Recovery Boiler and Power Boiler Optimization – Paprican's Approach

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Kraft Pulp Mill Capacity

- 70 % of North American kraft mills are limited by recovery boiler capacity
- Most recovery boilers are limited by plugging; emissions of TRS or particulates (PM) limit most of the others
- Plugging is caused by high K and Cl or by carryover; sootblowing is ineffective for the removal of carryover deposits

Chloride Sources, Effects and Control

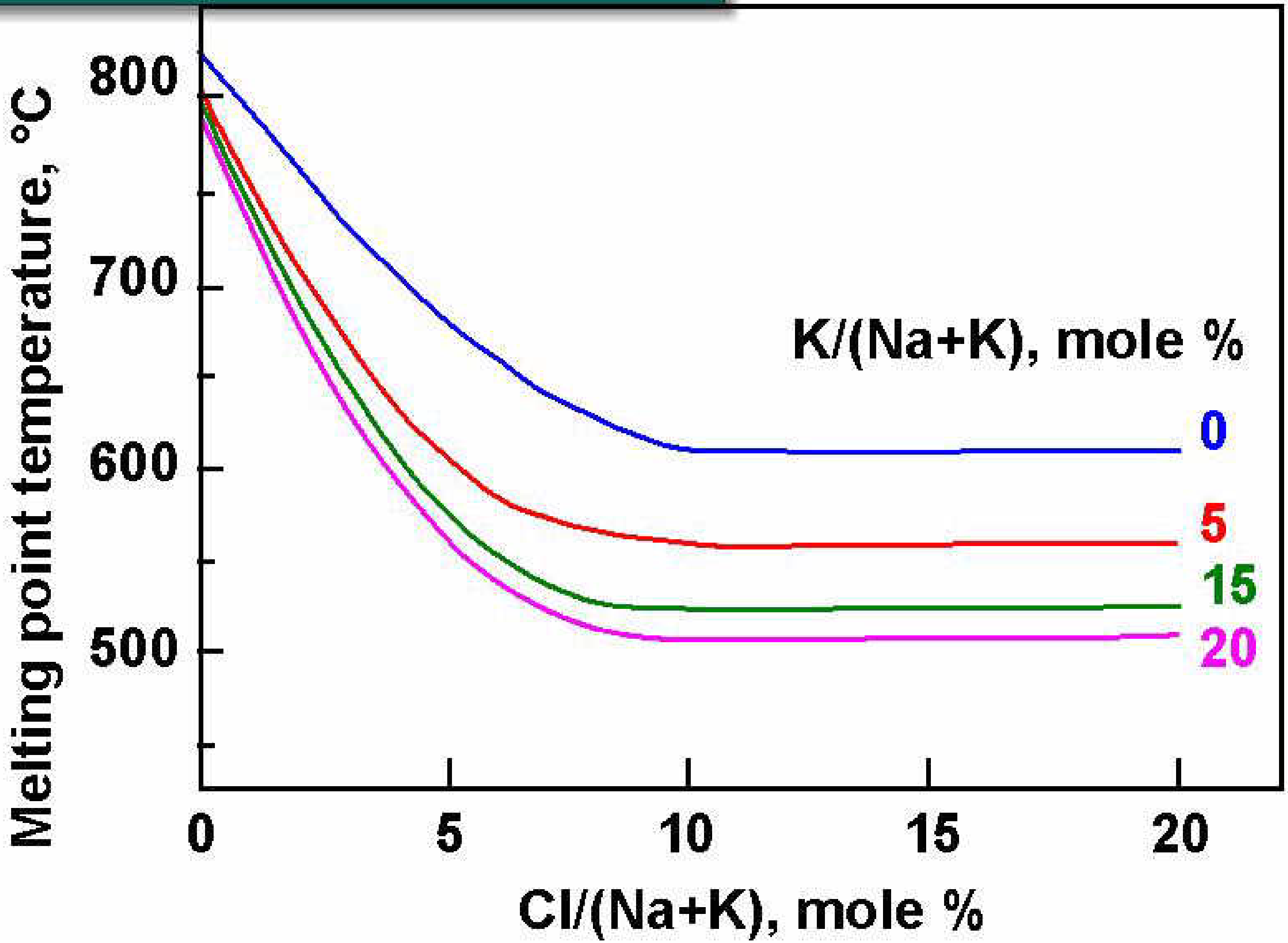
Chloride Sources

- Type of wood
  - 1.2 to 14 kg Cl/adt of wood
- Mill location
  - Coastal (3-5 wt%) or Inland (0.2-0.6 wt %)
- Make up saltcake
- Low grade caustic
  - Diaphragm (1-2 wt%)
- Degree of E stage filtrate recycle

Chloride Effects

- Decreased sticky temperature
  - Increased sootblowing
  - Increased chill-and-blows
  - Reduced boiler throughput
  - Increased water washes
- Carbon steel corrosion / superheater corrosion problems

Sticky Temperature

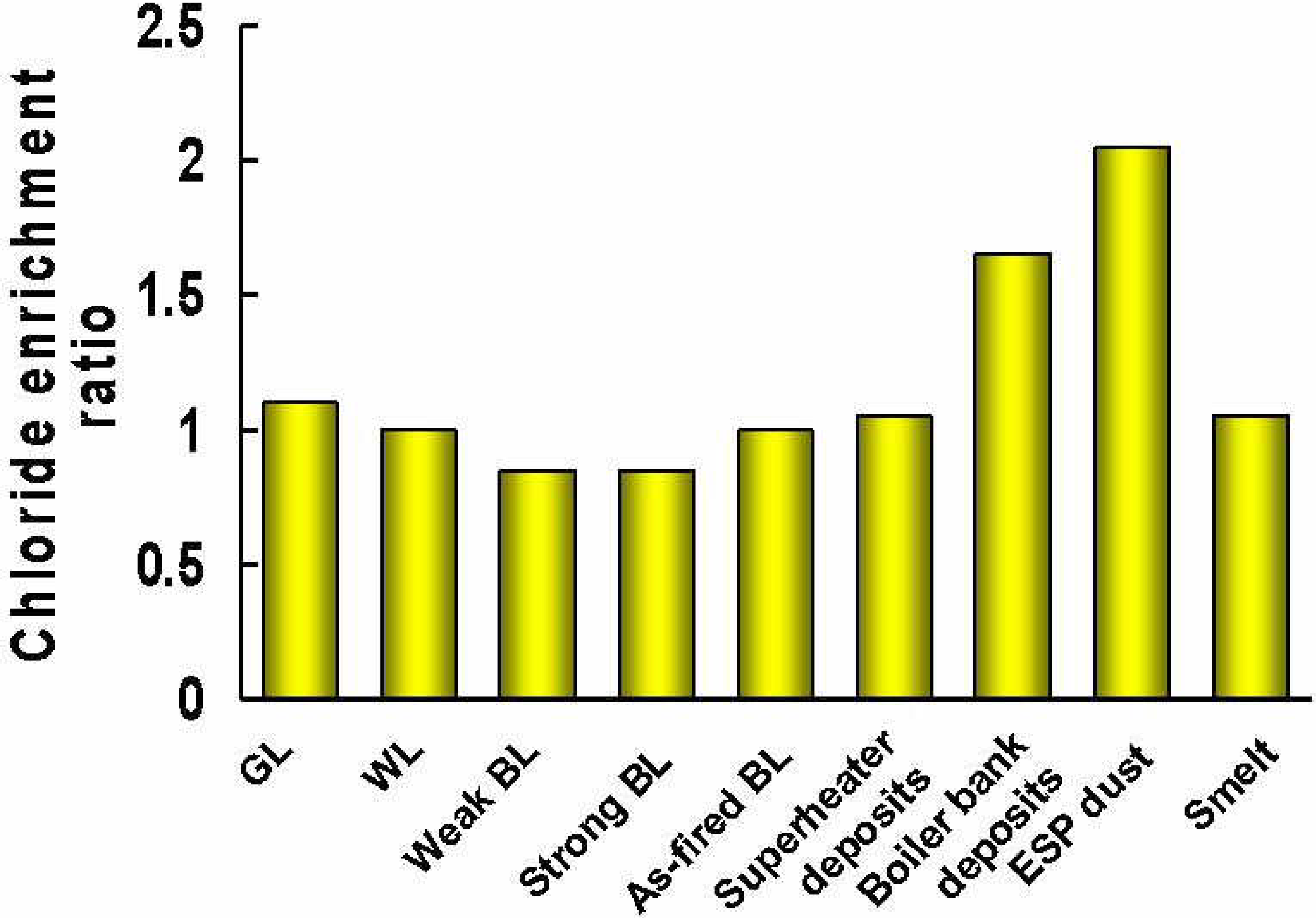


Chloride Control

Options

- Sewer Electro-Static Precipitator (ESP) dust
- Use low-chloride caustic
- Operate at high sulphidity
- Use additives for deposit control
- Treat ESP dust

Why ESP Dust?


Chloride enrichment ratio
2.5
2
1.5
1
0.5
0
GL
WL
Weak BL
Strong BL
As-fired BL
Superheater deposits
Boiler bank deposits
ESP dust
Smelt

Sewering

- Enrichment in ESP
- Add saltcake for Na & S makeup
- Sodium – Sulphur balance?
- Chemical makeup costs?

Low Chloride Caustic

- Diaphragm grade – 5000 ppm Cl
- Membrane grade – 50 ppm Cl
- Price difference?
- Sodium carbonate?
- Acid removal from saltcake /sesqisulphate?
- Treatment of caustic to remove Cl?

