Using Bleaching Stage Models for Benchmarking Hardwood ECF Bleach Plants

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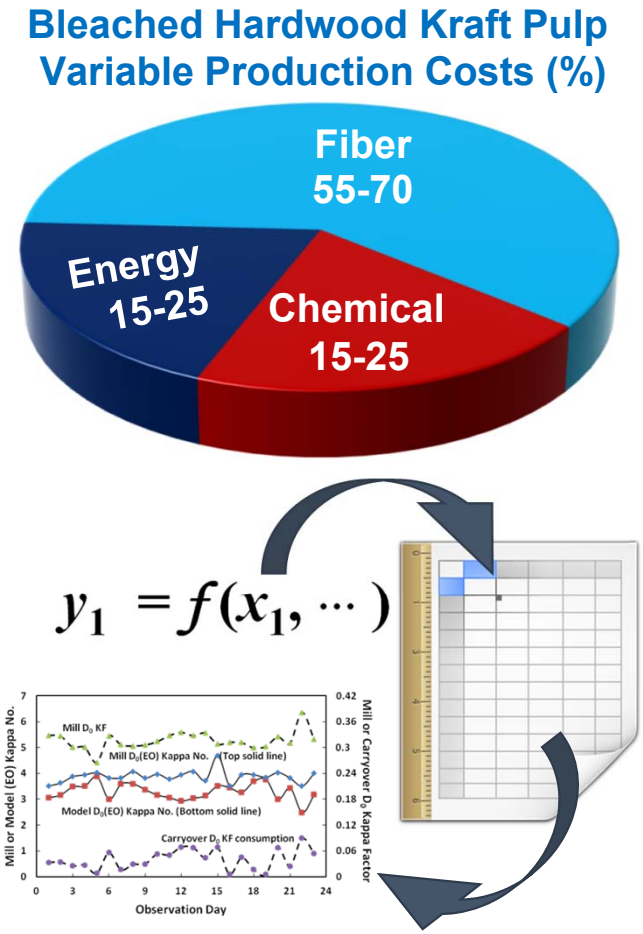
Introduction

- Tools needed to benchmark & quantify bleach plant inefficiencies
  - Portion variable cost due to chemicals consumed
  - Roughly two-thirds of chemical costs is ClO_2 usage
- Common issues identified
  - Brownstock carryover consuming ClO_2 in D_0 stage
  - Extraction carryover consuming ClO_2 in D_1 stage
- Can hardwood bleaching models be used to benchmark & quantify ECF inefficiencies like with softwoods?



Hardwood Delignification Model

- D_0(EO) or D_0(EOP) model:

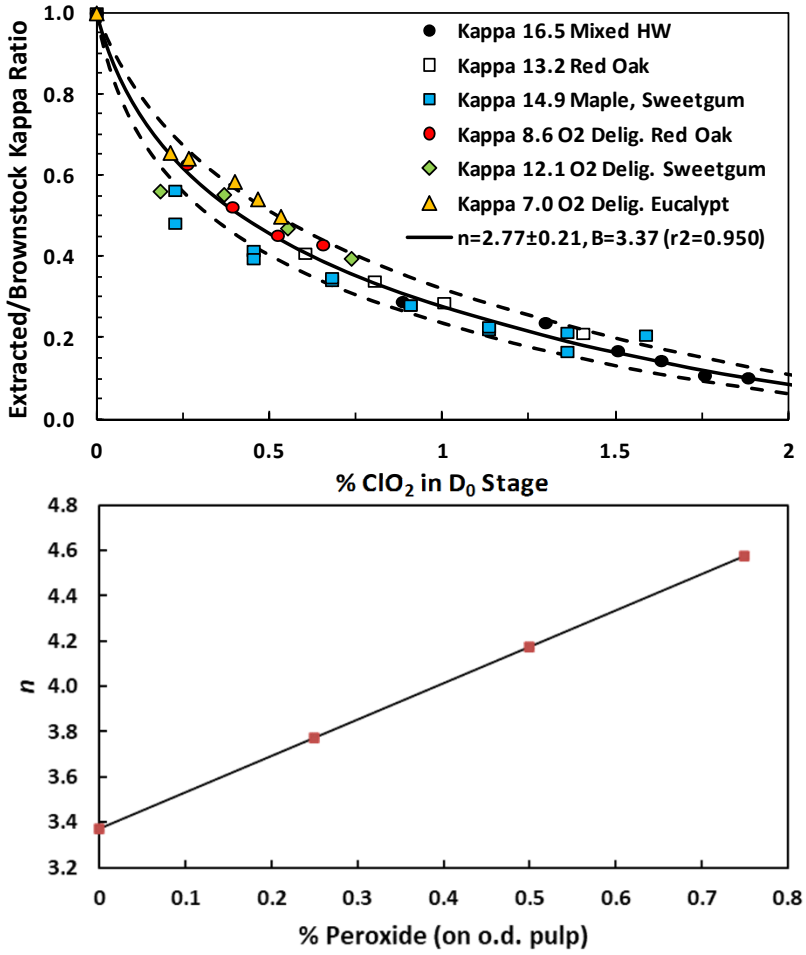
$$\frac{Extracted\ \ Kappa}{Brownstock\ \ Kappa} = 1 - \frac{1}{n} \ln\left(\frac{[ClO_2] + 2.77 \cdot e^{-n}}{2.77 \cdot e^{-n}}\right)$$

