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



17

High Solids Technology

Crystallization		*Evaporation*
• Enhanced FC Crystallizer	• FF Crystallizer	• Switching FF Evaporator

18

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

19

Falling Film Concentrators

- 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

21

Falling Film Concentrators

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

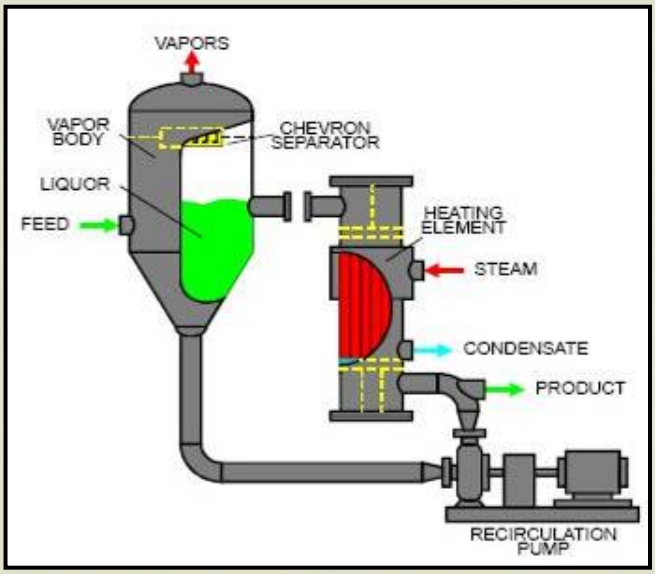
22

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)