High Sulphidity

- NaCl converted to HCl
- HCl purged in stack gas
- Limited purge

$$2NaCl + SO_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow Na_2SO_4 + 2HCl$$

Additives

- High melting point materials
  - MgO; CaO; SiO_2 Al_2O_3
- Added to black liquor or injected at superheater
- Works in some boilers
- Extensive modeling improves chances of success

Treat ESP Dust

- Leaching
- Evaporation crystallization
- Freeze crystallization
- Ion exchange

Leaching

- Add sufficient hot water to dissolve NaCl and not Na_2SO_4
- Separate with filter or centrifuge
- Portion of leachate purged
- Kvaerner's Ash leaching system

Evaporation Crystallization

- ESP fully dissolved
- Solution evaporated
- Sulphate crystallizes and slurry filtered
- US Filter/HPD – Chloride Removal Process (CRP)
- Andritz–Ash–Re-Crystallization (ARC)
- Eka–Precipitator Dust Recovery (PDR)

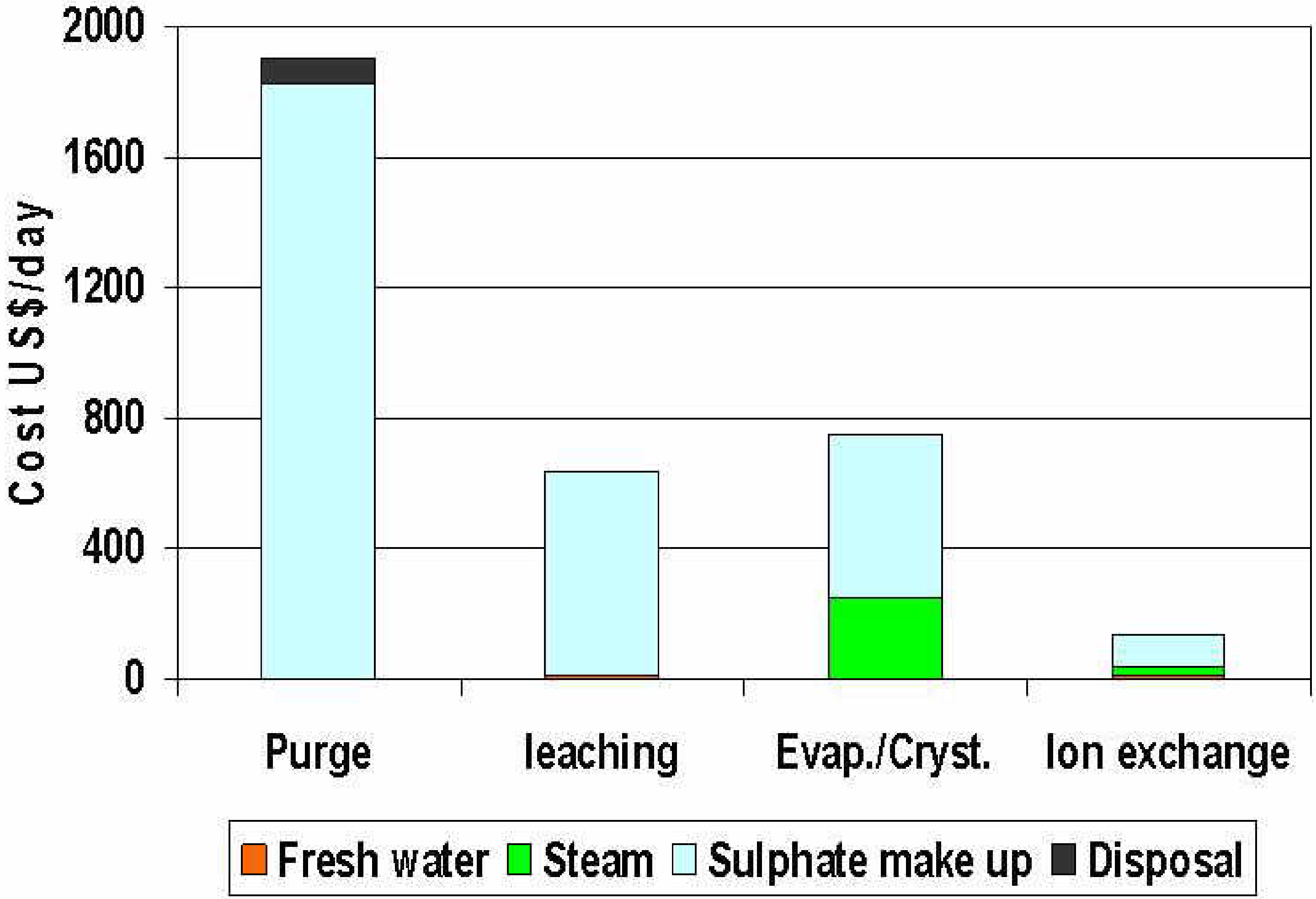
Freeze Crystallization

- ESP fully dissolved
- Solution frozen
- Sulphate crystallizes
- Slurry filtered
- Mitsubishi process widely used in Japan

Ion Exchange

- ESP fully dissolved
- NaCl separated from Na_2SO_4 by ion exchange
- Retains NaCl but rejects or excludes sulphate and carbonate
- Water regeneration
- Noram-Eco-Tec-Paprican – Precipitator Dust Purification (PDP)

Treating 20t/d ESP



NaOH Purification Unit

- Same operation as the PDP system
- No filtration step is required (NaOH solution is free of suspended solids)
- Solution has to contain no more than 10% wt NaOH (for longer resin life)
- Now testing at higher caustic strength

Costs for caustic treatment

- For 12 t/d of NaOH (at 10% concentration)
- Capital cost about CA $ 445 K
- Resin life (at room temp.) about 3 years
- Estimated operating cost: CA $ 45 K/y
- Savings if low Cl caustic costs $100/t more than diaphram caustic –
  $100/t X 12 t/d X 350 d/y = $420,000/y
- Net savings $375 K/y; payback – 1.2 y

Recovery Boiler Air System Optimization

(Paprican's Approach)

Recovery Boiler Combustion Air Distribution

- Air is injected at multiple vertical levels and from all 4 boiler walls
- The interactions of these air jets create a high velocity chimney which promotes carryover
- The location and strength of the chimney (peak velocities) is determined by the air flow, the splits and the distribution between boiler walls

Recovery Boiler Combustion Air Distribution

- Unbalanced air distribution between the walls at a given level pushes the chimney closer to the boiler walls and associated liquor guns, increasing carryover and PM emissions
- Interlacing of the secondary and tertiary air flows can reduce the size of the chimney and peak gas velocities
- Optimization of the vertical air splits increases bed temperatures and reduction efficiency while decreasing TRS emissions

Paprican's Recovery Boiler Air System Optimization Program

- The product of 9 years of research on boiler flow patterns, carryover and sootblowing control.
- Applied successfully on over 45 recovery boilers in the last 6 years. Now being commercialized through the Boiler Optimization Business Unit.
- The first six mills that used this technology produced over 130,000 more tonnes of pulp per year (generating $100 million in added income per year) and two mills avoided significant capital expenditures.

Poor Recovery Boiler Air Distribution

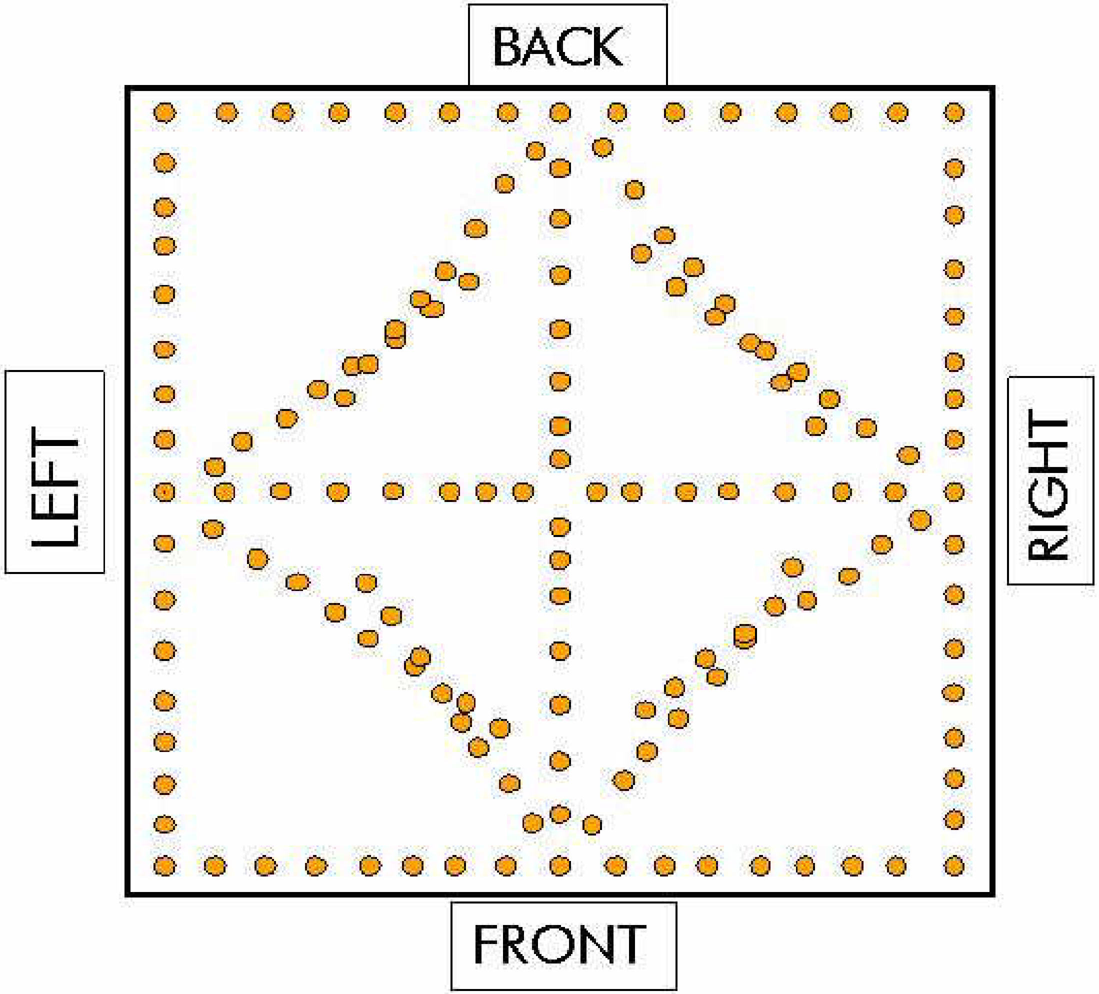
- High carryover
- Rapid boiler plugging
- Low reduction efficiencies
- Smelt spout plugging problems
- High TRS and PM emissions
- Reduced boiler throughput

- Setting up your recovery boiler air system without the proper tools is akin to timing your car's engine by ear.