  - Chlorine dioxide in D_0, $[ClO_2]$ (% on o.d. pulp)

- Tuning parameter, *n*:

$$n = 1.61 \cdot P + 3.37$$

  - Peroxide reinforcement in (EOP), *P* (% on o.d. pulp); *P* = 0% for (EO) stage
  - *P* was 0.33% to 0.52% on o.d. pulp for the two southern US mills examined



Hardwood D_1 Brightening Model

- D_1 brightening model (US mixed HWs)

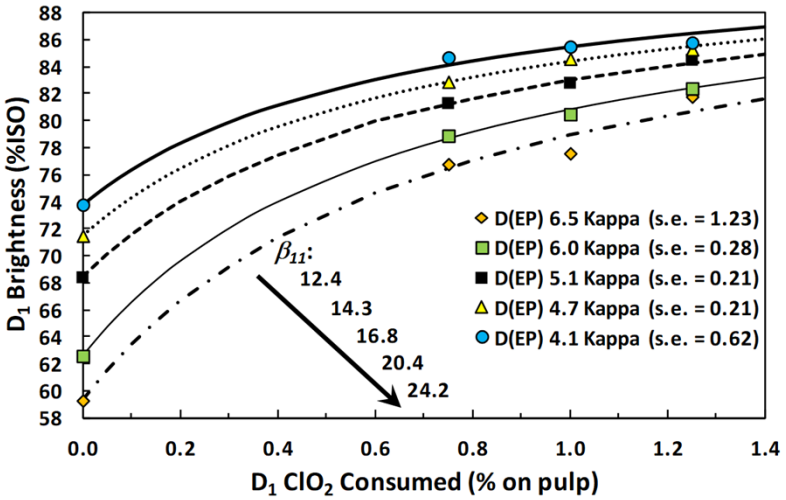
$$D_1\ Brightness = c_{01} - \frac{\beta_{11}}{\frac{\beta_{11}}{c_{01} - B_E} + [ClO_2]}$$

