

5th International Colloquium on Eucalyptus Pulp

Porto Seguro, May 2011.

Eucalyptus Chip Compaction Disturbance Analysis in a Vapor Phase Continuous Digester

Flávio M. Correia, CENIBRA, Brazil

flavio.correia@cenibra.com.br

Jorge L. Colodette ;UFV, Brazil

Adair J. Regazzi ;UFV, Brazil

José L. Gomide ; UFV, Brazil



OUTLINE

- *Introduction*
- *Continuous digester considerations*
- *Methods*
- *Results and Conclusion*

Some Opinions...

Due to continuously increasing production rates also the amount of the fault situations in the digesters has increased as well. The economical losses for the pulp mill might be significant if the fault situations are not observed and pulp production output has to be limited. In order to normalize process operation properly after a process fault the identification of fault is extremely important. One of the major disturbances in the digester is abnormal compaction and the disturbances in the chip column movement.

Observation and Visualization of the Chip Compaction Disturbances in Digester

H-M. Puolakka, M. Tervaskanto & T. Ahvenlampi
University of Oulu,
Department of the Process and Environmental Engineering,
Systems Engineering Laboratory
P.O Box 4300
FIN-90014 UNIVERSITY OF OULU
FINLAND

Factors affecting Kraft Pulping...

- Temperature
- Chemicals
- Wood Quality
- Residence Time

Residence Time

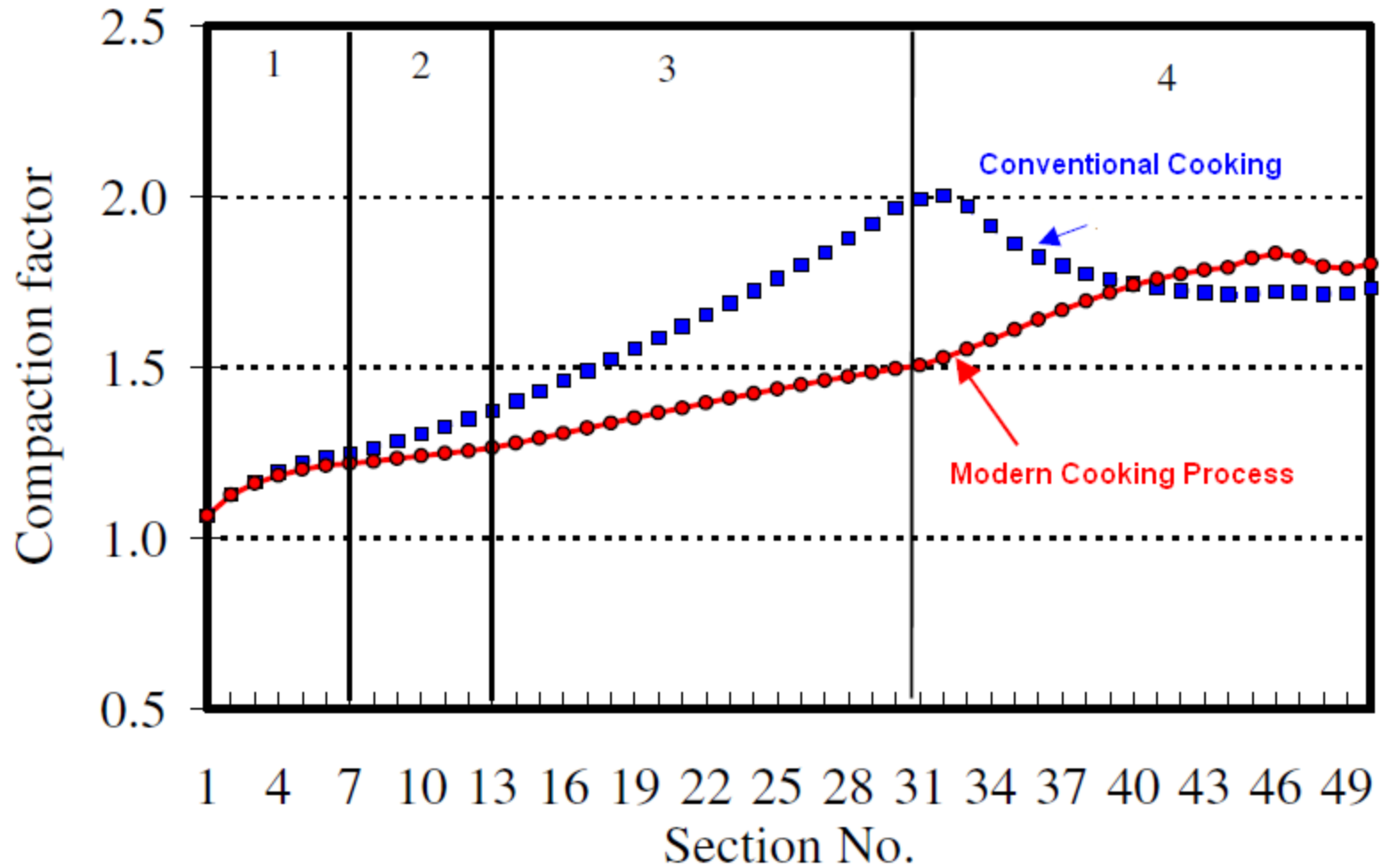
- Usually :
 - Calculated as function of production rate, digester volum and a **constant compaction factor**.
- But ...
 - Compaction factor depends of several variables...

What is "compaction"?

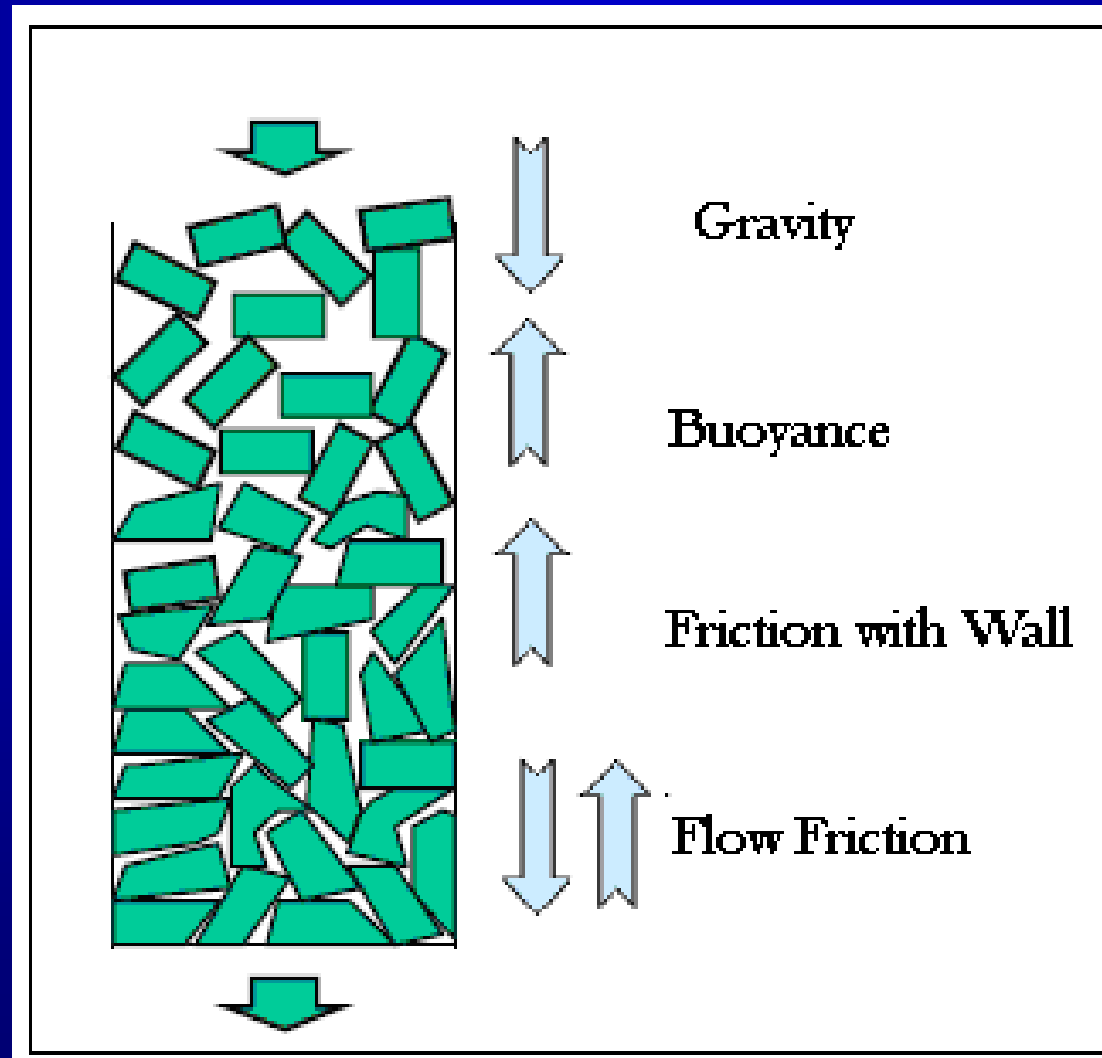
Chip Compaction

$$C = \frac{\text{Wood dry weight inside of digester}}{\text{Wood dry weight in feed of digester}}$$

Simulation profile of chip compaction.



Forces affecting Chip Compaction



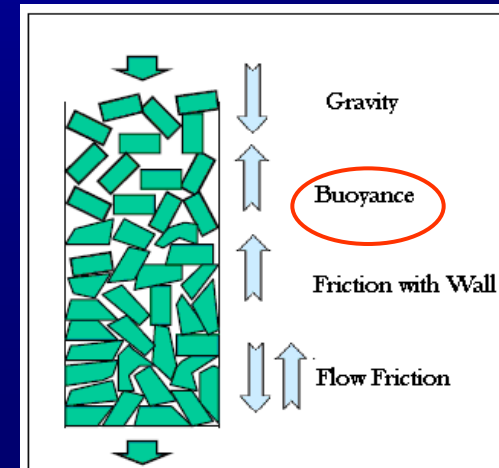
Factors affecting chip compaction disturbances

- **Chip Size**

Chip size - Thickness

- Industrial chips: Typical thickness 4-8 mm
- **Diffusion spread of liquor along the length is $\sim 3-5$ times higher than in the thickness direction** (AGARWAL e GUSTAFSON, 1993).

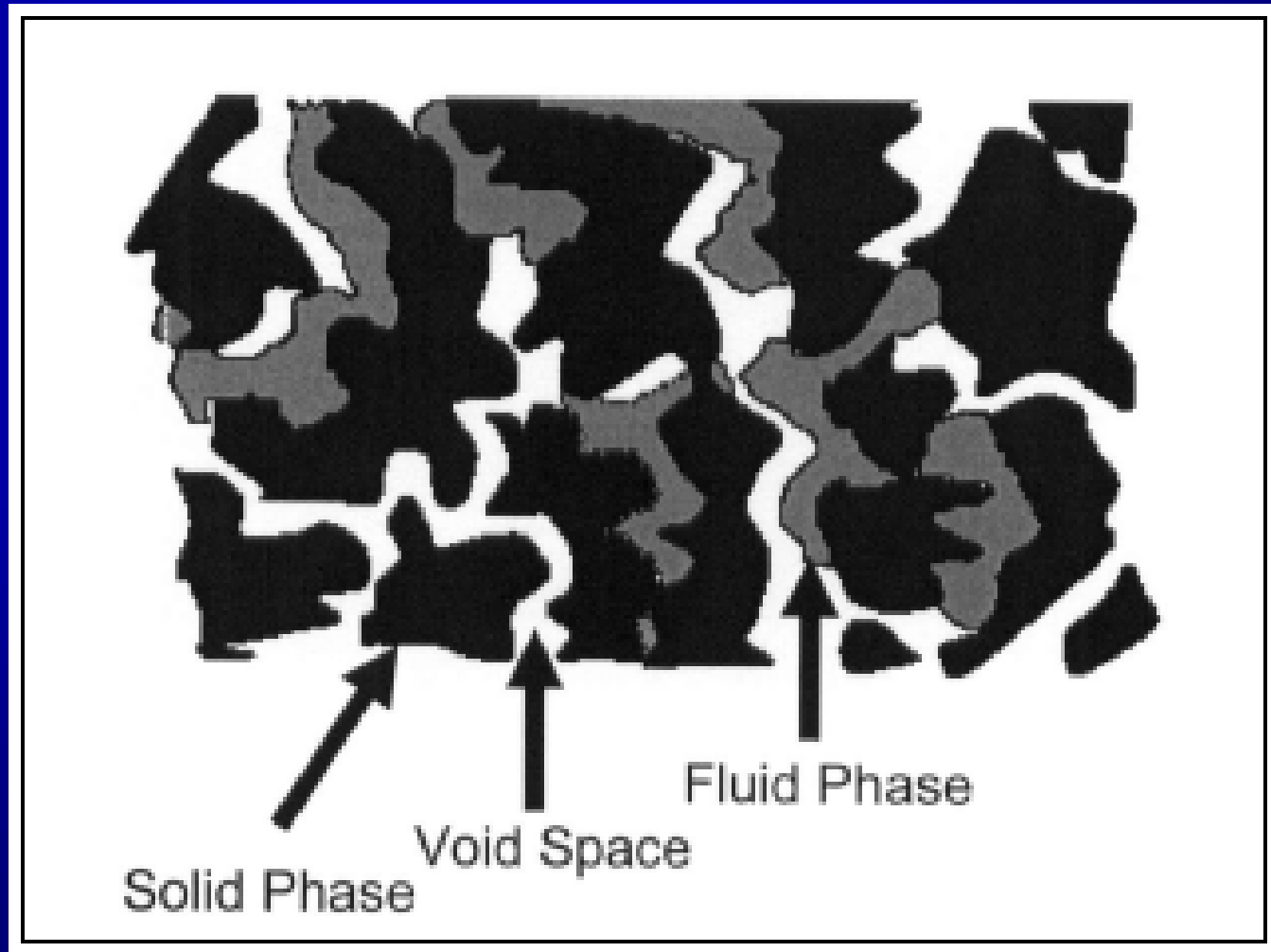
↓ Thickness ; ↑ Impregnation ➡ ↓ Buoyance



Factors affecting chip compaction disturbances

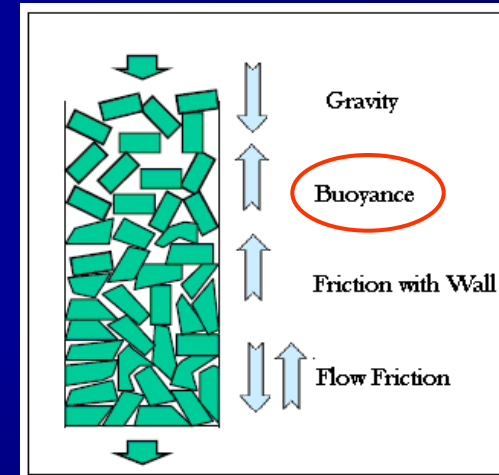
- **Chip Size**
- **Chip Density**

Chip Density



(LEE, 2006).