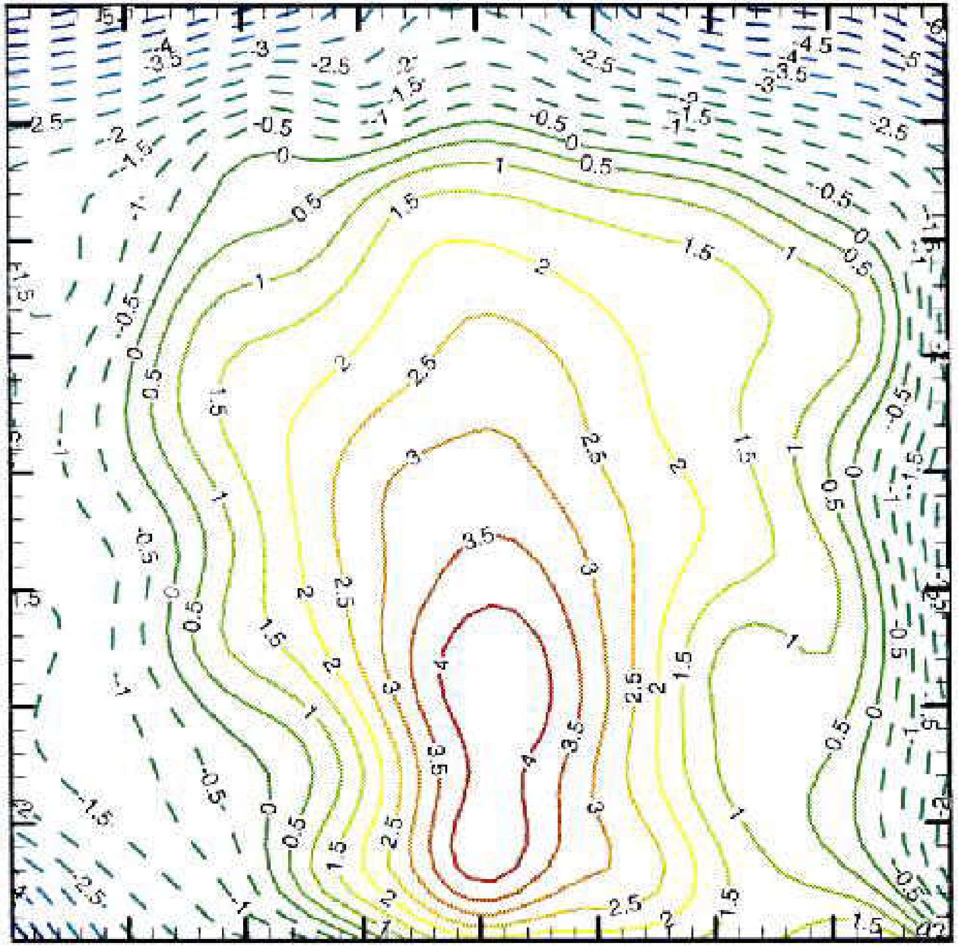
Key Measurements

- Combustion air flow and distribution
- Cold flow gas velocity profiles (not often required now)
- Gas velocities with fossil fuel and black liquor firing (not often necessary now)
- Char bed and furnace temperature profiles
- Carryover

Typical Cold Flow Velocity Measurement Locations



Mill C Cold Flow Velocity Profile Before Optimization

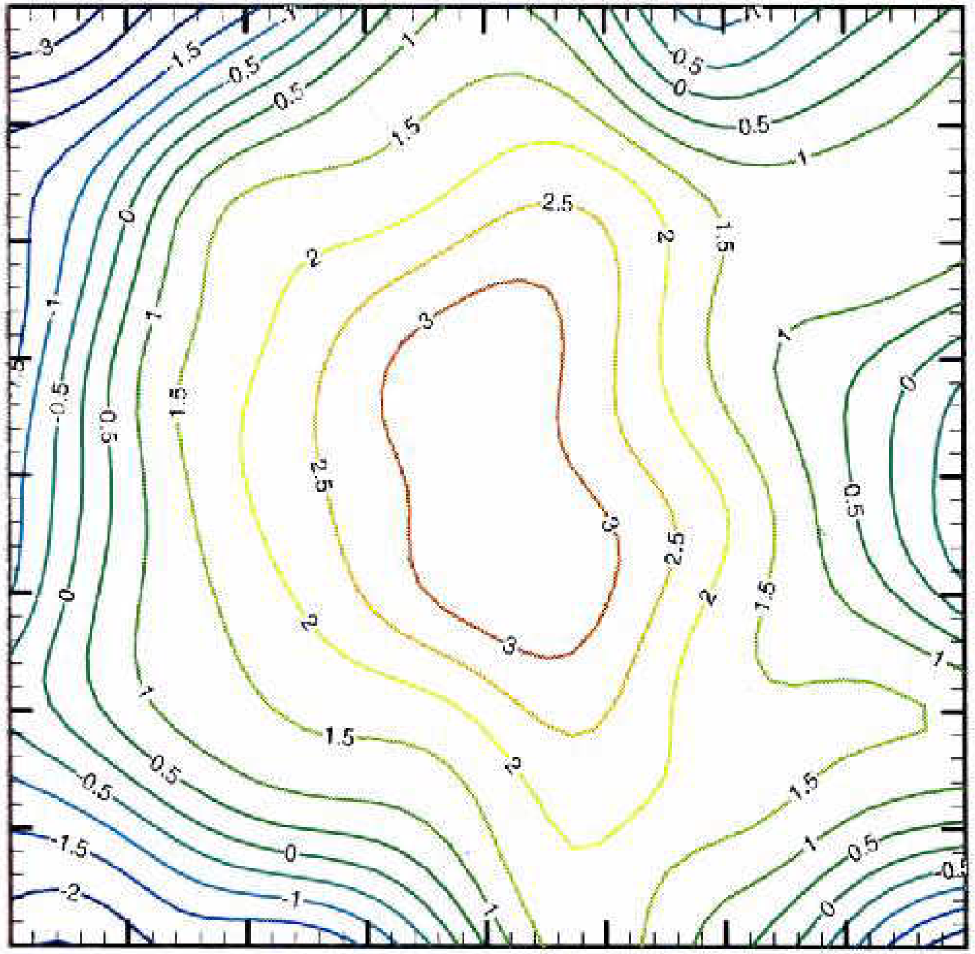


Front

Problem Analysis

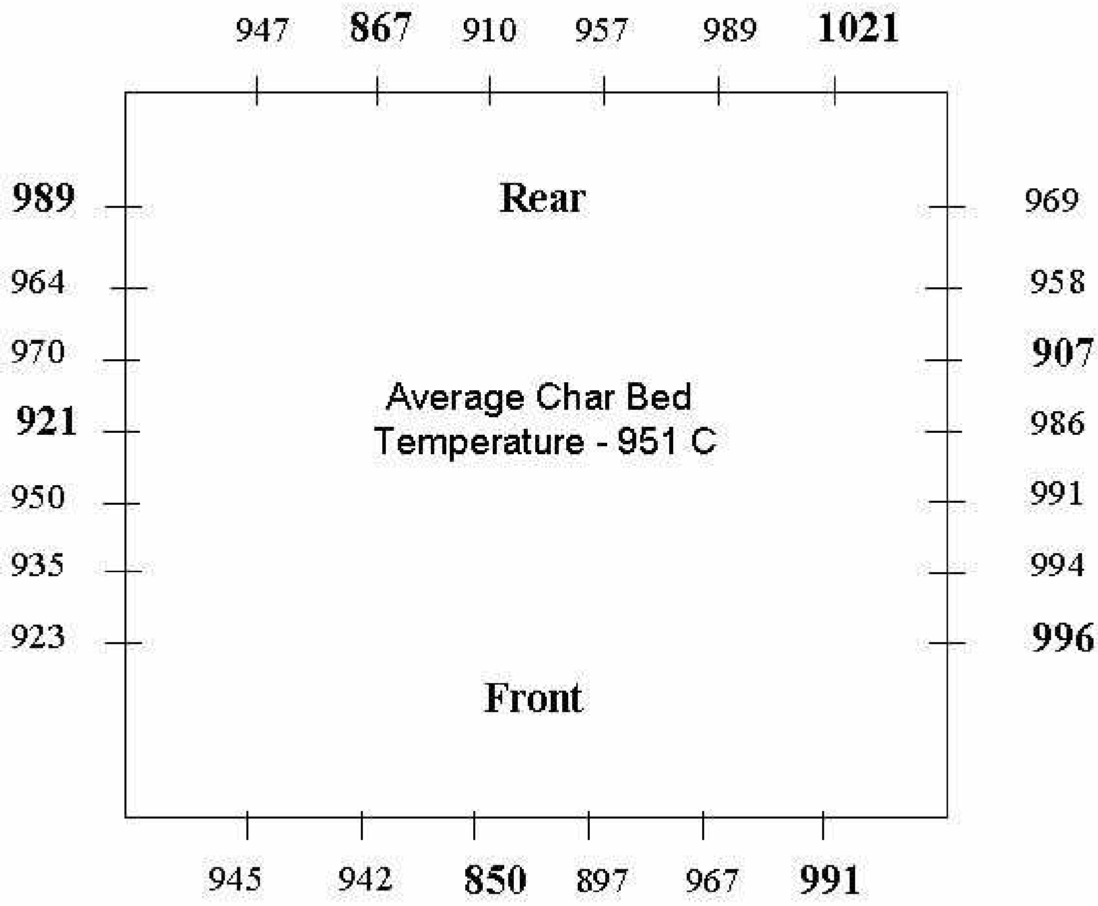
- High carryover (chimney at front wall)
- Rapid boiler plugging (washing every 6 to 8 weeks)
- High green liquor dregs (note downflow along rear spout wall) and subsequent recaust problems
- High TRS emissions
- Reduced boiler and chemical recovery system throughput