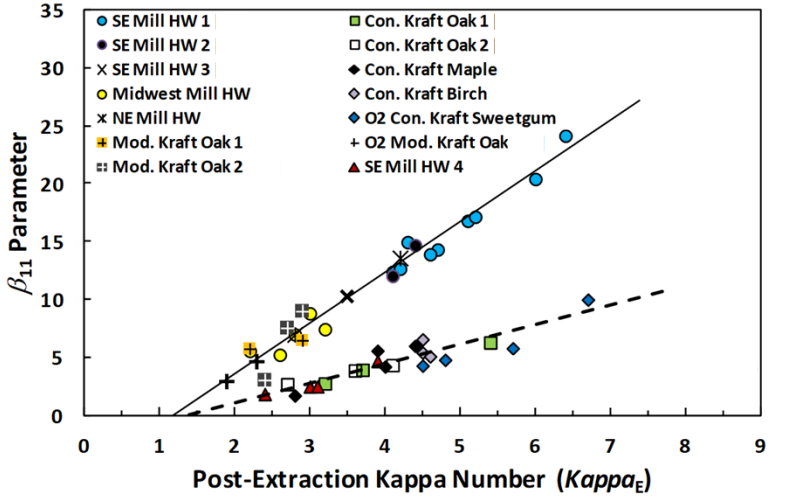
  - Chlorine dioxide in D_1, $[ClO_2]$ (% on o.d. pulp)
  - Extracted brightness, B_E (% ISO)
  - Brightness limit, c_{01} (% ISO);
    93.4% ISO Mill 1 or 92.5% ISO Mill 2

- Tuning parameter β_{11}:

$$\beta_{11} = a(Extracted\ \ kappa) - b$$

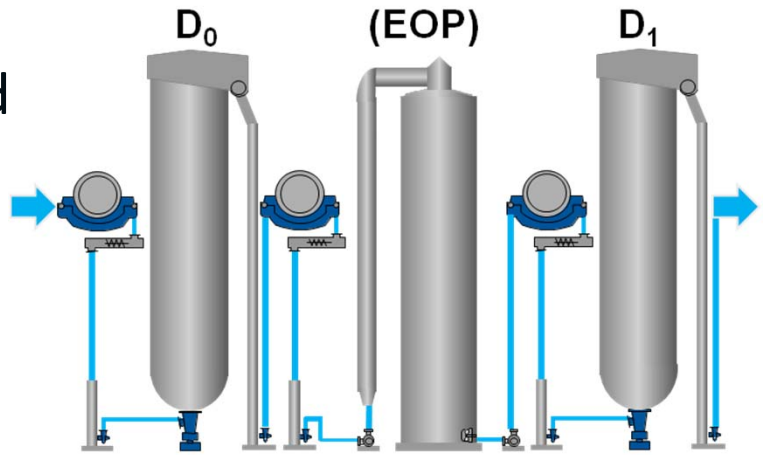
  - Mill 1: a = 4.36 and b = 4.84
  - Mill 2: a = 1.68 and b = 1.96





Objectives

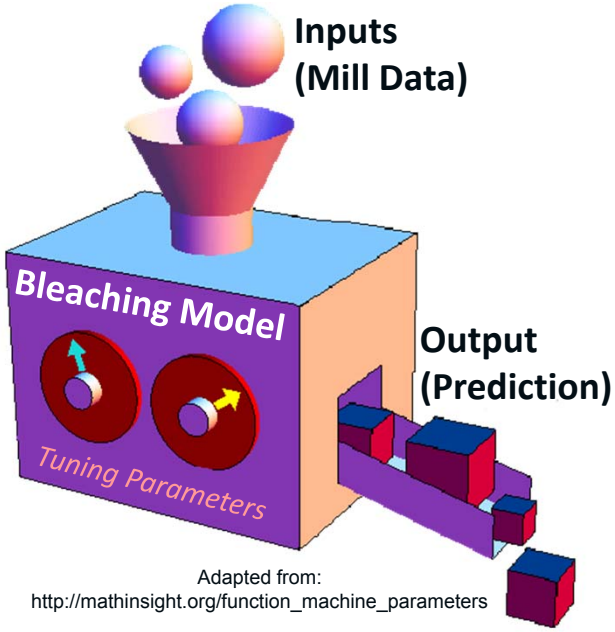
- Survey daily average data from two southern US kraft mills bleaching 11 to 16 kappa mixed hardwood brownstocks:
  - Mill 1 – D_0(EOP)D_1 full sequence (D_1 brightness ≈ 84% ISO)
  - Mill 2 – D_0(EOP)D_1 partial sequence (D_1 brightness ≈ 86% ISO)
- Use bleaching models:
  - Chlorine dioxide consumed by brownstock carryover
  - Chlorine dioxide consumed by extraction carryover




Source: Doug Pryke, *2015 TAPPI BPOW* (Atlanta, GA)