Vaporization



↓ **Density** ; ↑ **Impregnation / Diffusion** ➡ ↓ **Buoyance**

Factors affecting chip compaction disturbances

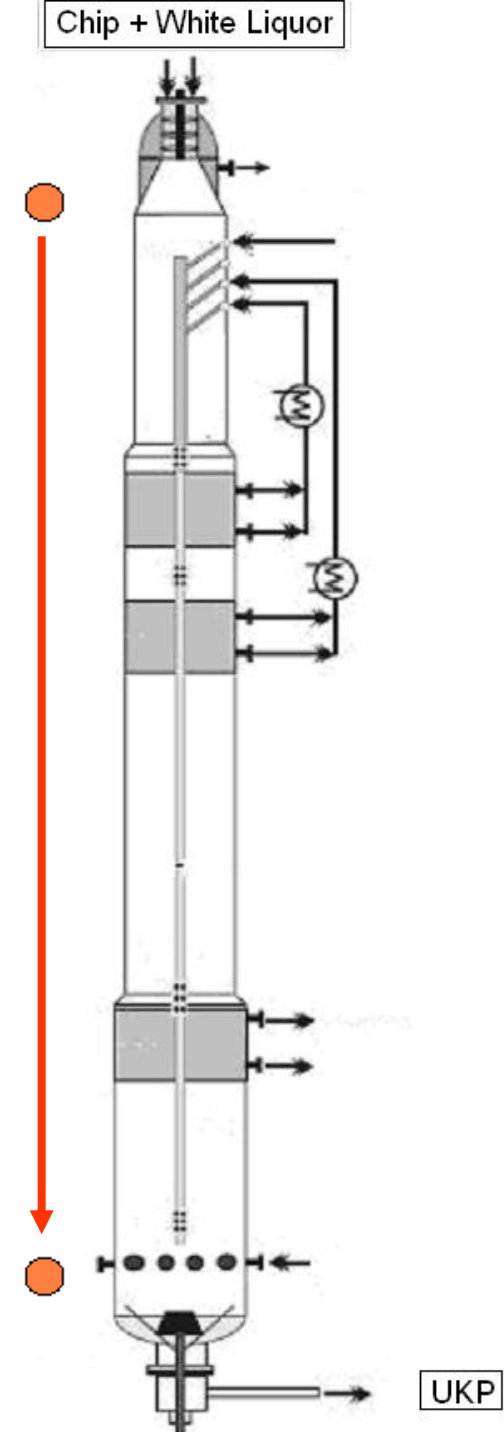
- **Chip Size**
- **Chip Density**
- **Chip Flow**

- Basic Questions ...

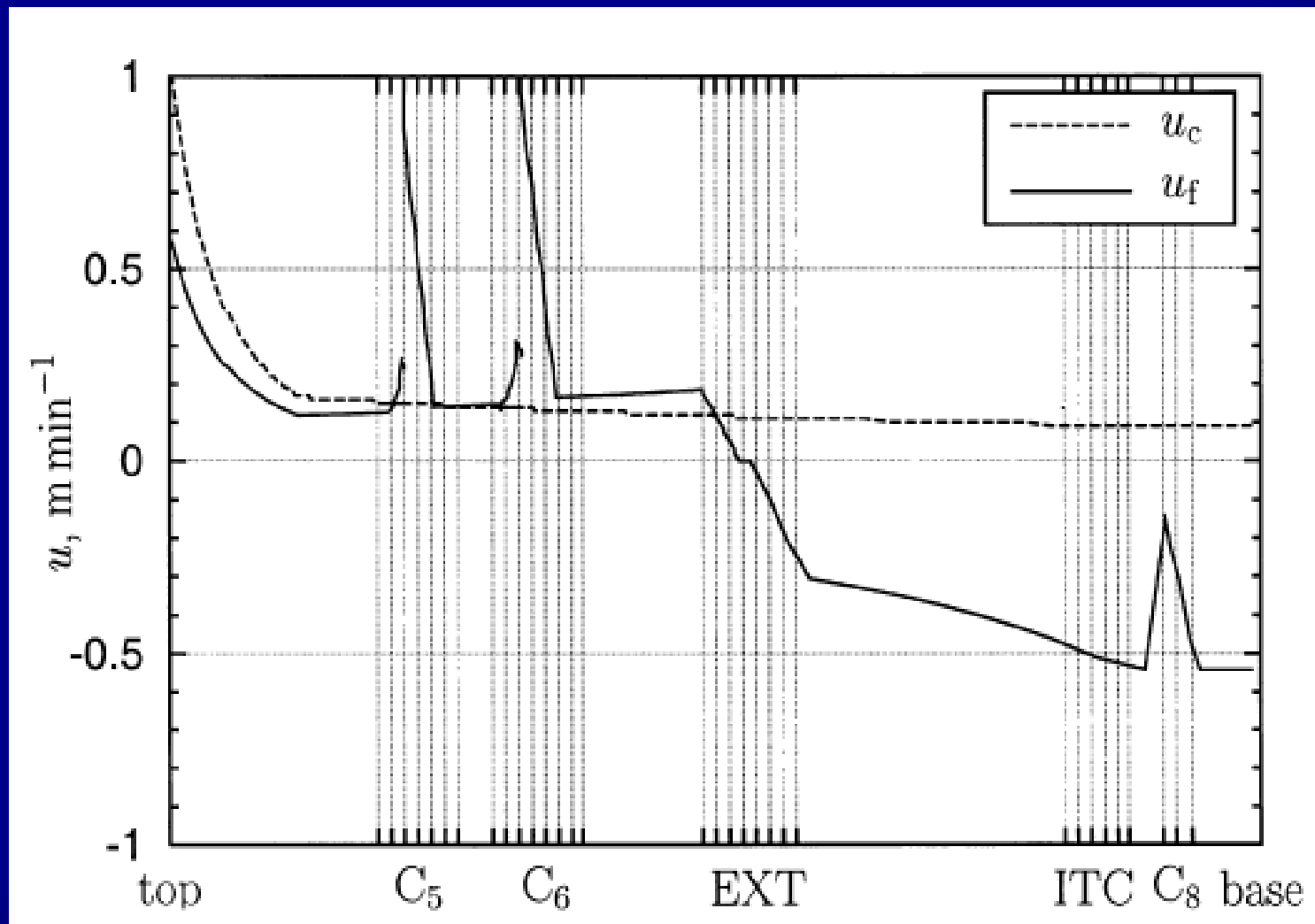
Considering :

Digester – 24h Normal Operation

Would chip have a constant velocity from top to the bottom digester?

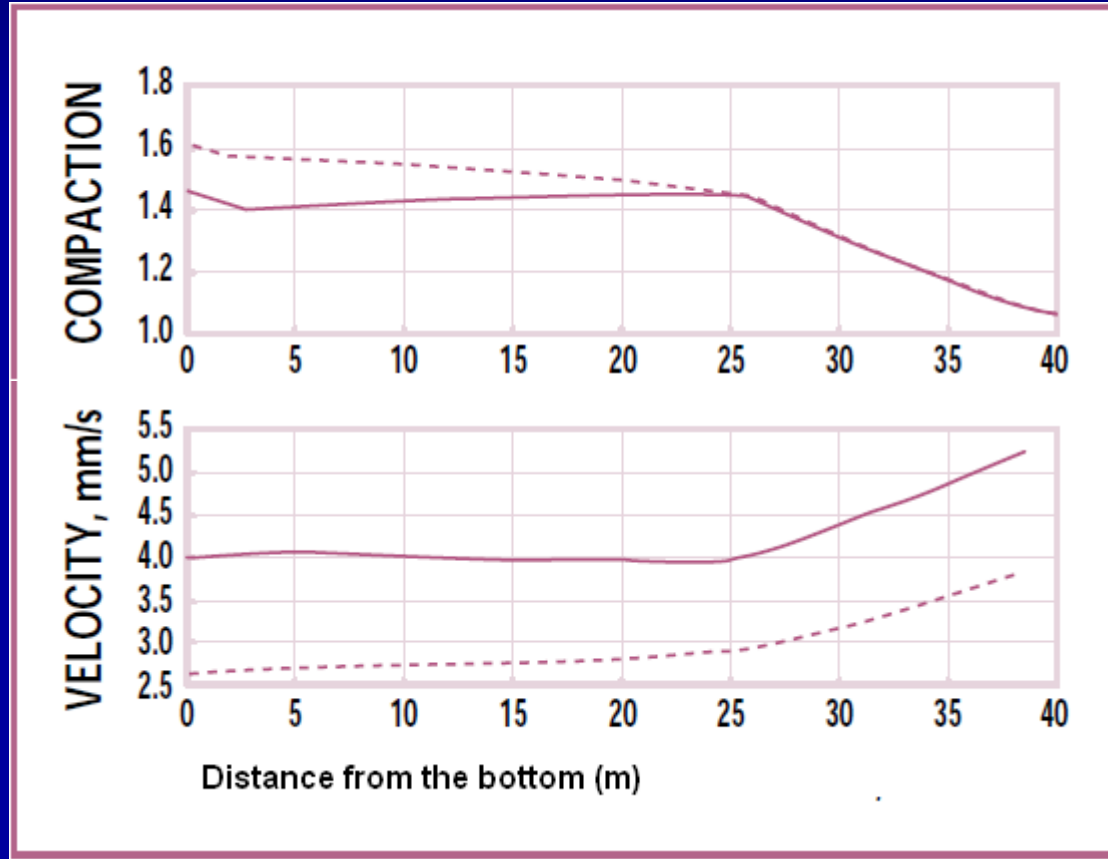


Superficial velocities of the chips and the free liquor



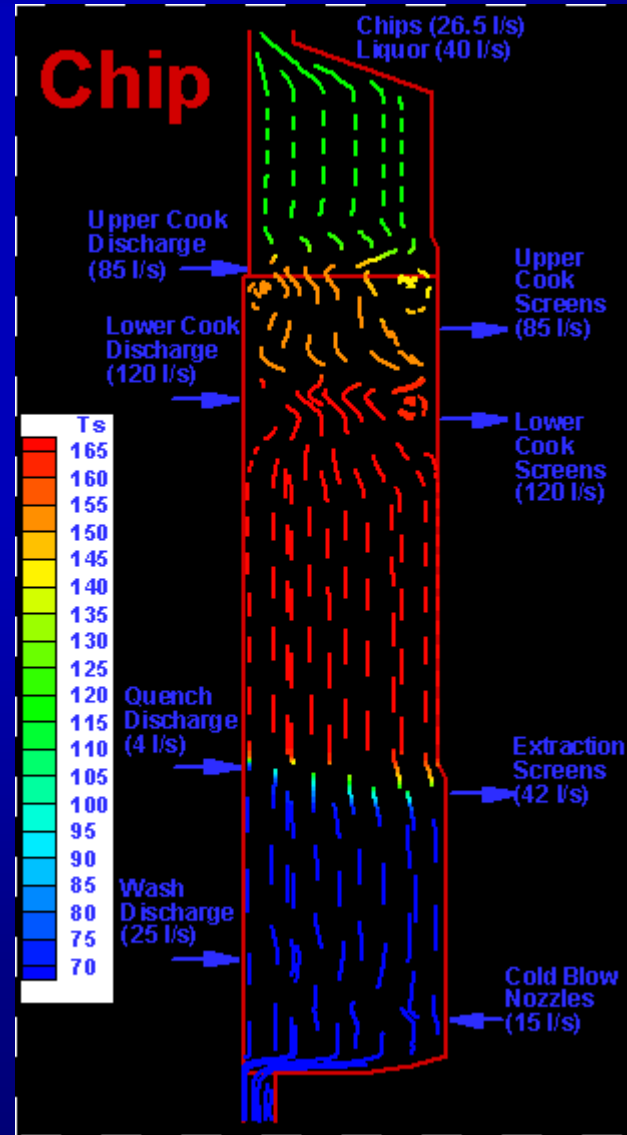
Fernandes and Castro (1999).