Mill C Cold Flow Velocity Profile After Optimization

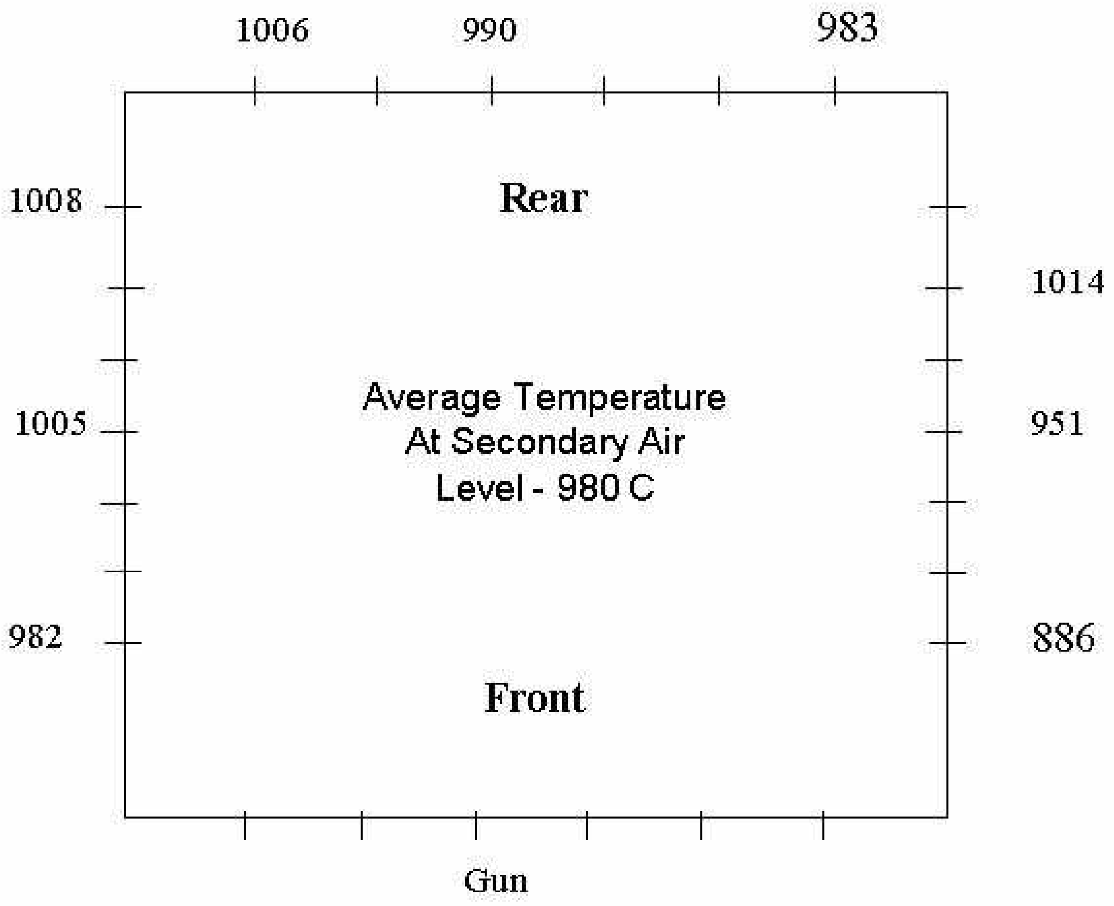


Front

Char Bed Temperatures



Secondary Air Temperatures
- Brasilian RB 1



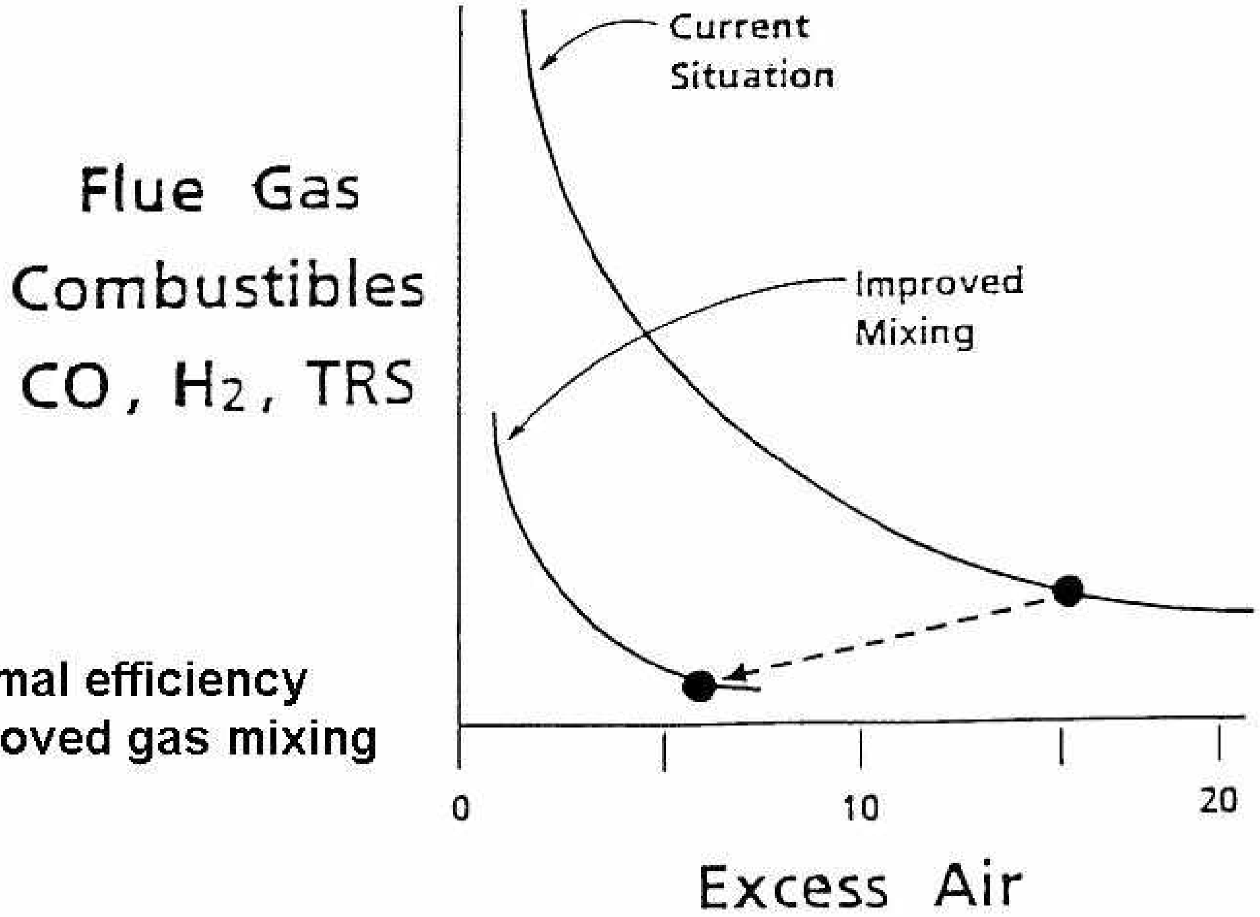
Temperature Profile – Brasilian RB 2

Level	North Side °C	South Side °C	Difference (N – S), °C
Char Bed	983	966	17
Secondary Air	1038	996	42
Tertiary Air	955	922	33

Temperature Profile – Brasilian RB 3

Level	North Side °C	South Side °C	Difference (N – S), °C
Char Bed (E – W)	997 (1002)	979 (947)	18 (55)
Secondary Air	1041	995	46
Tertiary Air (E - W)	(943)	(903)	(40)