Models to Estimate Washer Carryover

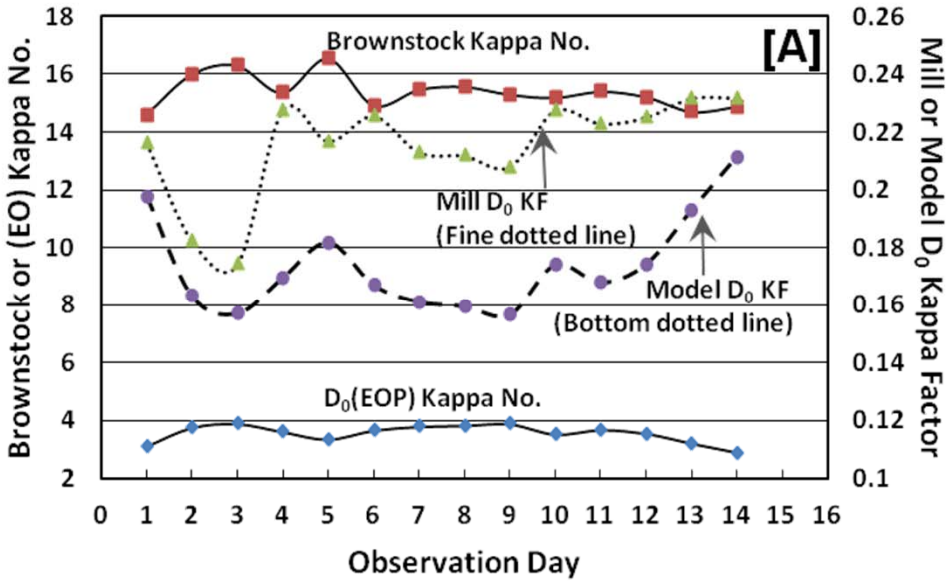
Bleaching Model	Inputs (Mill Data)	Output (Prediction)
D_0(EOP) [Delignification]	ClO_2, Brownstock Kappa	Extracted Kappa
	Brownstock Kappa, Extracted Kappa	ClO_2
	ClO_2, Extracted Kappa	Brownstock Kappa
D_1 [Brightening]	ClO_2, Extracted Kappa	D_1 Brightness
	Extracted Kappa, D_1 Brightness	ClO_2
	ClO_2, D_1 Brightness	Extracted Kappa

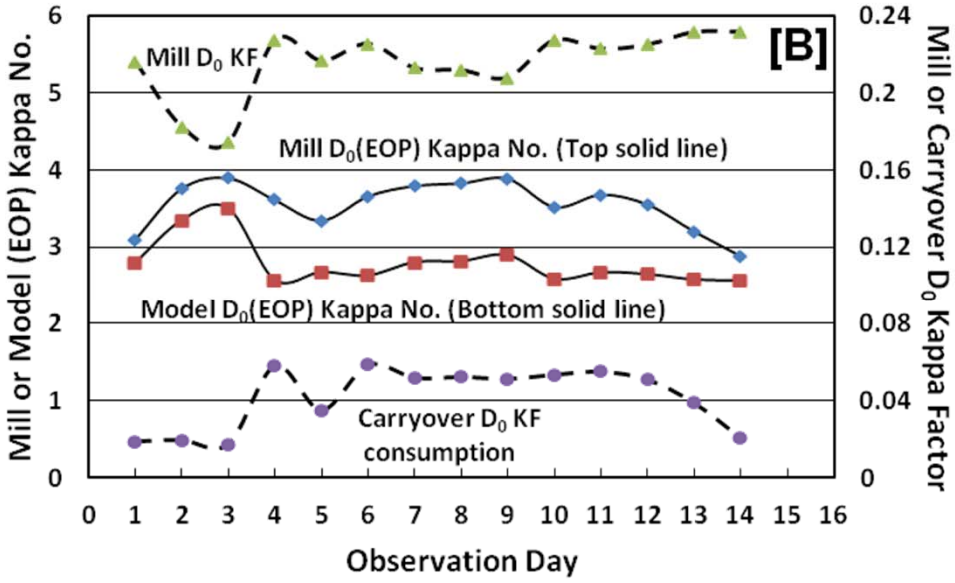


Adapted from:
http://mathinsight.org/function_machine_parameters

- Delignification & brightening models
  - Outputs for given inputs
  - Computed compared to mill's values
  - Differences used to approximate washer carryover