Chip Velocity and Compaction Digester Profile



(solid line) high production rates
(dashed line) low production rates

Chip Flow



Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio

Liquid / Wood Ratio

- * $L/W = 4,5$: chip and liquor moves with the same speed.
- * $L/W < 4,5$: chip speed $>$ liquor speed (*desired*)

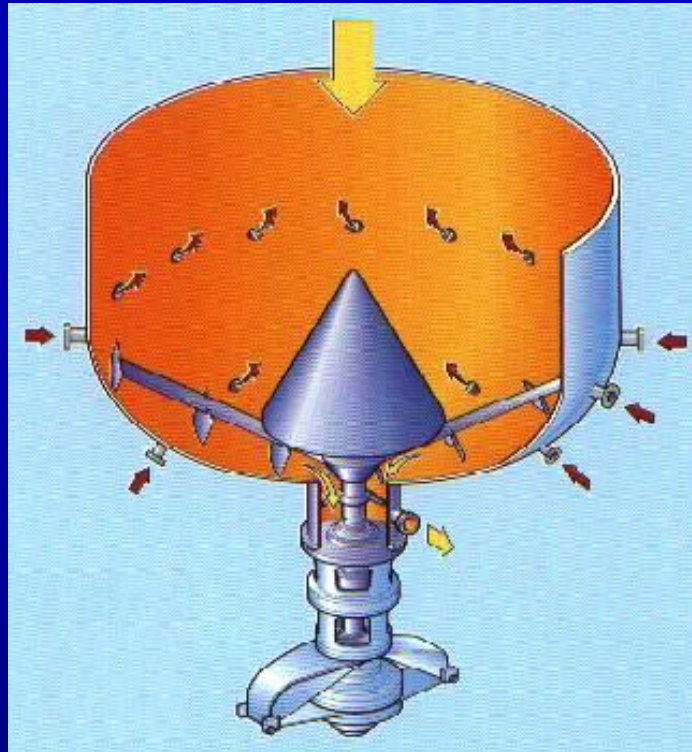
(Michelsen, 1995)

↓ **L/W ratio** ➡ **better chip colum movement**

Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio
- **Dilution Factor**

Dilution Factor



↓ Dilution Factor : ↓ counter-current flow ➡ better column movement

Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio
- Dilution Factor
- **Surface Forces**

Surface Forces

- Related to fluid viscosity and surface vessel wall(*pressure and friction*).

Occurring between the column of chips and the digester wall , and between chips and liquor.

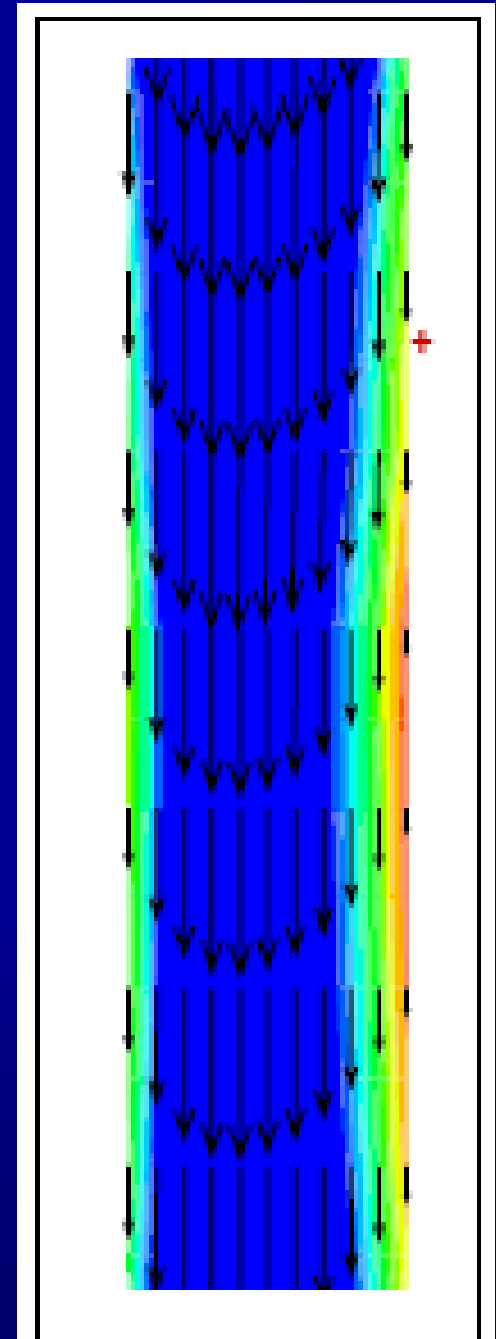
weld overlay repairing



Digester wall after weld overlay reparing



Chips Velocity Profile

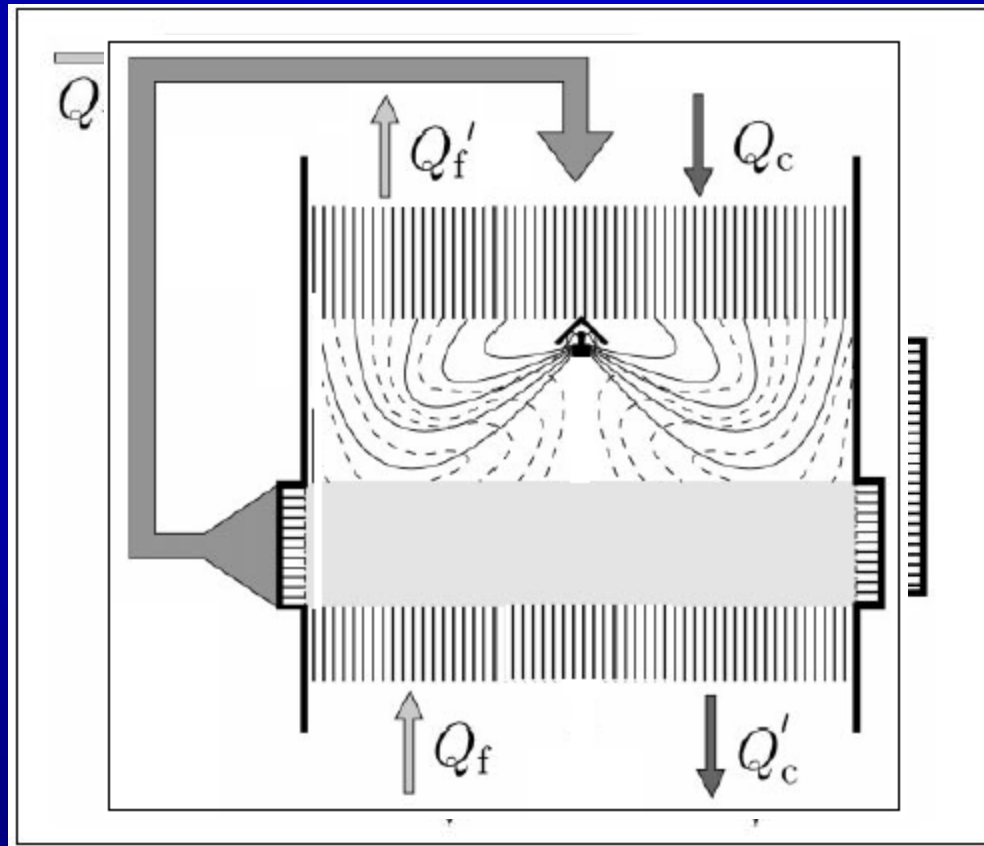


(HE *et al* 1999).

Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio
- Dilution Factor
- Surface Forces
- Liquor Flow

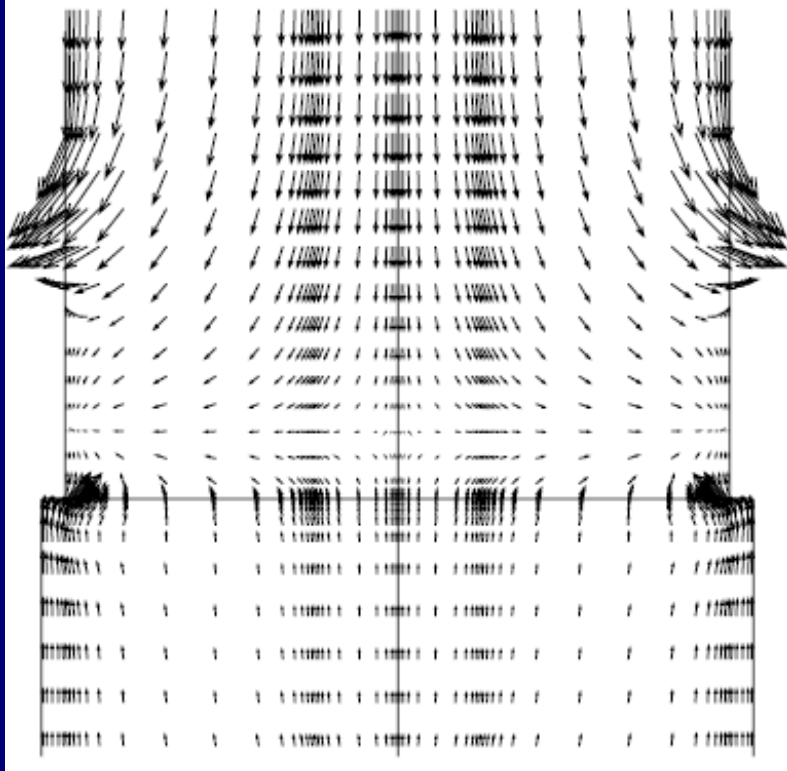
Liquor Flow



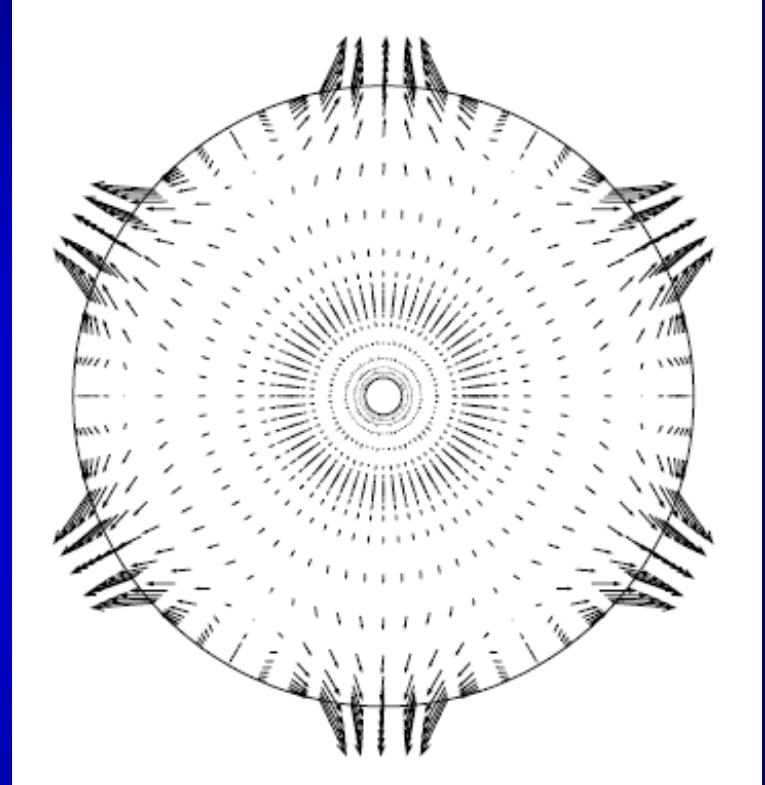
re-circulations of the concurrent zone.

re-circulation counter-current zone

Velocity vectors near the extraction area

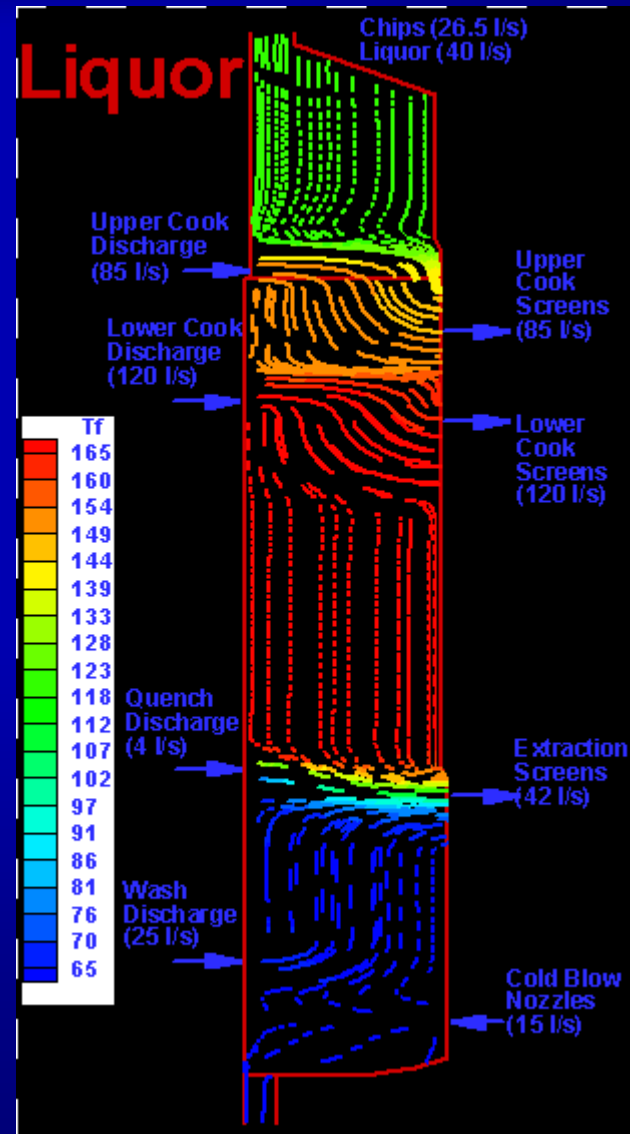


Velocity vectors for free liquid at the extraction screen area



Pougatch, K *et al* (2006)