Excess air needed to compensate for inadequate mixing



+3% thermal efficiency with improved gas mixing

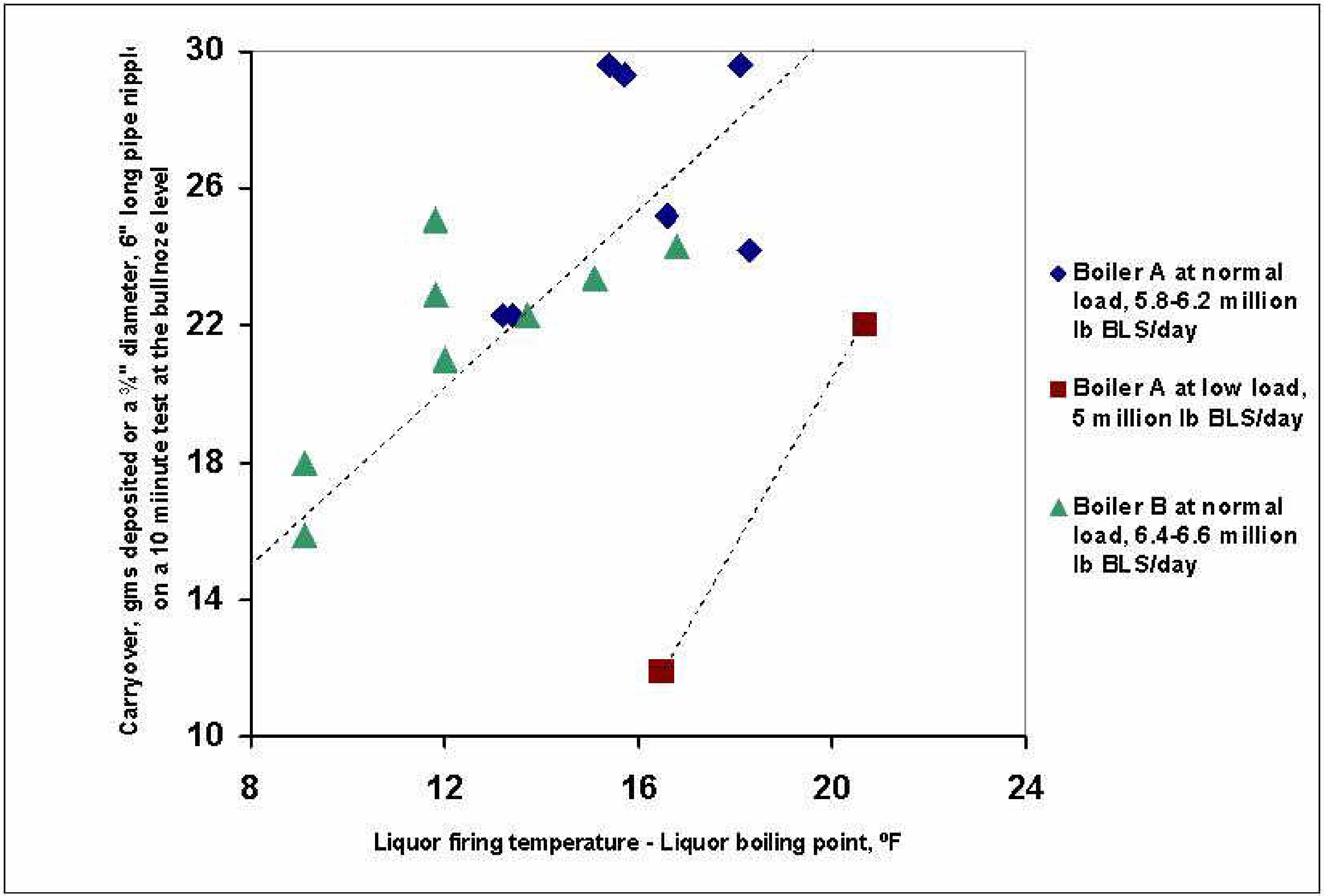
Recovery Boiler Optimization

- Both the air system and the liquor firing system have to be optimized
- Balance and optimize air first
- Optimize liquor firing parameters (gun pressures, gun angles & firing temp.)
- Adjust air splits to maximize lower furnace temperatures & minimize carryover

Optimizing Liquor Distribution in Existing Recovery Boilers

- Developed simple tools to measure and quantify carryover as liquor firing variables (firing rate, T, P, nozzle size, etc.) were changed
- Successful trials completed in 21 recovery boilers; guidelines developed for conventional splash plate nozzles were validated in the last 9 boilers and issued to our Member Companies in June 2003
- Typical result of application : increased boiler throughput by 3.3 % while reducing carryover by 50 %

Effect of Liquor Firing Temperature on Carryover



Factors Affecting The Maximum Recovery Boiler Throughput

- Combustion air system design and set up
- Boiler design (pressure, aspect ratio, air port and liquor gun locations, heat transfer area, etc.)
- Liquor chemistry (heating value, swelling behaviour, viscosity, Cl, K, etc.)
- Liquor spray system (nozzle type, T, P, etc.)

Heat Loading in Recovery Boilers (Optimized by Paprican)

Recovery Boiler	Heat loading Million BTU/h/ft^2	Aspect ratio
J	1.2	2.5
E	1.16	2.3
F	1.14	2.6
G	1.22	2.8
H	1.23	3.1

Benefits of Air System Optimization

Mill	**A, No. 2**	**B**	**C**	**D**
Type of boiler	ABB	B&W	B&W	ABB
Water washes per year	17 → 6 → 1	10 → 3 → 2	8 → 2	4 → 2
Liquor firing rate		**Up 18%**	**Up 8 %**	**Up 5 %**

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Benefits

- 5 - 20% increases in recovery boiler throughput ($8.5 to $34 million US per year in incremental pulp production in a 1000 tpd kraft mill)
- Reduction of water washes to 1 to 2/year ($500,000 - $2.5 million US per year)
- Dramatic reductions in TRS emissions and corresponding increases in boiler throughput

Benefits

- 3-7% increases in reduction efficiency ($240,000 - $500,000 US per year in a 1000 tpd kraft mill)
- Increased thermal efficiency (~$230,000 US per year for a 1 % increase)
- Decreased sootblowing steam use (reducing sootblowing steam use from 9 to 6 % provides $300,000 - $500,000 US per year in incremental steam production)

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Effect of Black Liquor Composition on Viscosity

- Paprican has a state of the art facility donated by Air Products
- Can evaporate and oxidize liquors
- Can measure viscosity at high solids (up to 78%) and high temperatures (up to 130 ^oC)
- Used to characterize the effect of process changes (PS, AQ, etc.) and liquor composition (soap content) on black liquor properties
- Now being used to characterize the effect of wood species, particularly southern US hardwoods, on black liquor properties

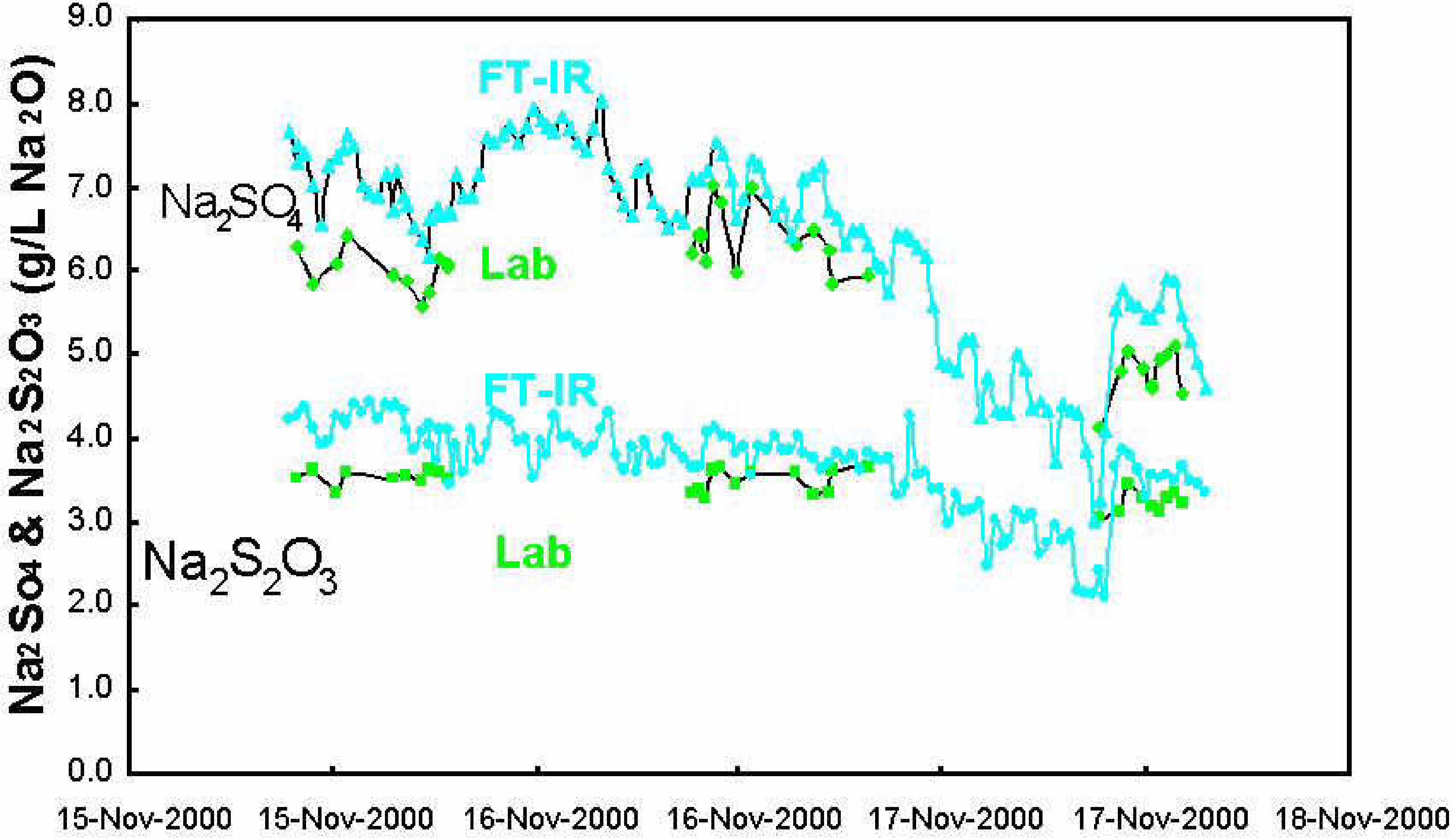
Factors Affecting Black Liquor Liquor Viscosity