Mill 1: D_0(EOP) Delignification Analysis

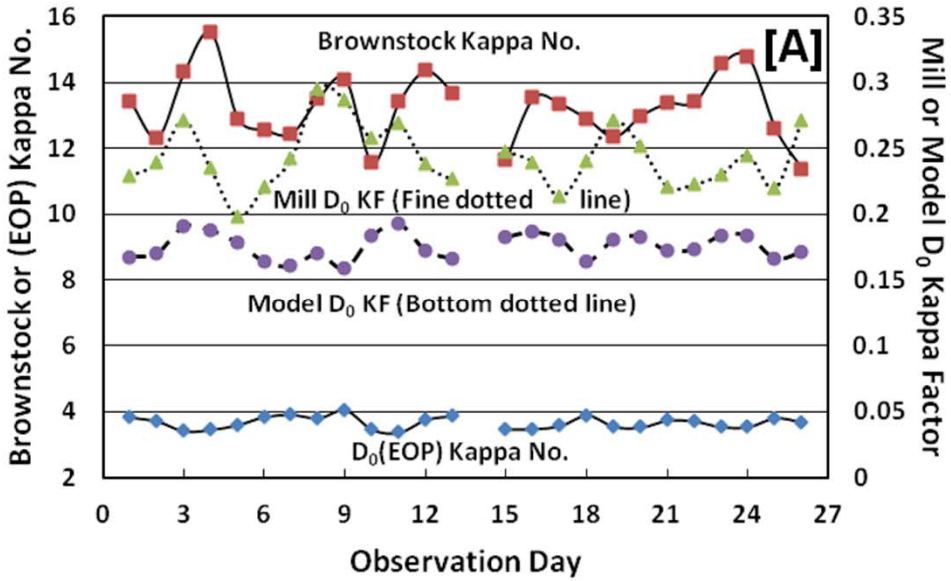


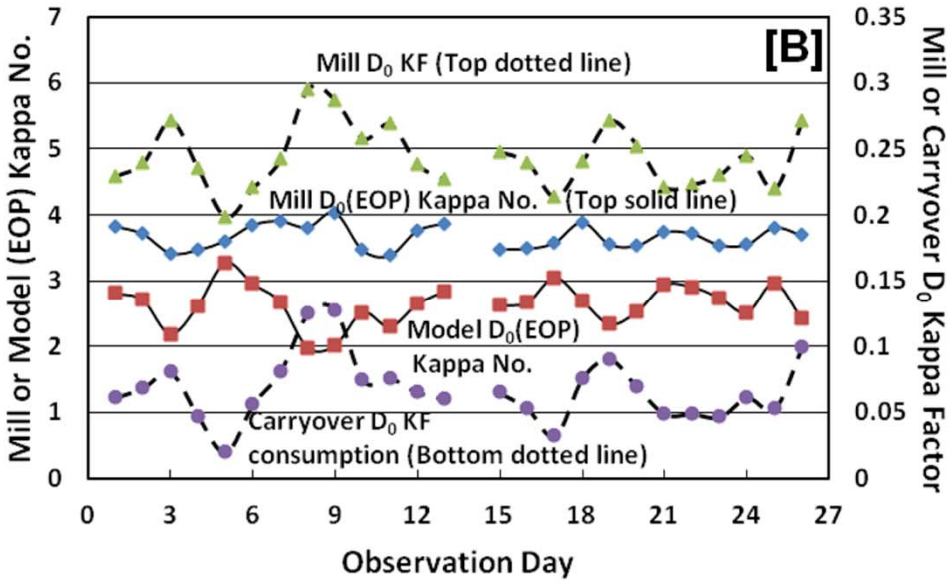


- BS kappa 14.6 – 16.5 during trial; $\bar{x}$ = 15.4
- Mill's kappa factor (KF) ~0.215
- Model under-predicted KF by ~0.04 units to reach mill's D_0(EOP) kappa
- Model under-predicted D_0(EOP) kappa by ~0.8 units at mill's KF dosage