Liquor Flow

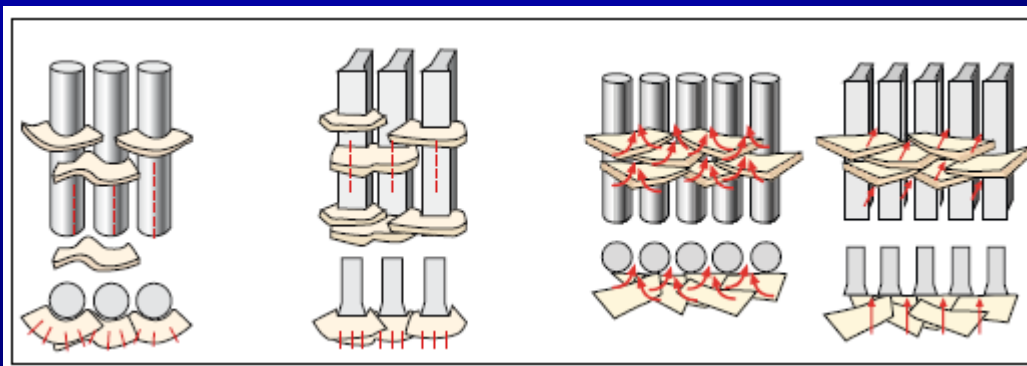
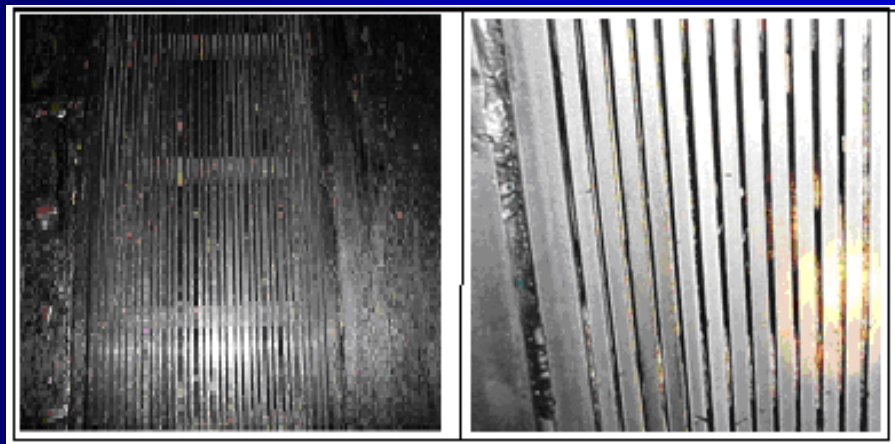


PSL - University of British Columbia
Canada

Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio
- Dilution Factor
- Surface Forces
- Liquor Flow
- Screens

Extraction Screens

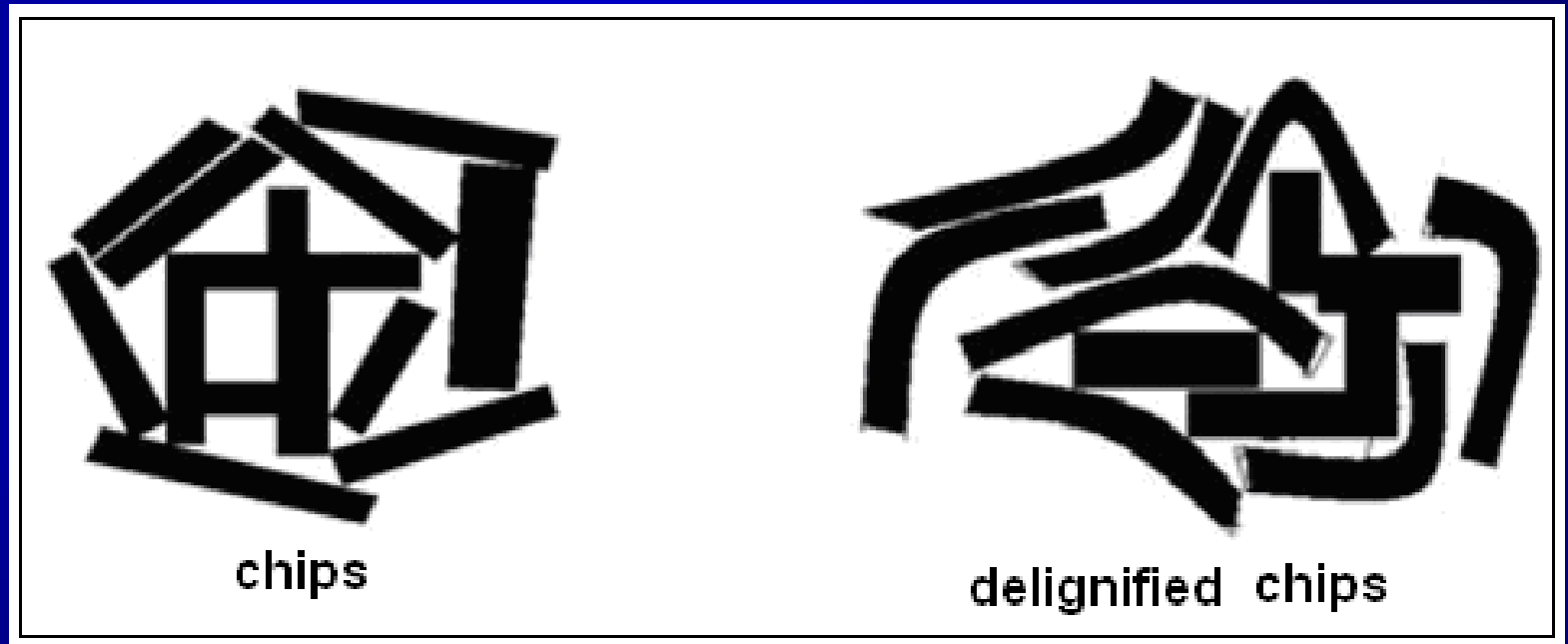


Lower friction design and higher open area...

Factors affecting chip compaction disturbances

- Chip Size
- Chip Density
- Chip Flow
- Liquid/Wood Ratio
- Dilution Factor
- Surface Forces
- Liquor Flow
- Screens
- **Delignification**

Delignification

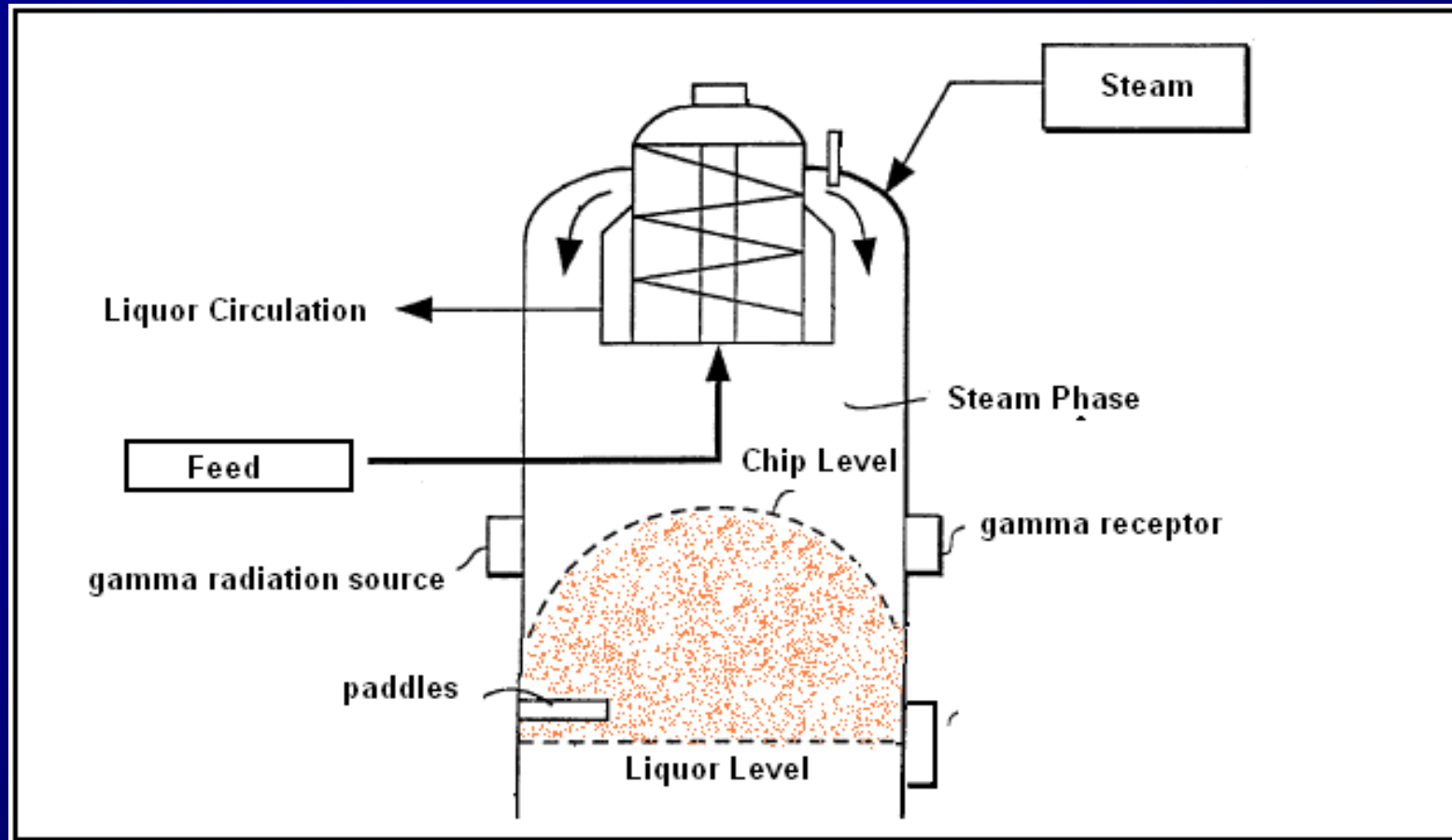


↑ Delignification : ↓ Porosity : ↑ Compaction

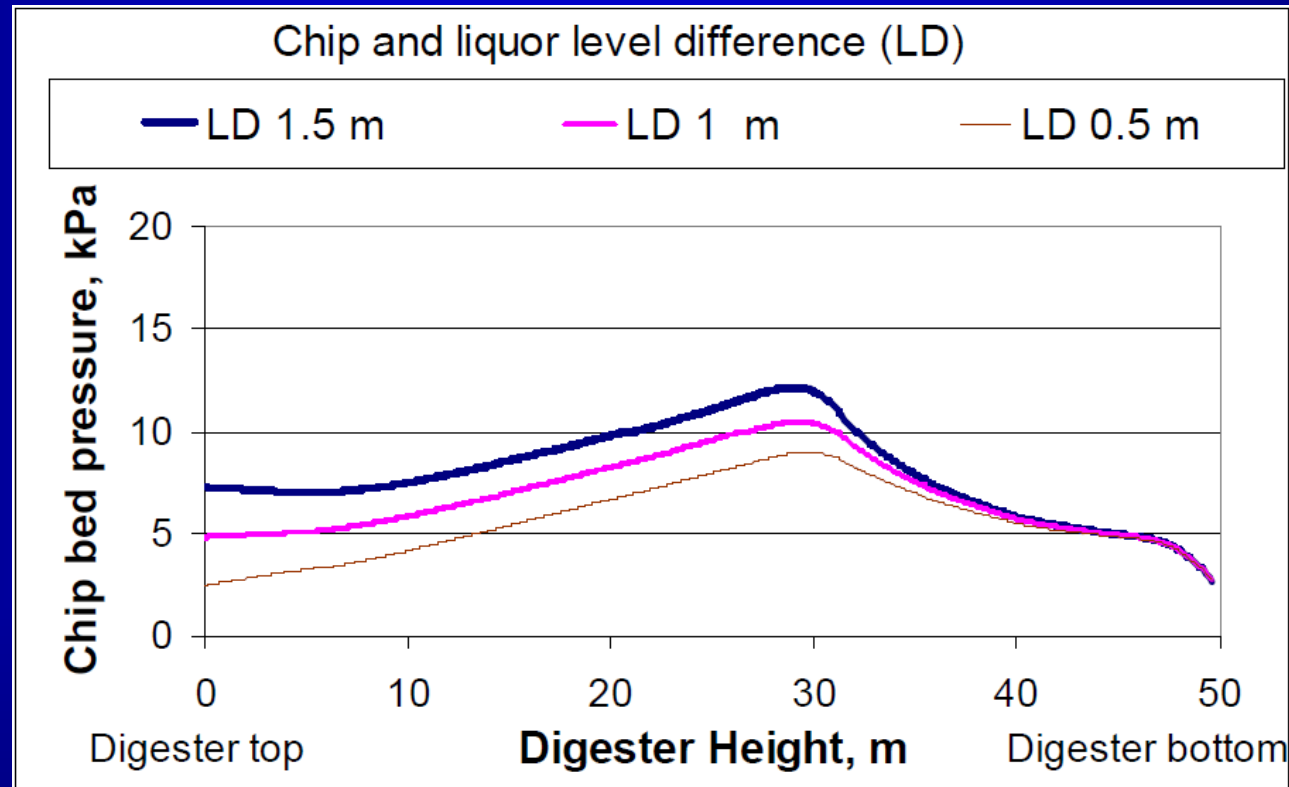
Factors affecting chip compaction disturbances

- **Chip Size**
- **Chip Density**
- **Chip Flow**
- **Liquid/Wood Ratio**
- **Dilution Factor**
- **Surface Forces**
- **Liquor Flow**
- **Screens**
- **Delignification**
- **Liquor and Chip Level**

Chip and liquor level difference



Chip and liquor level difference



Laakso, 2008

↑ chip and liquor level difference :

↑ force pushing chip bed downwards

Chip Compaction Disturbances

It is an international problem ...