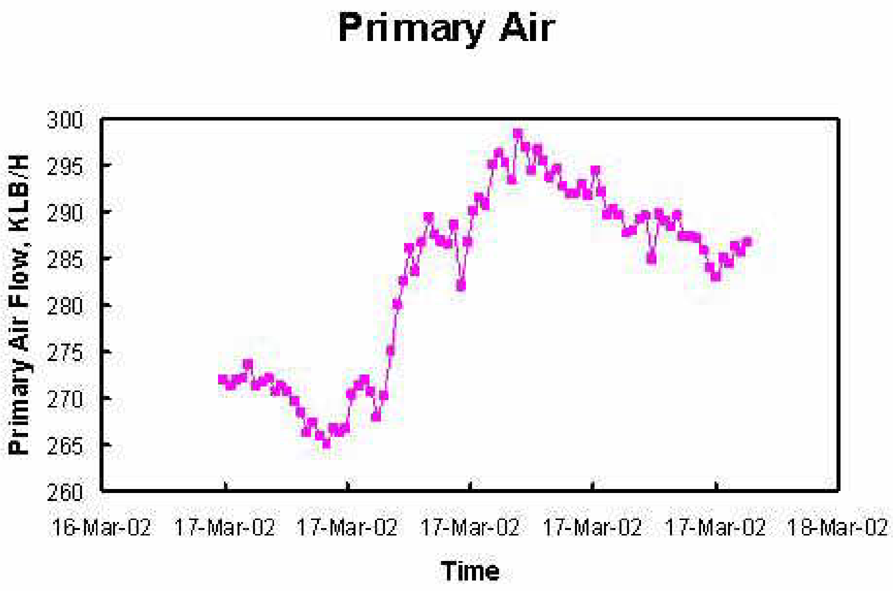
- Viscosity increases as the black liquor solids content increases or temperature decreases
- Viscosity versus REA curves are always U-shaped
- REA to minimize BL viscosity is around 2.0% on dry BLS for softwoods but varies from 0.5 to 4.0% for hardwoods depending on wood species
- Viscosity of softwood BL is > that of hardwood BL
- Viscosity of BL from PS and PSAQ pulping is generally lower than that for kraft BL

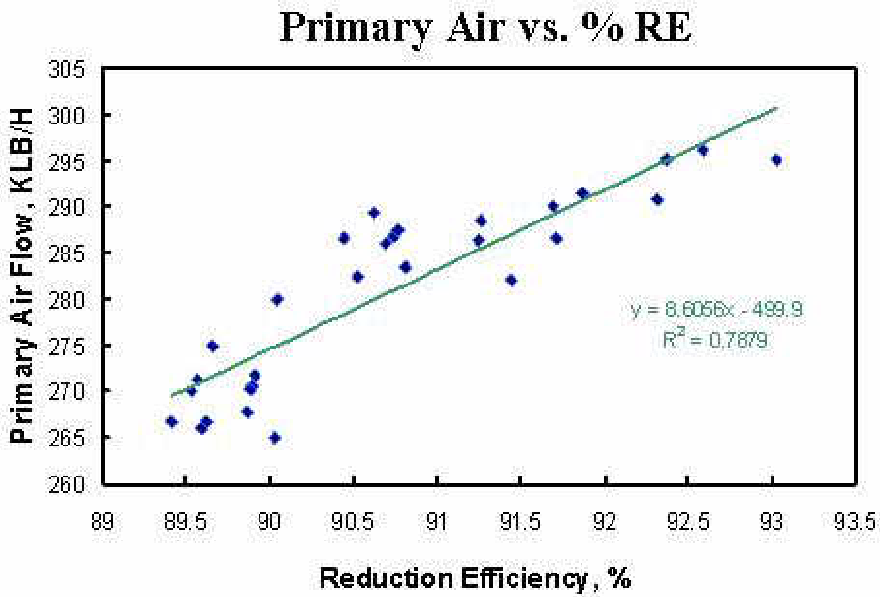
Optimizing Reduction Efficiency in Existing Recovery Boilers

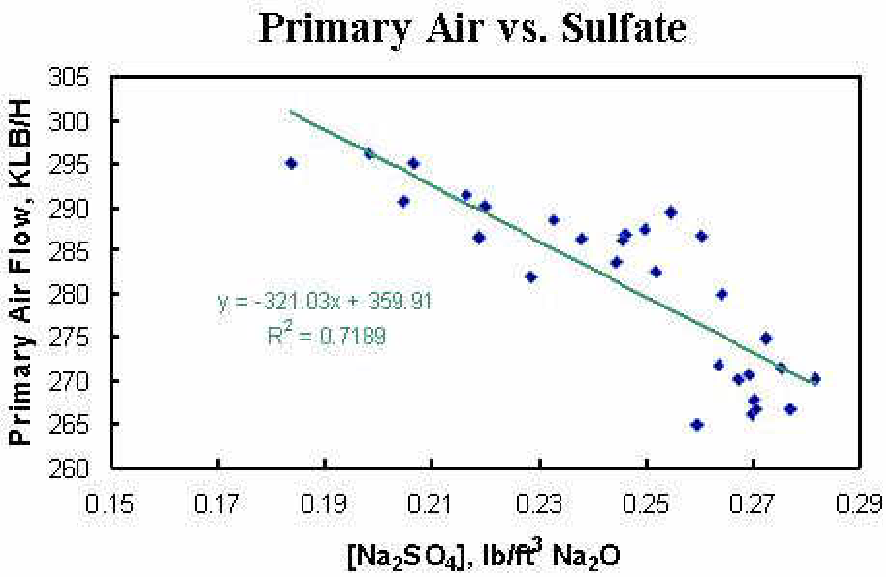
- FT mid-IR based on-line reduction efficiency sensor operated on one recovery boiler continuously for 9 months using an ATR cell; now being installed on 2 additional boilers
- Evaluated the effects of combustion air flow, air splits, primary air flow, liquor firing rate, & liquor temperature on reduction efficiency
- Increased average char bed temperature by 40 C and reduction efficiency from 89% to 93%