- Estimated BS washer carryover consumed 2.4 kg ClO_2/o.d. t (~8 kg saltcake/t)
- Good BS washing days 1 – 3, 14
- High carryover days 4, 6 – 12 consumed extra 0.05 KF units (3.1 kg ClO_2/o.d. t)

Mill 2: D_0(EOP) Delignification Analysis



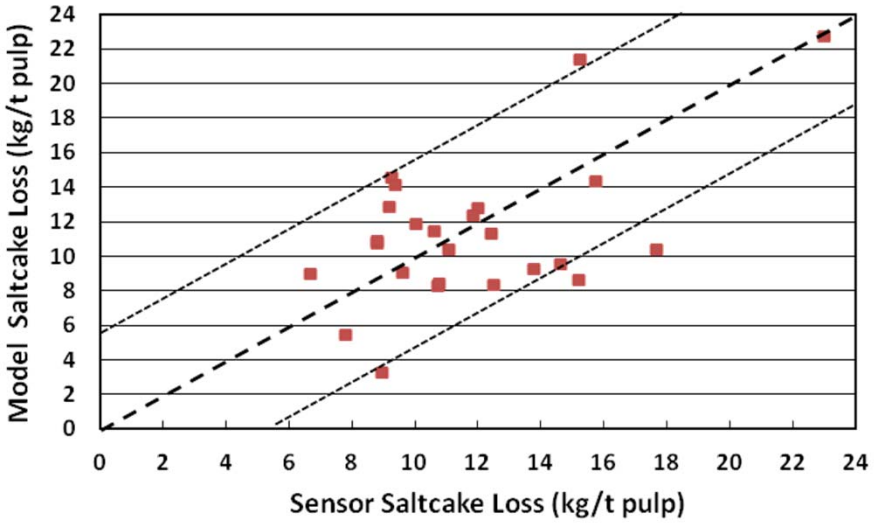


- BS kappa 11.4 – 15.5 during trial; $\bar{x}$ = 13.2
- Mill's kappa factor (KF) 0.200 to 0.290
- Model under-predicted KF by ~0.07 units to reach mill's D_0(EOP) kappa
- Model under-predicted D_0(EOP) kappa by ~1.1 units at mill's KF dosage

- Estimated BS washer carryover consumed 3.3 kg ClO_2/o.d. t (~11 kg saltcake/t)
- Good BS washing days 5 and 17
- Very high carryover days 8, 9 and 26 consumed extra 0.100 to 0.126 KF units (4.3 to 6.8 kg ClO_2/o.d. t)

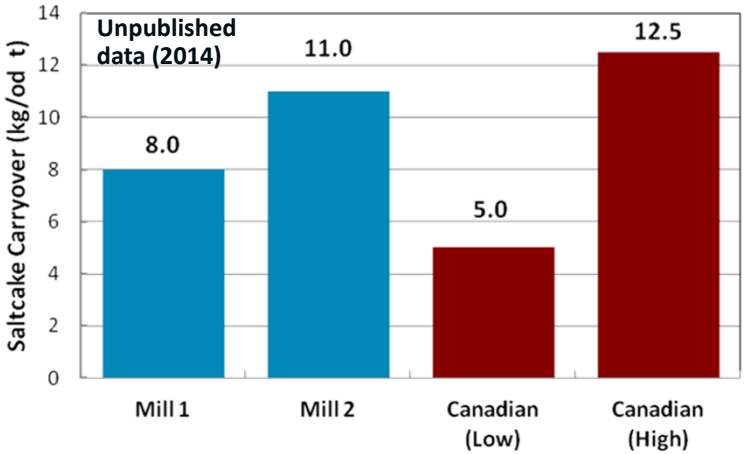
Mill 2: Brownstock Washing Comparison

- Daily brownstock washing monitored at Mill 2 with sensor data
- Sensor data indicate that washer loss were ~11.8 kg saltcake/t
- Model overall washer losses averaged 11 kg saltcake/t
- Sensor error was roughly ±5.7 kg saltcake/t (shown); model error was ±2.3 kg saltcake/t
- Both analyses show that carryover was contributing to D_0 bleach losses