: *Hanging*



: *Hangingo*



: *Cavacada*



: *Prisão de Coluna*

Normal running digester ...



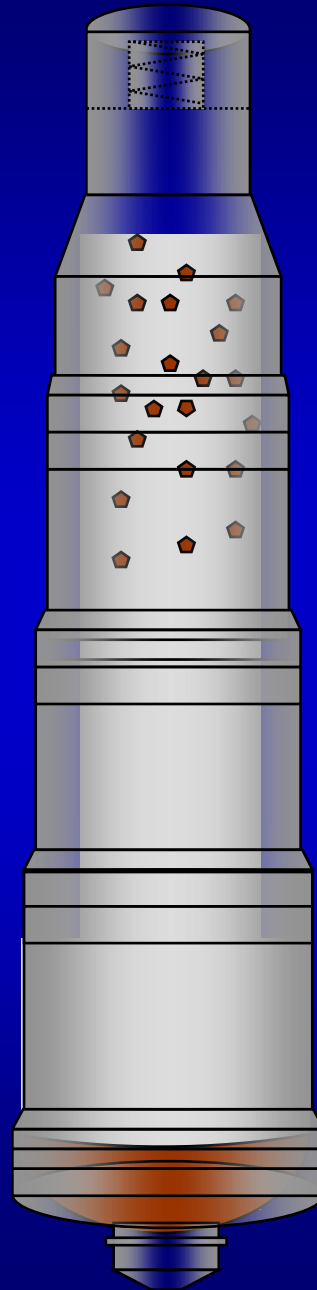
Continuous digester

- Continuous Feeding



Continuous Discharge

Normal running
digester ...



25/01/05 00:49:06

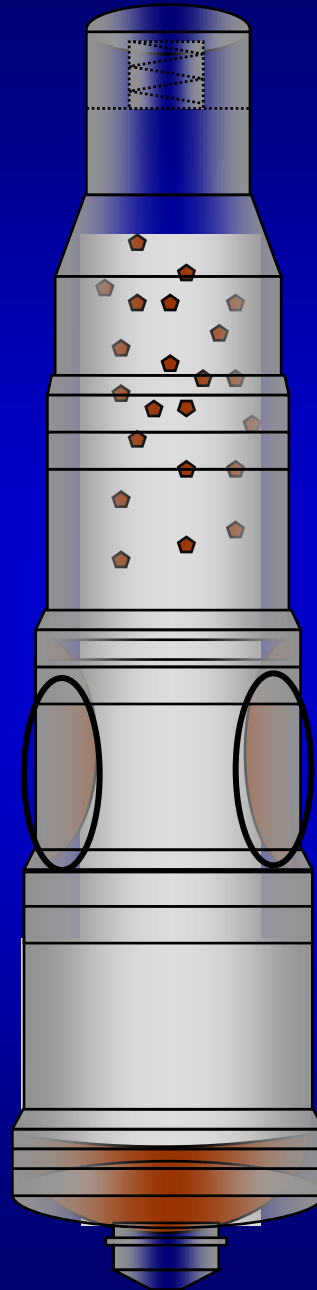
Normal Chip and Liquor Level

The graph displays two data series over time. The x-axis represents time from 23:00 to 00:45. The y-axis represents level, with a scale from 0.0 to 1.25. The red line (Normal Chip) starts at approximately 1.24 and fluctuates between 1.1 and 1.2. The green line (Liquor Level) starts at approximately 1.1 and fluctuates between 1.0 and 1.1. Both lines show a general downward trend over the period.

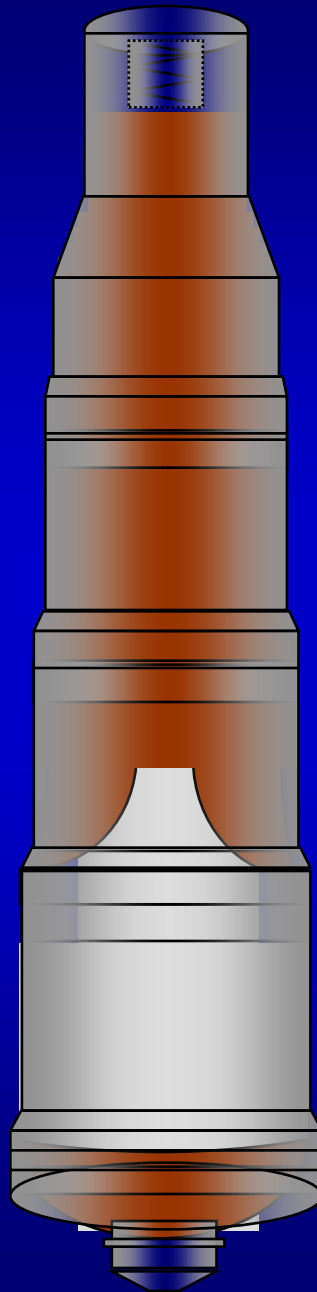
Category	Count	Percentage
Ready	1	100%
Gathering	0	0%
Dispersing	0	0%
Completed	0	0%
Cancelled	0	0%
Failed	0	0%
Timeout	0	0%
Aborted	0	0%
Unknown	0	0%
Other	0	0%

- *Channeling . . .*

- Channeling . . .

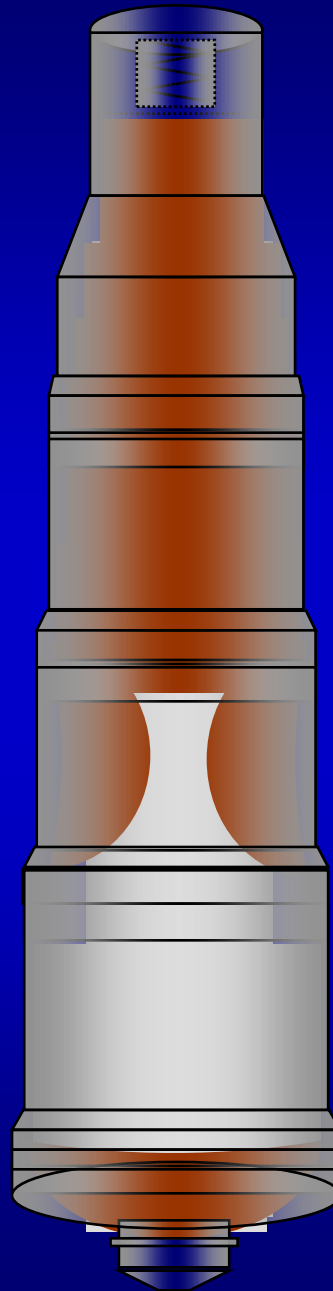


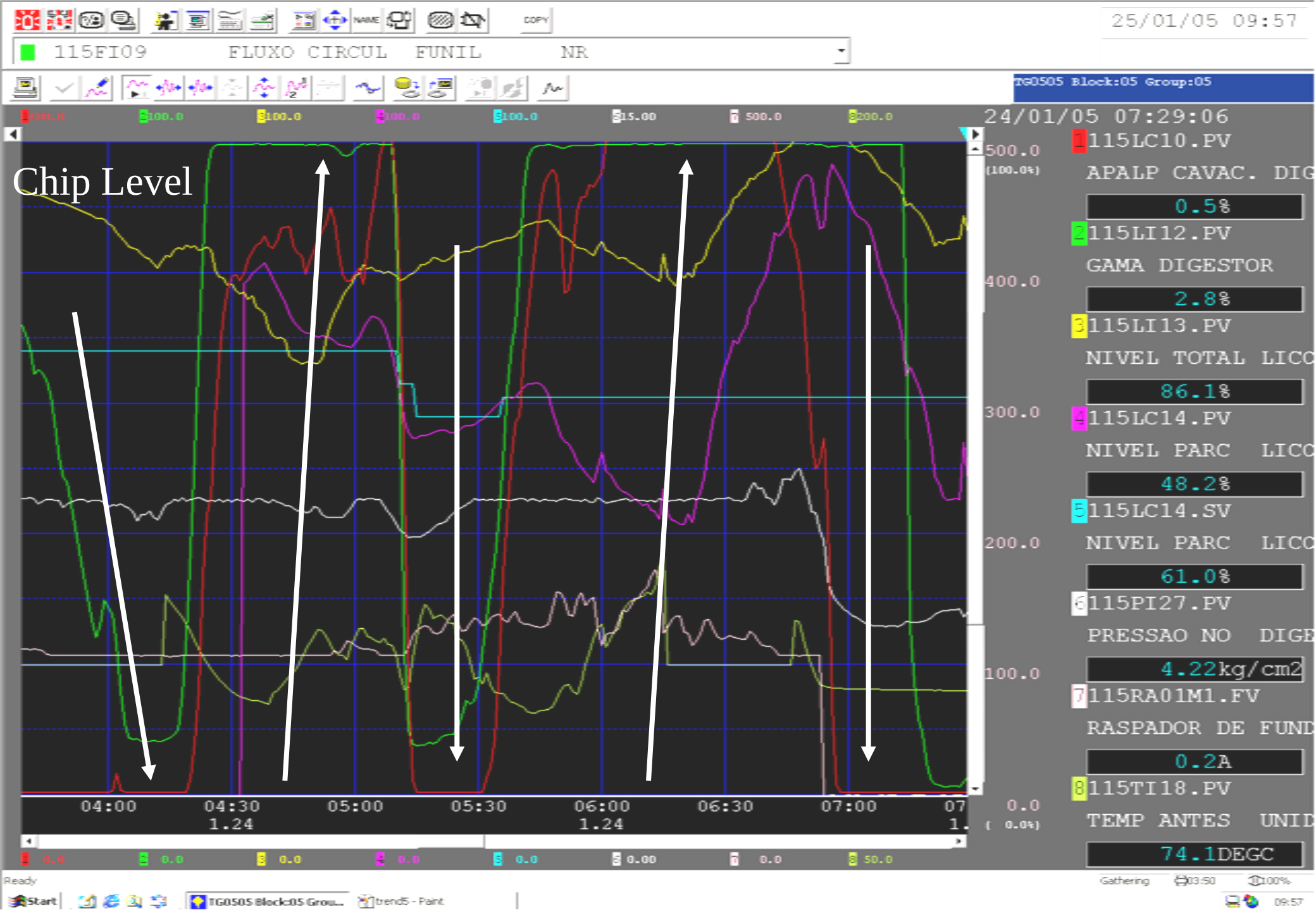
- High chip level . . .





Dropping chip level...





HANGING DIGESTER OPERATIONAL ISSUES

- *Instability Plug Movement (Retention Time)*
- *High Blowline Temperature*
- *High Blowline Kappa Deviation*
- *Blowline Consistency Variation*
- *High Pressure Drop Screen (Circulation Flow Impacts)*

How to reduce ?

Y RETENTION INDEX

- Read and storage main cooking process variable.
- Logical Mathematical Test in each one.
- Result: *Retention Index Equation*.
- Dinamic and on line at DCS Screen.