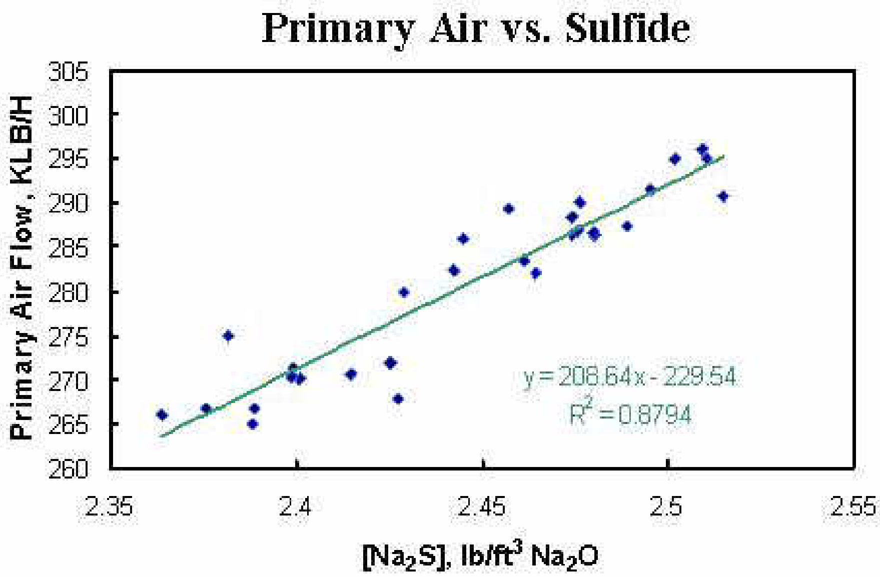
Raw GL Na_2SO_4 & $Na_2S_2O_3$ Trends

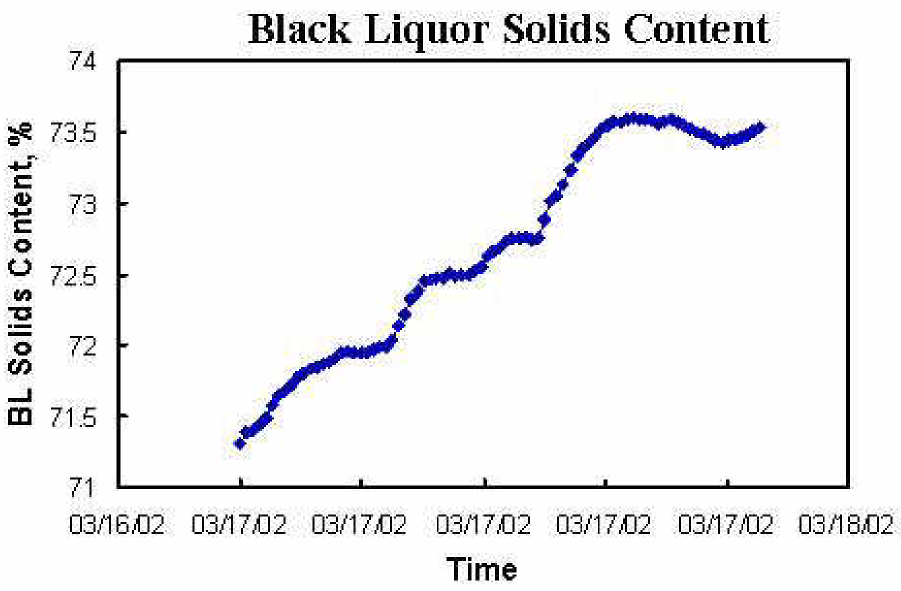


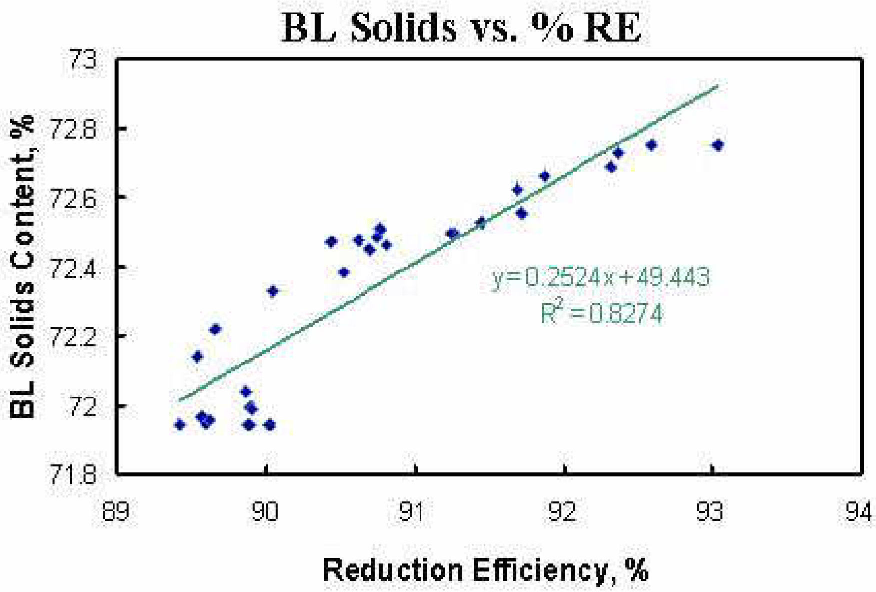

Primary Air
Primary Air Flow, KLB/H
300
295
290
285
280
275
270
265
260
16-Mar-02
17-Mar-02
17-Mar-02
17-Mar-02
17-Mar-02
17-Mar-02
18-Mar-02
Time

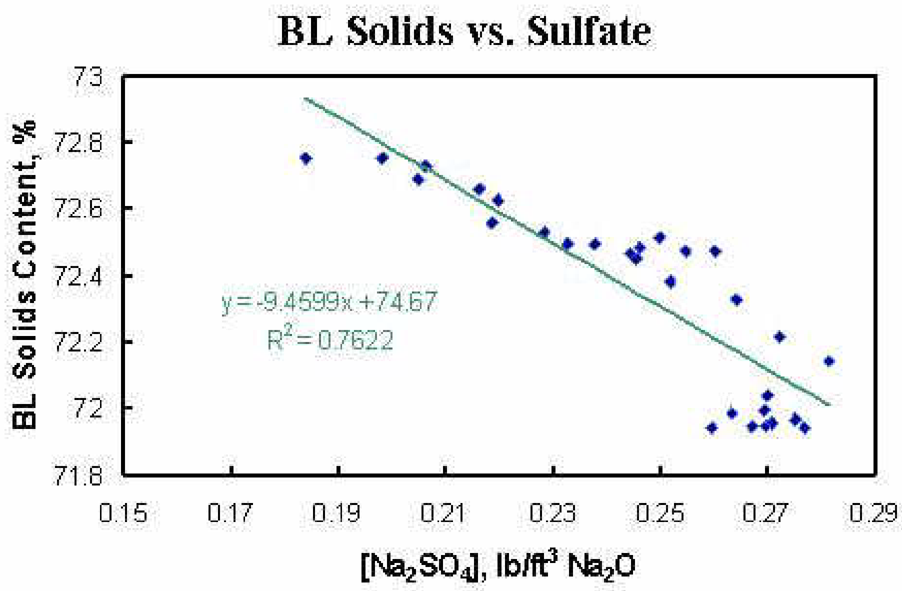

Primary Air vs. % RE
Primary Air Flow, KLB/H
y = 8.6056x - 499.9
$R^2 = 0.7879$
Reduction Efficiency, %

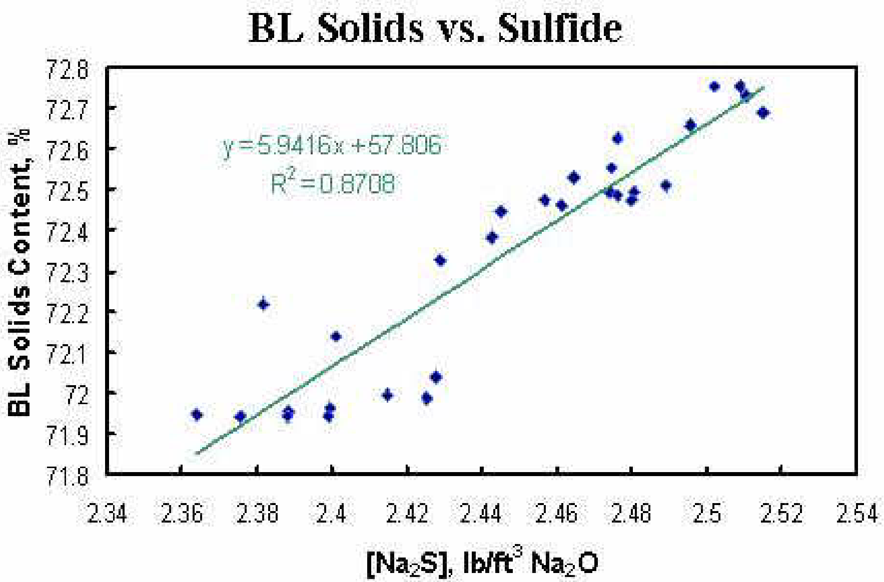

Primary Air vs. Sulfate
Primary Air Flow, KLB/H
y = -321.03x + 359.91
$R^2 = 0.7189$
$[Na_2SO_4]$, lb/ft^3 Na_2O


Primary Air vs. Sulfide
Primary Air Flow, KLB/H
y = 208.64x - 229.54
$R^2 = 0.8794$
$[Na_2S]$, lb/ft^3 Na_2O

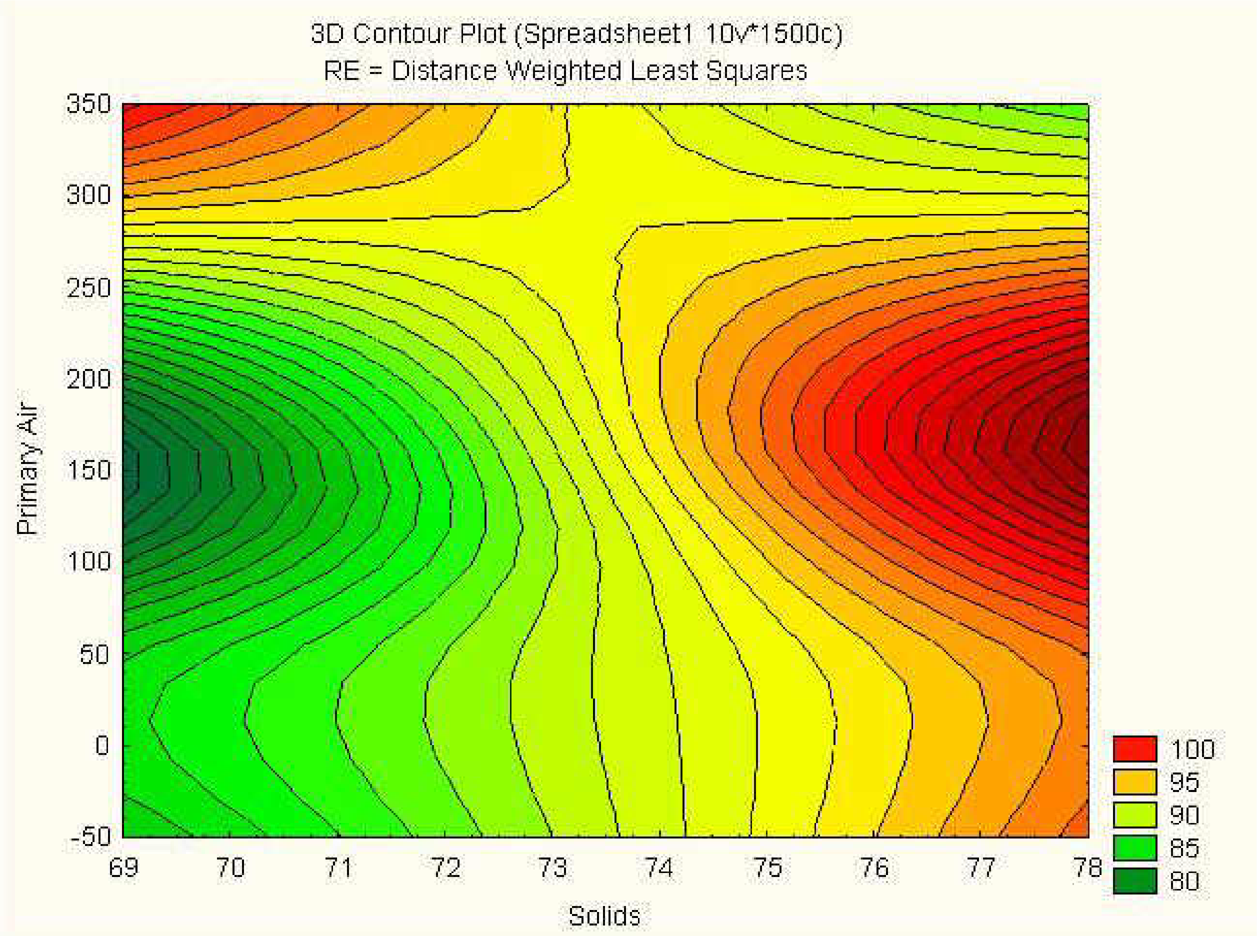

Black Liquor Solids Content
BL Solids Content, %
74
73.5
73
72.5
72
71.5
71
03/16/02
03/17/02
03/17/02
03/17/02
03/17/02
03/17/02
03/18/02
Time