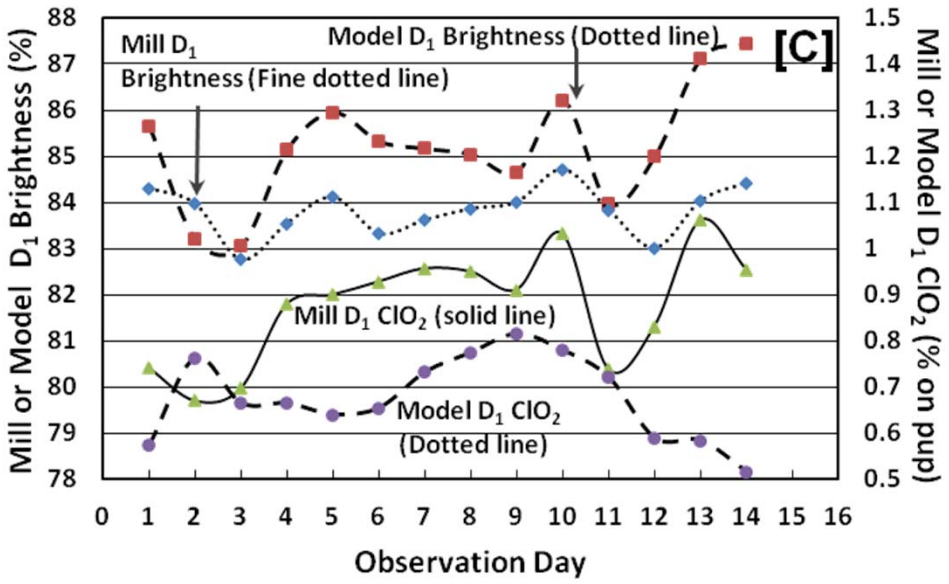
Summary: Hardwood D_0(EOP) Delignification Analyses

- Bleaching delignification
  - Approximate 8 to 11 kg saltcake/t carryover (12.1 to 16.7 kg COD/t)
  - Carryover consumed ~0.05 to 0.07 KF charge (3.1 to 6.8 kg chlorine ClO_2/o.d. t)
  - Comparable to Canadian hardwood brownstock bleach plants (unpublished data 2014)
- Mill 2 washer carryover calculated by D_0(EOP) delignification model; results similar to sensor measurement (~11.8 kg saltcake/t)