Retention Index (Y)

- *chip density difference*
- *paddle chip level*
- *total liquor level*
- *partial liquor level*
- *extraction liquor flow/RPM*
- *extraction pressure drop*
- *blow pressure drop*
- *blow pulp temperature*
- *blow pulp flow/RPM*
- *amperage scraper*
- *circulation temperature*

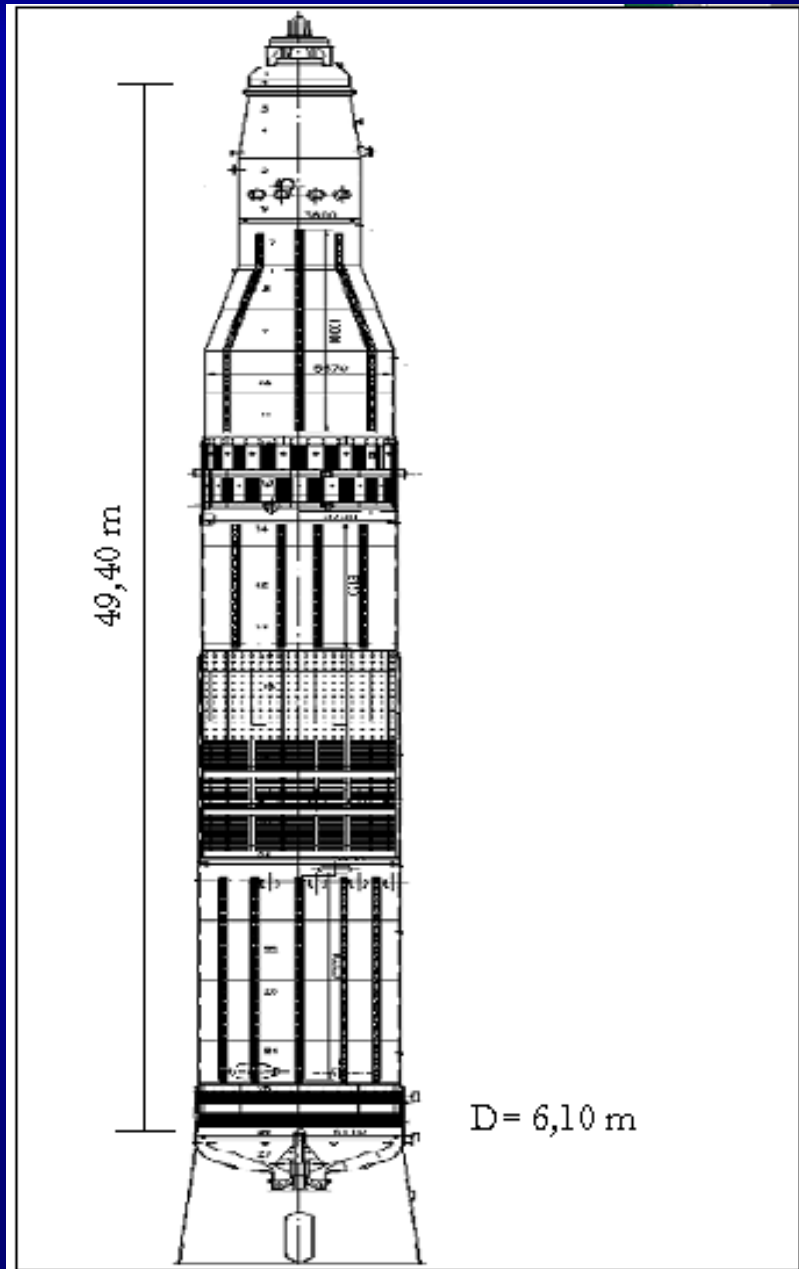
Materials and Methods

- **Industrial Chip Eucalyptus**
- *Eucalyptus grandis* and *Eucalyptus urograndis*
 - size : 18 - 25 mm ;
 - basic density : 470 - 500 kg/m³ ;

Industrial Digester 1

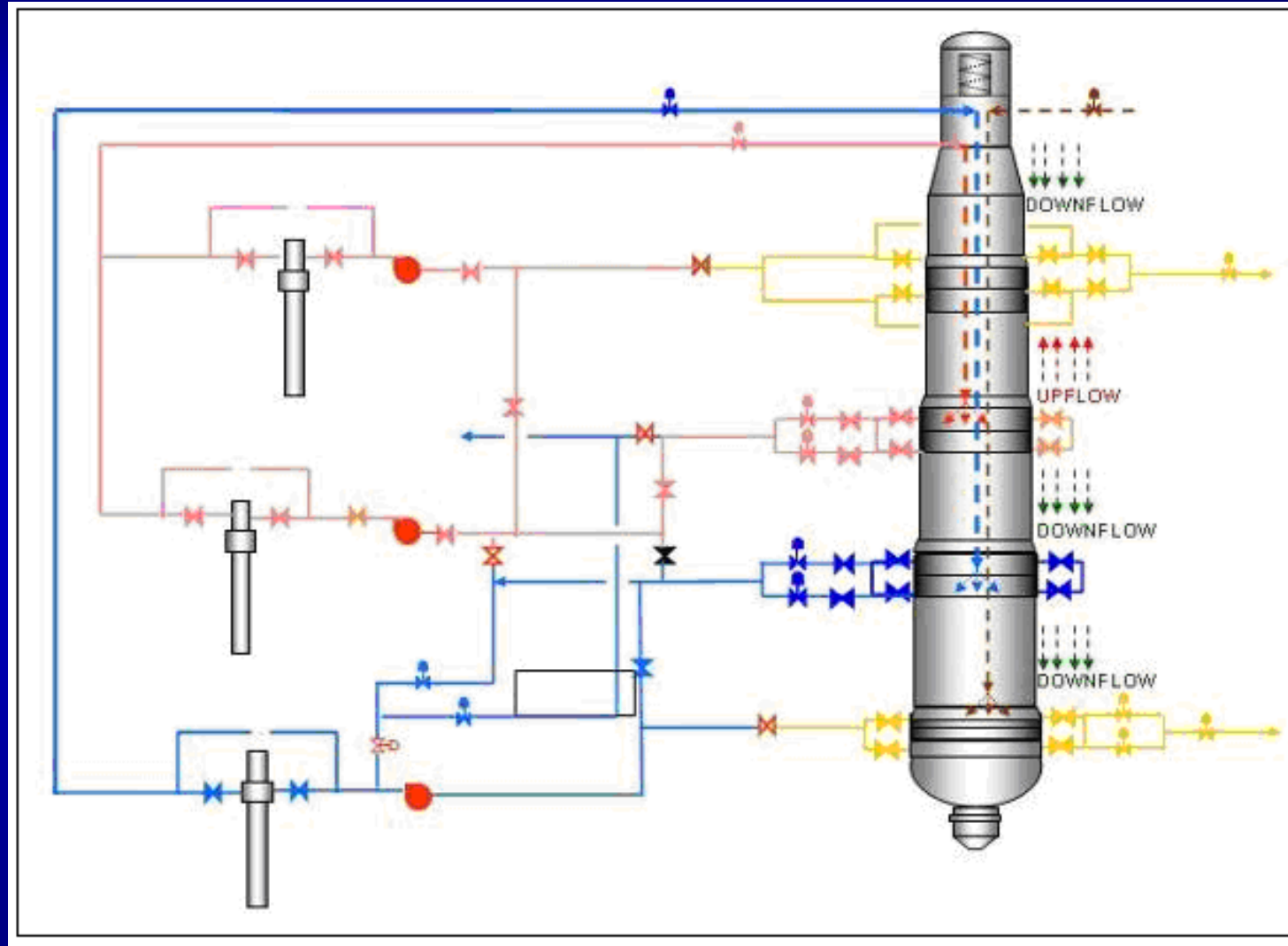
Kobudo Mari

Production :
500.000 adt/y



Industrial Digester 2 lo-solids

H = 54,60 m ;
D = 7,60 m ;
Production :
700.000 adt/y



Process Data

- Collected over four months;
- stored in a PIMS;
- available to the operator (DCS) .

Feed < 20 rpm = Ignored

total amount :

- 11,174 observations for the digester 1.
- 11,308 observations for the digester 2.

Y Index Schedule

Item	Process Variables	References		
	Schedule to Y Index →	0	1	2
1	chip density difference <i>(kg/m³)</i>	< 5	5 - 10	> 10
2	paddle chip level <i>(%)</i>	< 90	90 - 94	> 94
3	total liquor level <i>(%)</i>	> 84	83 - 84	< 83
4	partial liquor level <i>(%)</i>	> 55	50 - 51	< 50
5	extraction liquor flow/RPM <i>(m³/RPM)</i>	> 9,8	9,8 - 9,0	< 9,0
6	extraction pressure drop <i>(mm H₂O)</i>	< 0,18	0,18 - 0,20	> 0,20
7	blow pressure drop <i>(mm H₂O)</i>	< -0,5	-0,5 - 0,0	> 0,0
8	blow pulp temperature <i>(°C)</i>	< 83	83 - 88	> 88
9	blow pulp flow/RPM <i>(m³/RPM)</i>	< 7,8	7,8 - 8,3	> 8,3
10	amperage scraper <i>(Amp)</i>	< 115	115 - 120	> 120
11	circulation temperature <i>(°C)</i>	< 166	166 - 168	> 168

Y Index Schedule

N17		=SE(S17<5;"";SOMA(B17:M17))														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	AP
			TEMP DESC(1)	VAZ EXT/Rot(2)	VAZ DESC / rot (3)	NIV APALP (4)	NIV PARC LIC (5)	NIV TOT LICOR (6)	PDI35 EXT (7)	PR. HID. RASP (8)	DELTA DENS (9)	TEMP CIRC (10)	PDI25 (dif.P desc) (11)	INDICE		Temp Desc (1)
1																
2			83	9,0	23,0	90	56	88	1500	95	5	165	0,40	Y	Mín	80,4
3			88	10,0	24,5	99	58	91	2000	100	10	167	0,50		Méd	89,2
4			°C	M3/H.RPM	M3/H.RPM	%	%	%	mmH2O	kg3/cm2	m3/kg	°C	kg/cm2		Máx	96,7
10	1:15		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 01:15:00	89,0
11	1:30		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 01:30:00	90,3
12	1:45		1	0	0	0	0	0	0	0	0	0	0	1	2008-11-01 01:45:00	87,9
13	2:00		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 02:00:00	89,5
14	2:15		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 02:15:00	89,6
15	2:30		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 02:30:00	93,3
16	2:45		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 02:45:00	81,0
17	3:00		1	0	0	0	0	0	0	0	0	0	0	1	2008-11-01 03:00:00	87,7
18	3:15		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 03:15:00	89,5
19	3:30		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 03:30:00	89,3
20	3:45		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 03:45:00	89,2
21	4:00		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 04:00:00	90,1
22	4:15		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 04:15:00	90,3
23	4:30		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 04:30:00	93,1
24	4:45		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 04:45:00	88,0
25	5:00		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 05:00:00	92,5
26	5:15		1	0	0	0	0	0	0	0	0	0	0	1	2008-11-01 05:15:00	87,9
27	5:30		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 05:30:00	90,8
28	5:45		2	0	0	0	0	0	0	0	0	0	0	2	2008-11-01 05:45:00	88,5

DCS Control Room



viscosidade > 10: reduzir 6 rpm Dig 1 e 4 rpm no Dig 2 a cada 2h. Aumentar produção qdo abaixo de 92 por 3 horas.

Die 1 Agura / Die 2 Agura \ Gräbern Agura /

Digester 1 – Data Analysis

The SAS System

Variable	N	Sum	Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
TD	11174	7315.00	0.6546447	0.6408510	0.6684384
VE	11174	662.0000000	0.0592447	0.0540088	0.0644806
VD	11174	1878.00	0.1680687	0.1593001	0.1768374
NA	11174	554.0000000	0.0495794	0.0442394	0.0549193
NP	11174	126.0000000	0.0112762	0.0090531	0.0134992
NL	11174	2741.00	0.2453016	0.2357981	0.2548051
PEX	11174	0	0	.	.
AR	11174	167.0000000	0.0149454	0.0121031	0.0177877
TC	11174	906.0000000	0.0810811	0.0750790	0.0870831
DD	11174	2198.00	0.1967066	0.1877277	0.2056856
PD	11174	116.0000000	0.0103812	0.0077745	0.0129880
Y	11174	16663.00	1.4912296	1.4639488	1.5185105

Digester 1 – Data Analysis

The SAS System		The FREQ Procedure		
Y	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	3276	29.32	3276	29.32
1	3280	29.35	6556	58.67
2	2265	20.27	8821	78.94
3	1330	11.90	10151	90.84
4	598	5.35	10749	96.20
5	248	2.22	10997	98.42
6	98	0.88	11095	99.29
7	38	0.34	11133	99.63
8	20	0.18	11153	99.81
9	8	0.07	11161	99.88
10	6	0.05	11167	99.94
11	1	0.01	11168	99.95
12	4	0.04	11172	99.98
13	2	0.02	11174	100.00

Digester 1 – Data Analysis

The SAS System		The CORR Procedure								
1 With Variables:	Y									
10 Variables:	TD	VE	VD	NA	NP	NL	AR	TC	DD	PD
Pearson Correlation Coefficients, N = 11174 Prob > r under H0: Rho=0										
	TD	VE	VD	NA	NP	NL	AR	TC	DD	PD
Y	0.62056 <.0001	0.37615 <.0001	0.49152 <.0001	0.34285 <.0001	0.24719 <.0001	0.40414 <.0001	0.25083 <.0001	0.24659 <.0001	0.36829 <.0001	0.27654 <.0001

Digester 1 – Data Analysis

The SAS System		The REG Procedure			
Dependent Variable: Y Stepwise Selection: Step 10					
Summary of Stepwise Selection					
Step	Variable Entered	Variable Removed	Number Vars In	Partial R-Square	Model R-Square
1	TD		1	0.3851	0.3851
2	NL		2	0.1637	0.5488
3	VD		3	0.1495	0.6984
4	DD		4	0.1048	0.8032
5	TC		5	0.0649	0.8681
6	NA		6	0.0475	0.9156
7	VE		7	0.0445	0.9600
8	PD		8	0.0276	0.9876
9	AR		9	0.0067	0.9943
10	NP		10	0.0057	1.0000

Digester 1 – Data Analysis

$$Y = 0,01125 + 1,02845*.TD + 1,12405*.VD + 1,12678*.NA + 1,10346*.NL + 1,13105*.TC + 1,01439*.DD$$

$$R^2 = 91,56 \%$$

(*) -Significant at 1% probability by t student test.