BL Solids vs. % RE
BL Solids Content, %
73
72.8
72.6
72.4
72.2
72
71.8
89
90
91
92
93
94
Reduction Efficiency, %
y = 0.2524x + 49.443
R2 = 0.8274


BL Solids vs. Sulfate
BL Solids Content, %
73
72.8
72.6
72.4
72.2
72
71.8
0.15
0.17
0.19
0.21
0.23
0.25
0.27
0.29
[Na2SO4], lb/ft3 Na2O
y = -9.4599x + 74.67
R2 = 0.7622


BL Solids vs. Sulfide
BL Solids Content, %
72.8
72.7
72.6
72.5
72.4
72.3
72.2
72.1
72
71.9
71.8
2.34
2.36
2.38
2.4
2.42
2.44
2.46
2.48
2.5
2.52
2.54
[Na2S], lb/ft3 Na2O
y = 5.9416x + 57.806
R2 = 0.8708

Contour Plot – RE, Solids, 1° Air



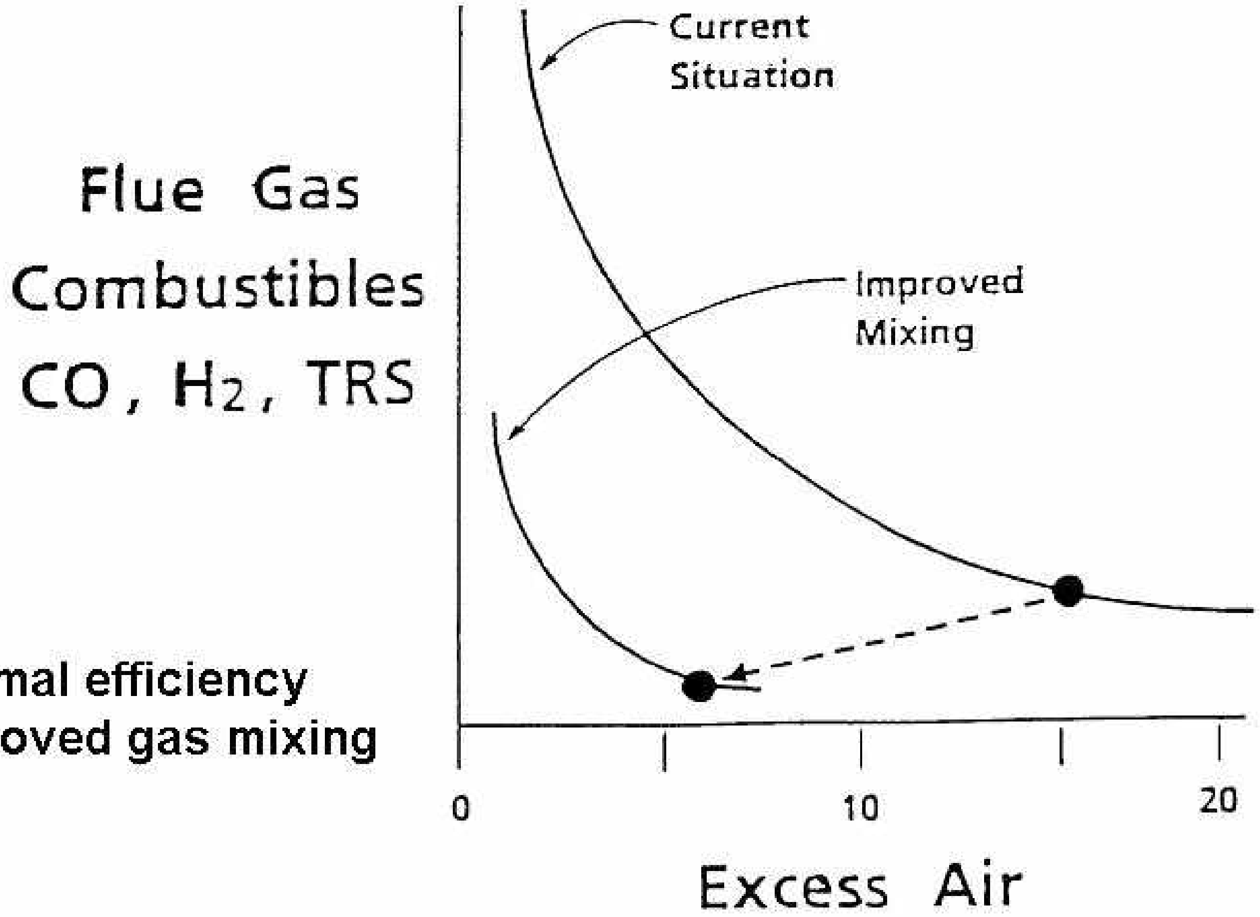
Power Boiler Optimization

- Now transferring air system optimization technology to power boilers to reduce fossil fuel use and emissions (PM, NOx and dioxins).
- Baseline tests completed in 9 boilers; follow up optimization work finished in 5 of these and planned in 3 of the other boilers.
- Balancing the air and optimizing the air splits significantly increased steaming rates and steam production from hog fuel (by up to 75%) while reducing unburnt carbon in the fly ash.

Power Boiler Optimization

- Baseline tests involve checking the mill's air flow instrumentation, boiler temperature profiles, boiler exit or stack oxygen and CO concentrations, and multiclone and ESP ash carbon content at two or more hog firing rates
- Optimization involves adjustments to the air splits, hog feed and overfire air distribution
- Optimization may require some capital investment in stack emission monitors (O_2 and CO), damper controls or even air system upgrades, detailed in our recommendations

Excess air needed to compensate for inadequate mixing



+3% thermal efficiency with improved gas mixing

Problems Identified with Power Boilers

- Non optimal air splits
- Poorly designed OFA systems (layout / location) and inoperable dampers often prevent effective boiler optimization
- Non-uniform / mis-matched UGA and fuel distribution
- Errors in control logic and non-optimal combustion control strategies
- Poor calibration of gas analyzers

Symptoms of Poor PB Operation

- High flyash flow rates and ash carbon content
- Clinkering of bottom ash
- Steaming rate on hog fuel limited
- High auxiliary fuel usage
- Fire hazard in flyash conveyors and bins due to burning ashes

Results from Recent Optimization Trials

- Reduced excess air: Boiler exit O_2 reduced to 4 - 5% from 10%, increasing the boiler thermal efficiency by about 2.5%
- Increased hog steaming rate: Steam from hog increased from 200,000 lb/h to 350,000 lb/h in tests on one boiler by correcting problems with air system control and by opening previously inoperable OFA dampers.
- Emissions (CO, dioxins, PAH) reduced by 60-80% in tests on one coastal hog fuel boiler by reducing excess air

Examples of Trial Results

- Hog steam increased from 99 to 110 t/h by
  - increasing the undergrate air flow
  - upgrading the HMZ over fire air system, and
  - installing a new NCG/methanol burner closer to the grate.
- Hog steam increased from 202 to 234 klb/h by
  - increasing the overfire air flow from 110 to 140 klb/h (OFA/UGA ratio from 0.7 to 0.95), and
  - balancing the rear and front OFA (Rear/Front OFA to 1.15 from 1.6)
- Hog steam increased from 25 to 32.5 t/h by
  - shifting from auto control to manual control
  - reducing gas firing to the minimum (4%), and
  - increasing the FD Fan outlet air pressure by 20%

Summary of Estimated Savings

Mill ID	Boiler ID	Trial Results				
		Date	Hog Steam Increase, t/h	Hog Steam Increase, %	CO_2 Savings, t/yr	Fuel Cost Savings, M$/yr
Mill A	Boiler A1	2003	22.7	25.0	373,162	**3.09**
	Boiler A2	2003	37.2	36.1	611,986	**5.06**
Mill B	Boiler B1	2004	9.7	35.8	159,598	**1.32**
	Boiler B2	2004	11.5	55.0	189,214	**1.57**
Mill C	Boiler C	2005	11	11.1	180,987	**2.16**
Mill D	Boiler D	2004	21.5	20.5	353,747	**2.93**
Mill E	Boiler E	2004	14.5	15.8	238,824	**1.98**
Mill F	Boiler F	2004	21.7	31.2	357,489	**2.96**
Mill G	Boiler G	2004	11.7	30.7	192,504	**1.59**
Mill H	Boiler H	2005	13.7	16.7	226,136	**2.09**

Paprican's Boiler Optimization Business

- Intend to license patented approach to an existing boiler manufacturer or service company with a strong network of service engineers
- What companies do Brasilian mills use?
- What company gives Brasilian boilers the best service? To whom should we be talking?

Recovery Area Expertise at Paprican

- Scaling - evaporators, recaust and digester
- Evaporator capacity / de-bottlenecking
- Recaust and kiln control and de-bottlenecking
- Corrosion - evaps, recaust and BL piping
- Recovery and Power Boiler Corrosion :
  - superheater and near drum corrosion
  - floor tube cracking
  - primary air port cracking
  - carbon steel / composite cut line corrosion
- Tall oil soap recovery and acidulation

Current Research Activities

- On-line characterization and control of black liquor properties
- Air and fuel delivery systems optimization in power boilers
- Optimization of black liquor delivery and reduction efficiency in larger recovery boilers (> 4 guns)
- Methods to reduce concentrator scaling
- Sensors for kappa number, washing efficiency, lime availability / reactivity, wood and hog moisture content, wood species and decay