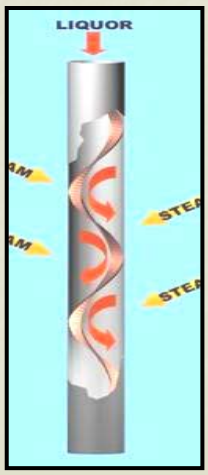
23

Forced Circulation Crystallizer



24

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

25

Forced Circulation Crystallizer

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

26

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

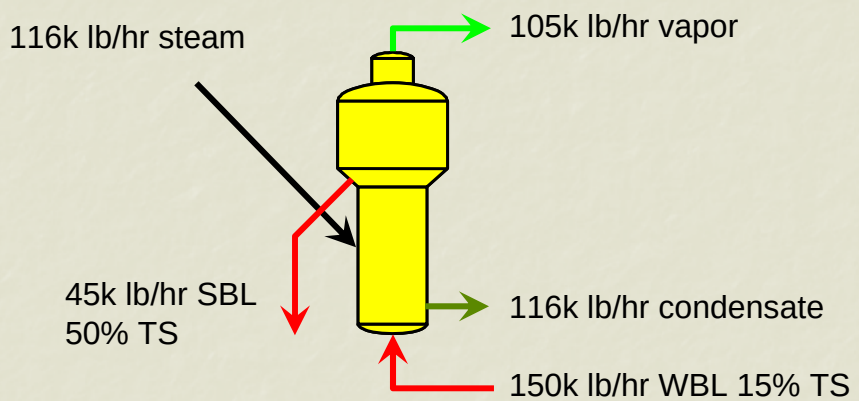
27

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

28

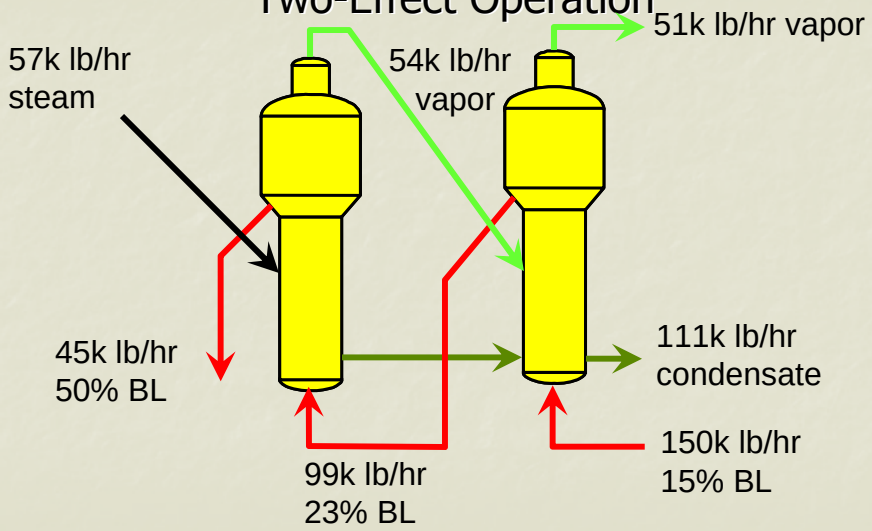
Single Effect Operation



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

29

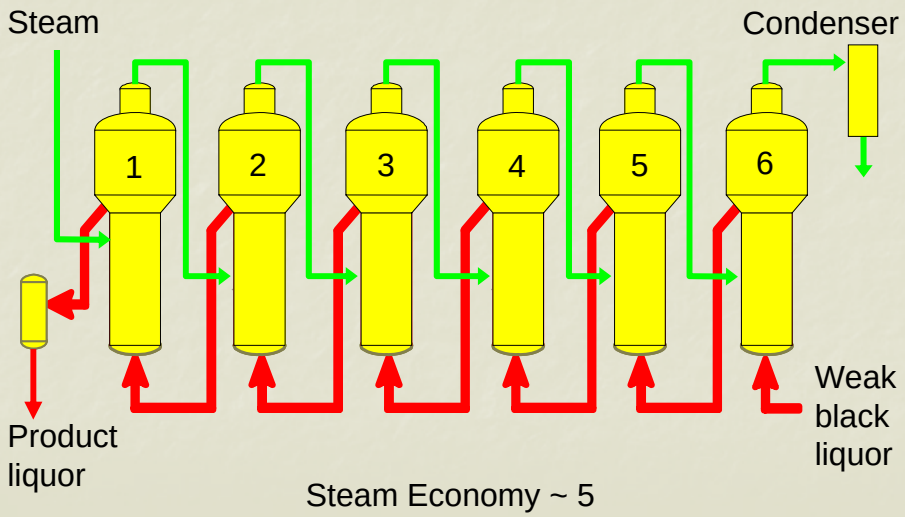
Two-Effect Operation



Steam Economy = 105/57 = 1.8

30

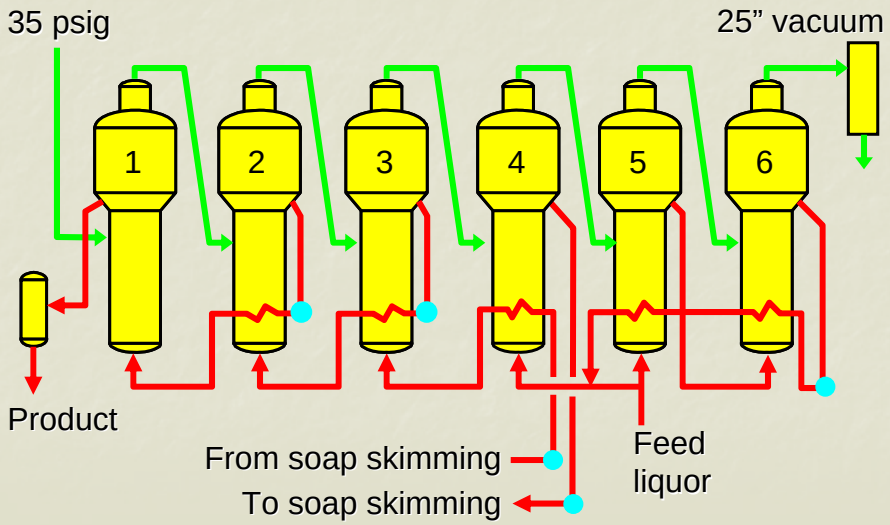
Simple Six-Effect Evaporator Set



Steam Economy ~ 5

31

Typical Six Effect Set



32

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 ΔT available
- Actual ΔT much lower due to BPR

33

Cumulative BPR Impact on ΔT

	Temp., °F	Temp., °C
Steam temperature	274	134
Condenser temp.	132	56
ΔT maximum	142	79
Sum of BPR's	43.7	24.3
ΔT actual	98.3	54.6
Capacity loss	31%	31%

34

Multiple Effect Evaporation

- Available ΔT per effect
  - Six effect train: 98.3/6 = 16.4º F
  - Seven effect train: 98.3/7 = 14.0º F
  - Eight effect train: 98.3/8 = 12.3º F
- Minimum ΔT required with LTV Evaporators
  - Below 13-15ºF, LTV effects "stall" and behave poorly

35

Why the ΔT/effect limit with LTVs?

- Need to go back to $Q = U \times A \times \Delta T$
  - Low ΔT 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)

36

Rising Film (LTV) Multiple Effect Evaporation

- ΔT/effect limit
  - Sets number of LTV bodies which fit within overall ΔT
  - Sets steam economy
- LTV trains
  - Six effects maximum
  - Few 7 effect trains around
    - Unstable & very "twitchy"

37

Rising Film (LTV) Multiple Effect Evaporation

- Little turndown capability
  - At low capacities, ΔT drops below ΔT/effect limit
  - Minimum operation
    ~ 70% of design rate
- Older mills rely on several LTV sets for flexibility.

38

Falling Film (FF) Multiple Effect Evaporation

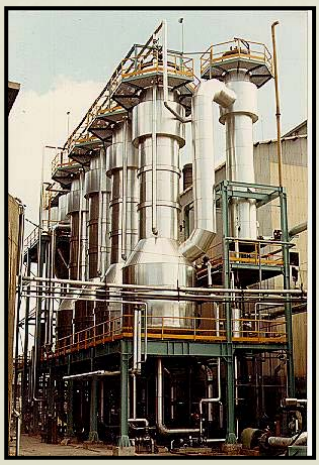
- Film created by mechanical means
  - Liquor recirculation and distribution device
  - No minimum ΔT issues
- Higher efficiencies achievable

39

Falling Film (FF) Multiple Effect Evaporation

- 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



40

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.

41