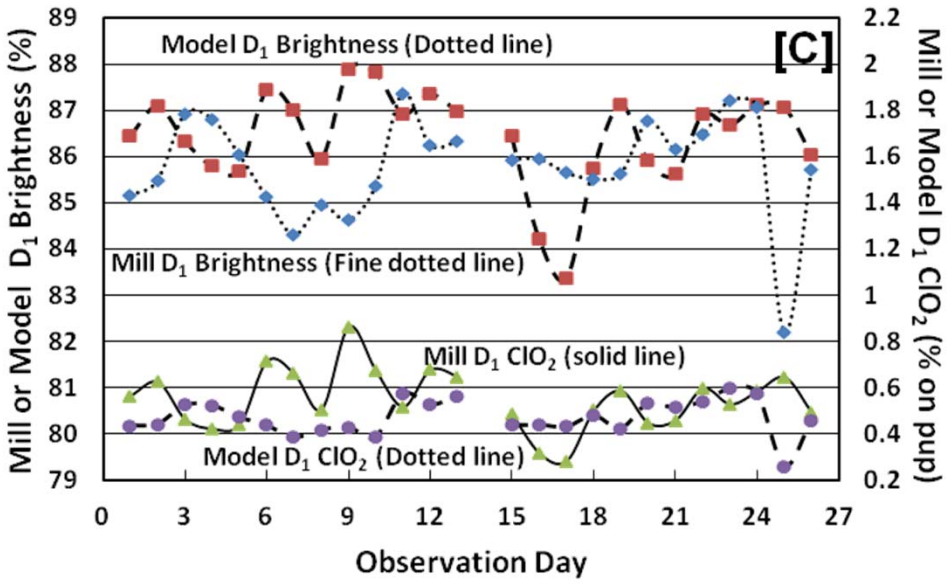
Mill 1: D_1 Brightening Analysis

- Mill D_0(EOP) kappa no. ran 2.9 to 3.9
- Mill D_1 brightness ~84% ISO
- Model brightness ~83% to 87% ISO
- Predictions target off
  - Days 4 to 7, 10, and 12 to 14
  - Brightness down by 1 to 3 points
- Carryover consumed between 2.5 and 4.8 kg ClO_2/o.d. t pulp (beyond model error)
- Estimated carryover was ~0.80 kappa units higher than measured (~5.9 kg COD/t pulp)



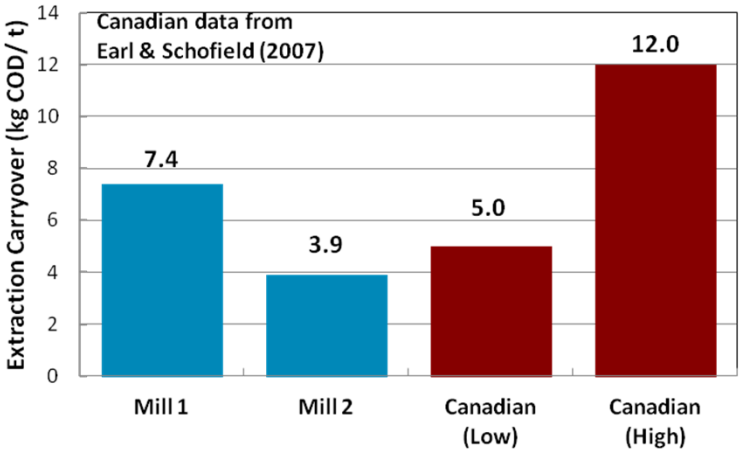
Mill 2: D_1 Brightening Analysis

- Mill D_0(EOP) kappa no. ran 3.4 to 4.0
- Mill D_1 brightness 85% to 87% ISO
- Model fluctuated 85.5% to 87.9% ISO
- Predictions close to measured values on majority of days
  - First -half trial: Model > Measured by ~1.1 points
  - Second-half trial: Model ≈ Measured
- Carryover consumed between 0 and 1.3 kg ClO_2/o.d. t
- Estimated carryover averaged 0.35 kappa units higher (or 3.9 kg COD/t)



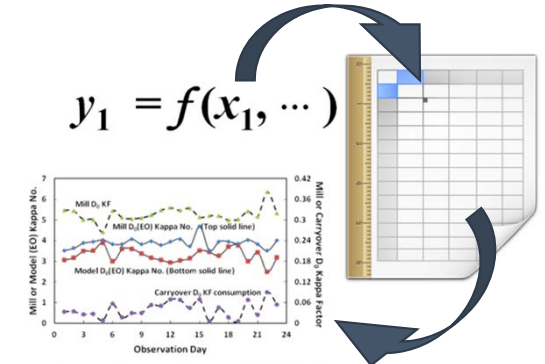
Summary: Hardwood D_1 Brightening Analyses

- Mill 2 had better (EOP) stage washing than Mill 1 according to brightness model
- Moderate to adequate (EOP) washing with the southern US Mills during trial
- Canadian hardwood extraction washers range from 5 to 12 kg COD/t (2007); southern US Mills are within lower range



Overall Conclusions

- Hardwood delignification & brightening models
  - Analyze daily mill data
  - Approximate brownstock & extraction washer carryover levels in bleach plant
- Models could be used
  - Identify days of poor pulp washing (*e.g.*, screen plugging/scaling, weak washer vacuum pressure, *etc.*)
  - Determine how well defoamers/drainage aids affect washer performance at bleach plant
  - Determine how recycled shower water sources affect ClO_2 consumption



Questions?

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