Digester 2 – Data Analysis

The SAS System			The REG Procedure			
Model: MODEL1			Dependent Variable: Y			
Summary of Stepwise Selection			PEX	AR	DD	PD
Step	Variable Entered	Number Vars In	Partial R-Square	Model R-Square		
1	1	VD	0.2754	0.2754		
	2	AR	0.2169	0.4924		
	3	NP	0.1299	0.6222		
	4	TD	0.1258	0.7481		
	5	NA	0.1139	0.8620		
	6	DD	0.0835	0.9455		
	7	NL	0.0207	0.9662		
	8	VE	0.0063	0.9724		
	9	PEX	0.0051	0.9775		
	10	PD	0.0021	0.9796		

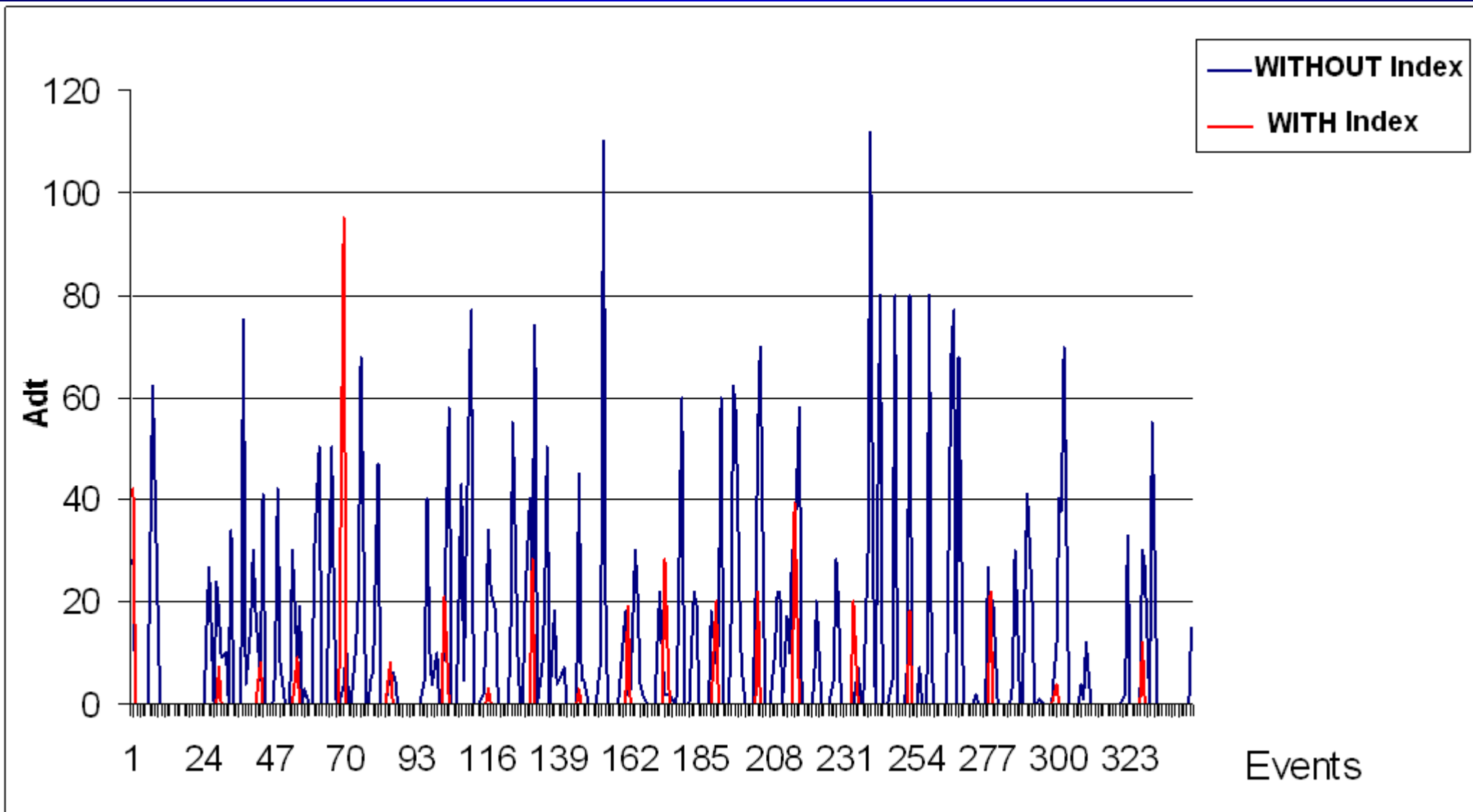
Digester 2 – Data Analysis

$$Y = 0,083110 + 0,95393*.TD + 1,01250*.VD + 1,00987*.NA \\ + 1,52048*.NP + 1,05189*.AR + 1,26019*.DD$$

$$R^2 = 94,55 \%$$

(*) - Significant at 1% probability by t student test.

Compactions Disturbances Production Losses :



Conclusions ...

What to do during compaction disturbances ?

- Minimize chip variations ;
- Maximize vaporization step ;
- Increase top digester pressure ;
- Eliminate up-flow liquor ;
- Increase kappa number (considering limits) ;
- Increase level difference of liquor and chips ;
- Control the chip level through the chip meter ;
- Avoid discharge flow above the production rate;

Conclusions...

- Clustering variables help the operator decision analysis
- Adequate chip level control means adequate retention time control.
- High contribution from counter current liquor flow.
- Respect local mill culture at the same time looking for the best available practices...

Benefits Implementation Results...

- **Digester Level Improvement**
 - Improved Plug Movement
 - Higher Circulating Liquor Flow
- **Digester Blowline Temperature Reduction**
 - Increased Digester Dilution Factor
- **Digester Blowline Kappa Improvement**
 - Higher stability



Thank you ...

Developments in Continuous Cooking

- First Prototype Continuous Digester started in 1938 at a mill in Sweden with capacity of 20 t/d
- First commercial digester with capacity 30 tons per day commissioned in 1948 in a Swedish mill.
- In 1962 in digester washing called high heat washing became available
- High heat washing simplified the brown stock washing plant
- 1983 the first mill trials with modified Kraft cooking (MCC) were performed in Finnish mill.
- MCC was developed by STFI & Royal Institute of Technology Stockholm Sweden.
- 65% of global Kraft pulp production is manufactured by continuous cooking.

Development in Continuous Cooking

MCC	Split or multiple WL additions for alkali profiling and counter cooking methods to minimize lignin concentration at the end of cook.
EMC	High heat wash zone is simultaneously used for cooking and washing.
ITC	High heat wash zone is simultaneously used for cooking and washing
Advantages	• Low knots & rejects • Uniform cook with high yield • Improved Bleachability • Higher brightness ceiling
Low Solids Pulping	Dissolved wood solids are removed from the system by extracting spent liquor at multiple locations First commercial installation in 1993.
Black Liquor Impregnation	Black liquor pretreatment enhances the delignification during Kraft cooking and improves the selectivity of the cook
Advantages	Extracted Black liquor is added to the impregnation vessel with a retention time of 45 minutes. Improved pulp properties , improved tear strength(10 % Approx) at the same tensile strength

Adv/Disadvantages of Conventional Batch Digesting

Advantage

- Operational flexibility
- Produce diff. Grades in same digester
- Sharp kappa number change
- Tolerant to pins and fines
- Capacity increased by adding digesters
- Less sensitive to chips quality

Disadvantage

- High energy use
- Limited capability to extended
- Delignification

Adv/ Disadvantages of Con. Digesting

Advantage

- More constant steam demand
- More compact less space requ.
- Uniformity in pulp quality
- Extended Delignification possibility
- Better pulp strength

Disadvantages

- High capital investment
- Restriction for type and raw material quality

Some Opinions...

Due to its complexity, the influence from different disturbances, and its deficient instrumentation, the quality variations of the pulp from the digester is substantial. An interesting observation from the process measurements is a fairly strong correlation between the pulp quality (the Kappa number) and the chip level in the digester. This lead to certain speculations on an “accordion”-like movement of the mass, and cause-effect relationships between the Kappa number and the chip level.

A Dynamic Mechanistic Model and Model-based Analysis of a Continuous Kamyr Digester

Dr. Ing. Thesis
Finn Are Michelsen

Department of Engineering Cybernetics
The Norwegian Institute of Technology
University of Trondheim
1995

Some Opinions...

First, fiber properties of the pulp are dependent on the fluid mechanics occurring inside the digester. The flow and temperature distribution within the digester, especially within the cooking zone, have an effect on the residence time and temperature history of fibers.

MODELING OF KRAFT TWO-PHASE DIGESTER PULPING PROCESSES

Pingfan He, Martha Salcudean, Ian Gartshore and E.L. Bibeau*

Department of Mechanical Engineering, The University of British Columbia, Vancouver, BC V6T 1Z4

*Process Simulations Limited (PSL), #204, 2386 East Mall, Vancouver BC V6T 1Z3 (www.psl.bc.ca)

Some Opinions...

It is important to have optimal packing and flow conditions inside the digester, because too high packing and channeling of the liquor flow leads to non-uniform cooking, production disturbances and impaired fiber quality.

In reality, residence times along the digester are dependent on production rates and packing degree of the chip bed, which is not calculated by any means.

MODELING OF CHIP BED PACKING IN A CONTINUOUS KRAFT COOKING DIGESTER

Sampsa Laakso

Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the Faculty of Chemistry and Material Sciences, for public examination and debate in PUU 2 Auditorium at Helsinki University of Technology (Espoo, Finland) on the 12th of December, 2008, at 12 noon.

Some Opinions...

There are many disturbances in the digester control. . . .

. . . the major disturbance is the abnormal compaction.

DIAGNOSIS SYSTEM FOR CONTINUOUS COOKING PROCESS

**Timo Ahvenlampi, Manne Tervaskanto and
Urpo Kortela**

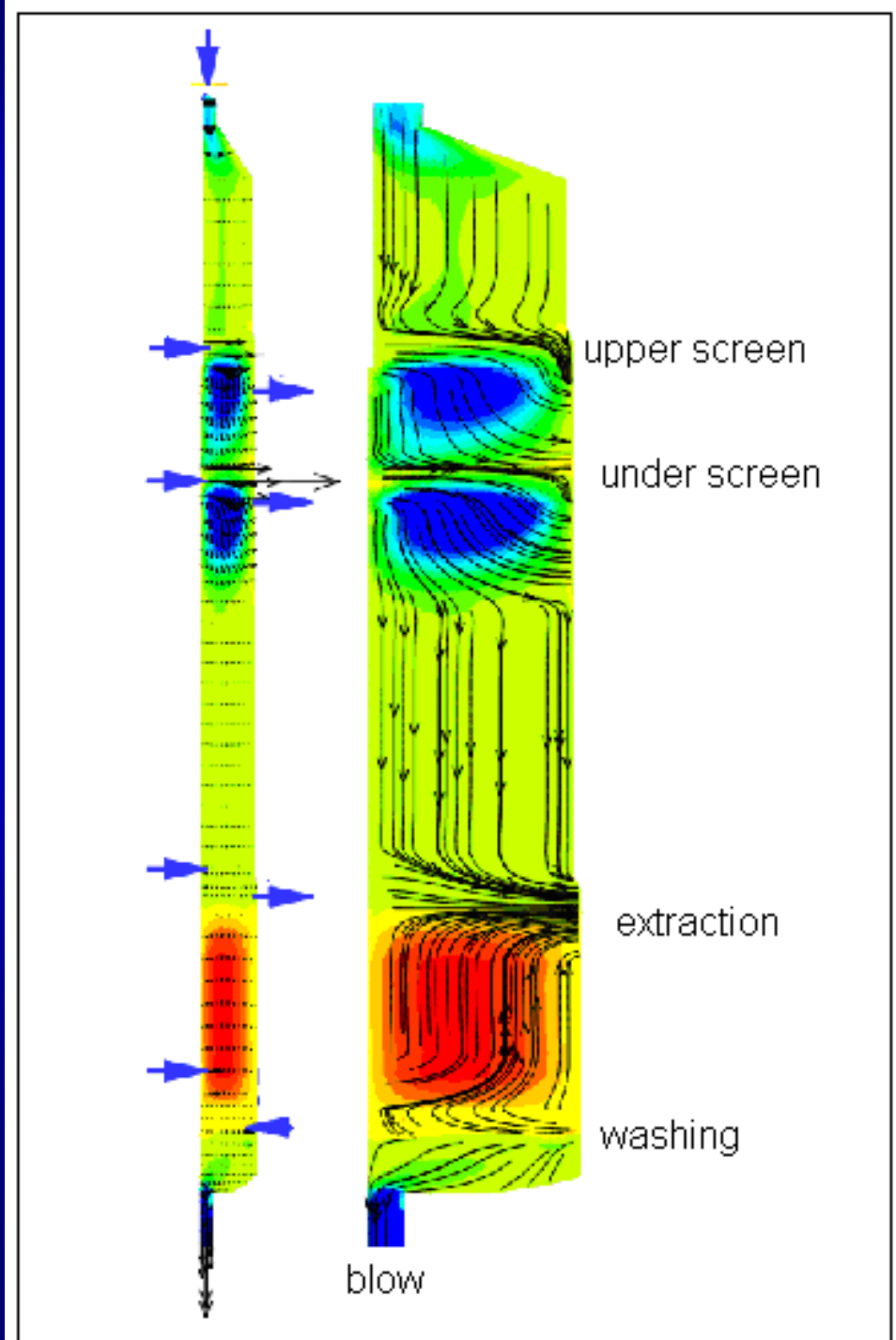
*Department of Process and Environmental Engineering,
Systems Engineering Laboratory, P.O. Box 4300,
FIN-90014 University of Oulu, Finland.
E-mail: timo.ahvenlampi@oulu.fi*

KRAFT PROCESS

- *A.K. Eaton :*
 - *Improvement in the manufacture of paper pulp - US Patent 106 143 ; August , 09 , 1870*
 - *Improvement in the manufacture of paper pulp- US Patent 119 224 ; September, 26 , 1871*
- $\text{Na}_2\text{CO}_3 > \text{Na}_2\text{SO}_4$.
- *Germany C.F. Dahl.*
 - *US Patent 296 935 ; April, 15 , 1884*

Liquor Flow

(HE et al 1999).



Some Opinions...

Perhaps the most difficult operational problem for the digester control is to stabilize the vertical movement of the chips.

This movement directly determines the residence time for the chips; a critical variable which affects the pulp quality.

A Dynamic Mechanistic Model and Model-based Analysis of a Continuous Kamyr Digester

Dr. Ing. Thesis
Finn Are Michelsen

Department of Engineering Cybernetics
The Norwegian Institute of Technology
University of Trondheim
1995

Some Opinions...

Industrial processes generate a lot of information for operators. The operators have many measurements to observe and control at the same time. This can be helped by combining the knowledge. Clustering (see e.g. [1] and [2]) is one of the methods for combination, because the information is saved in databases and it is available. Industrial processes are usually highly non-linear and it is very difficult or impossible to make accurate models with conventional modeling techniques. These kinds of systems can be called complex systems.

Informatica 29 (2005) 101–109

Clustering Algorithms in Process Monitoring and Control Application to Continuous Digesters

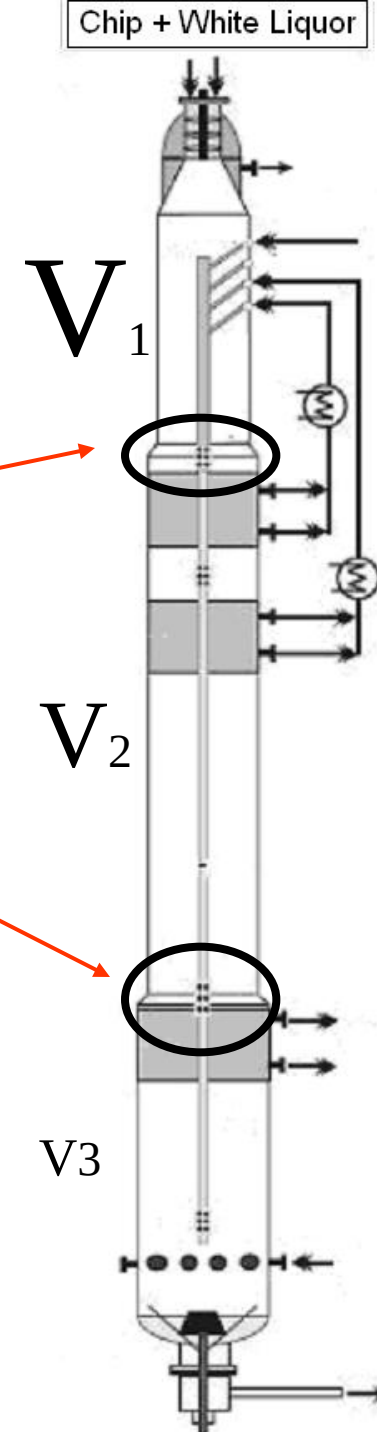
Timo Ahvenlampi and Urpo Kortela
Department of Process and Environmental Engineering,
Systems Engineering Laboratory, P.O. Box 4300,
FIN-90014 University of Oulu, Finland.
e-mail: timo.ahvenlampi@oulu.fi

- Basic Questions ...

Would the chip have a constant velocity from top to the bottom ?

No, of course...

Digester is not a “exact cilinder”



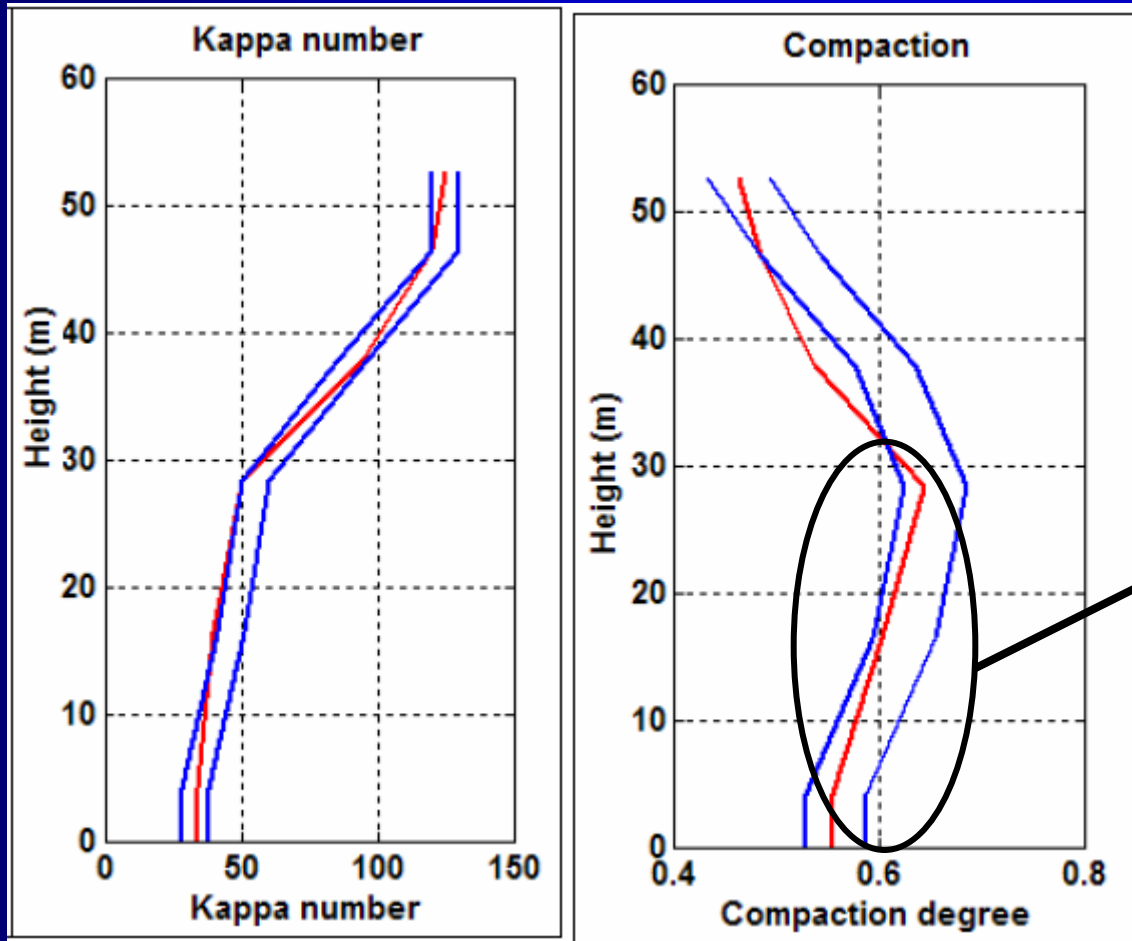
Surface Forces

$$\frac{dP_{chips}}{dh} = (\rho_{liquid}(1 - \varepsilon) + \rho_{chips}\varepsilon)g - \mu \frac{P_{chips}}{D_{digester}} \pm \frac{dP_{liquid}}{dh}$$

Saltin (1992)

ε	= void fraction of chips
μ	= Friction coefficient between chips and digester wall
D digester	= Diameter of digester (m)
g	= Gravity (m/s ²)
P chips	= Chip Pressure (Pa)
P líquido	= Liquid Pressure (Pa)
σ chips	= Chip Density (kg/m ³)
σ líquido	= Liquid Density (kg/m ³)

Delignification



Countercurrent
liquor flow effect

↑ Delignification : ↓ Porosity : ↑ Compaction

Puolaka *et al* 2005

MILL LOCATION



Digestors 1 / 2 – Comparative Data

* Valid Observations : 11.174 / 11.308

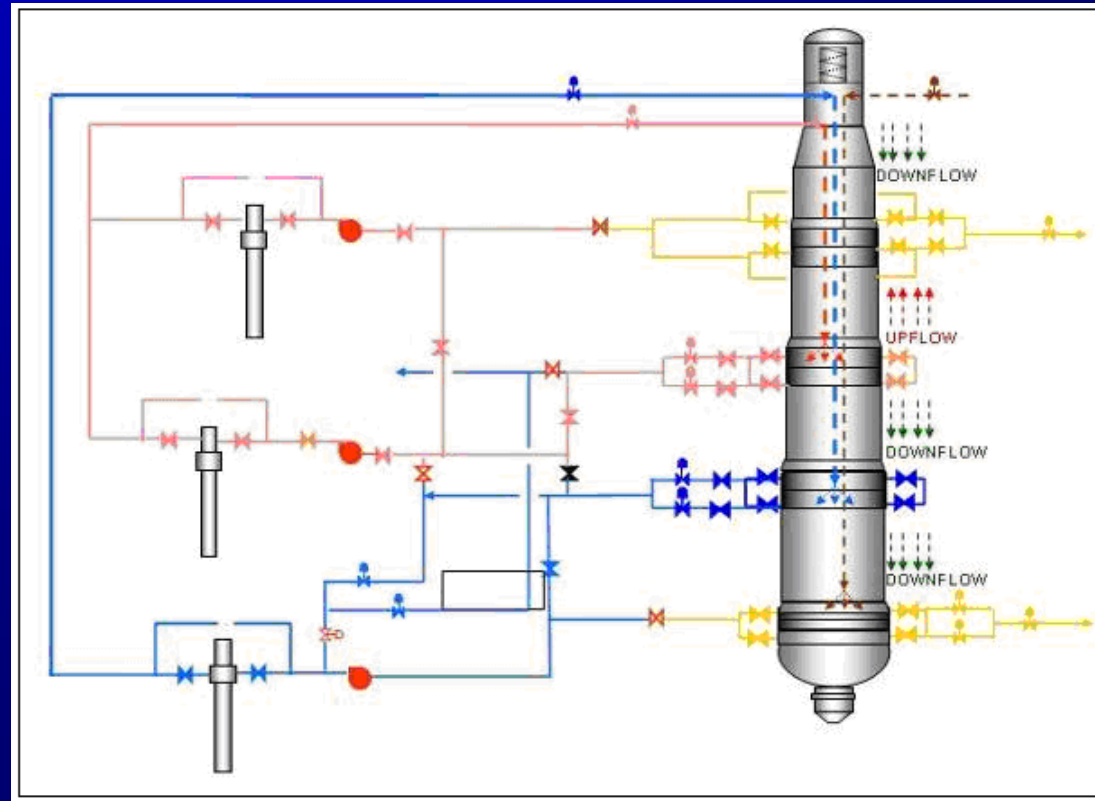
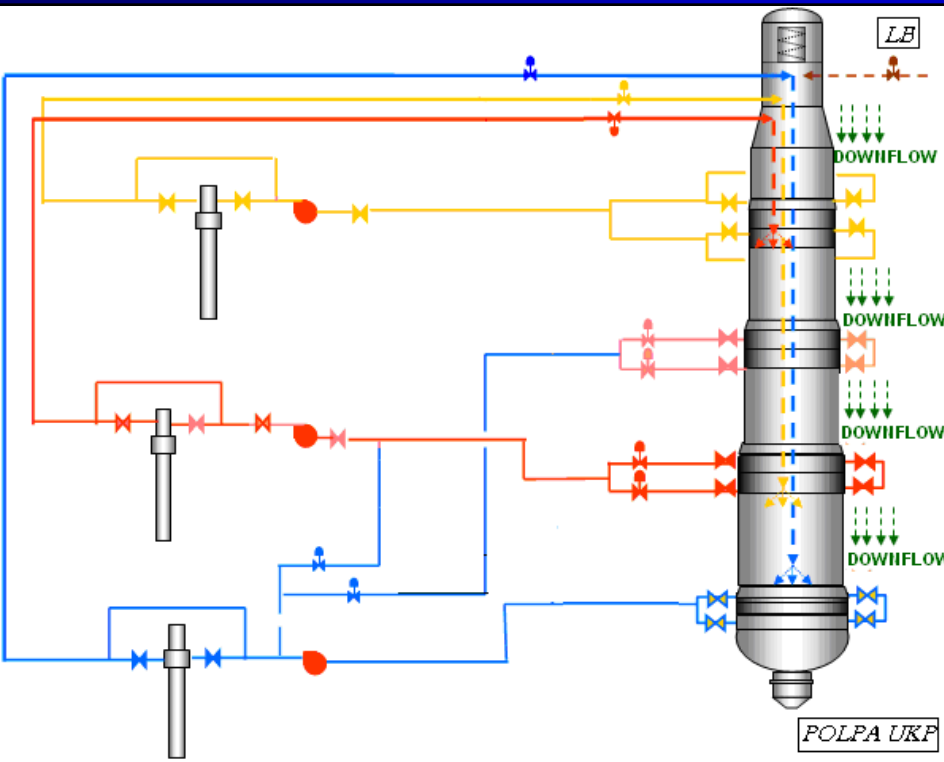
Y Average : 1,49 / 3,09

Y > 10 : 0,12 / 0,33 (%)

charge : 2,156 / 1,940 (adt/h.m2).

Digesters 1 / 2 – Comparative Data

up flow ?





Thank you ...