21st Century Fibrelines

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Abstract: The design and operation of three of the newest 21st century fibre lines are reviewed. The mills include Veracel Celulose, a Brazilian high-brightness eucalyptus pulp mill; Hainan Jinhai, a Chinese bleached hardwood kraft mill; and Celulosa Arauco Valdivia, a Chilean bleached eucalyptus and radiata pine batch mill. The configuration of each fibre line is outlined and the key features of the chosen technologies are discussed. Performance data for key mill operations and environmental control systems is given.

The design of a modern 21st century pulping complex is dramatically different from mills of the past. Pressures to maximize energy efficiency, improve product quality, reduce environmental impact, and optimize capital and operating costs have significantly shaped 21st century pulping and bleaching processes.

New mills have responded to these demands by adopting efficient, low impact designs on economies of scale that far surpass most existing mills. New fibre lines have been built mainly in Asia and South America where access to fast growing raw material and other production advantages give favourable levels of cost and return. This paper benchmarks three mills started up in the early 21st century.

THE MILLS

Veracel

The Veracel bleached eucalyptus pulp mill started production in May 2005 with a design capacity of 900,000 tpa. The mill is a joint venture between Aracruz Celulose and Stora Enso and is located in the north-eastern state of Bahia in Brazil. The Veracel fibre line consists of Lo-Solids pulping, two stages of oxygen delignification, and a four-stage, elemental chlorine free (ECF) bleaching sequence (Fig. 1). Logs are sourced from Veracel's own plantations, currently totalling 87,000 hectares. *Eucalyptus urograndis* is the main species pulped.

The mill has a design capacity of 900,000 adt per annum but actual production has consistently exceeded this target. Production in 2007 was in excess of 1,050,000 adt. The bleach plant, originally designed to operate as A/D0 (Eop) (D1n) D2 or A/D0 (Eop) D1 P has been modified to Dhot (Eop) D1 P. The pulp quality target of 97% prime quality, was achieved 59 days after start up.

Hainan Jinhai

The world's largest single-line pulp mill, Hainan Jinhai was designed to produce one million tpa of bleached hardwood kraft pulp. The mill is located on Hainan Island in southern China and covers 400 hectares. The management philosophy underlying the mill development was three-fold – economic benefit, social benefit, and ecological benefit.

Hainan Jinhai produced its first pulp in November 2004. The mill's fibre is *Eucalyptus grandis* and *Acacia crassicarpa*, in approximately equal volume, and is sourced internally from Asia Pulp and Paper's (APP) 233,300 hectare plantation forests, and imported from Indonesia, Cambodia, and Vietnam to make up the balance. Additional plantings are planned with the goal to become self-sufficient in wood. Hainan Jinhai utilises Compact Cooking, two-stage Dualox oxygen delignification, and DualD hot chlorine dioxide bleaching (Figure 2). The mill's produc-


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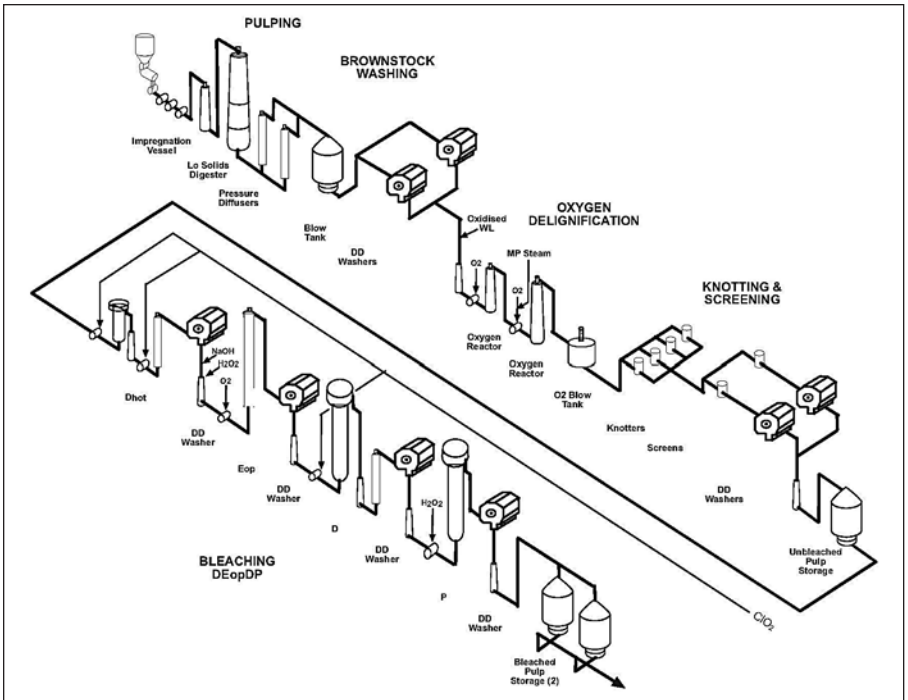


Fig. 1. Veracel bleached eucalyptus fibre line.

TABLE I. Digester key parameters

Parameters	Veracel	Hainan Jinhai	Arauco Valdivia	Arauco Valdivia
Digester Type	Continuous Steam/liquor	Continuous	Batch	Batch
Number of Vessels	2	2	10 x 400m^3	10 x 400m^3
Type of Cooking	Lo-Solids	Compact Cooking	SuperBatch-K	SuperBatch-K
Capacity, ad tpd	3,350	3,020	1,527	1,680
Wood Type	HW	HW	SW	HW
Wood Species	*E. urograndis*	*Acacia (50%) E. grandis (50%)*	*P. radiata*	*E. nitens (70%) E. globulus (30%)*
Chip Moisture %	43	40-50	58	50
Chip Thickness, mm	3 – 8	< 8	5 – 8	5 – 8
Chip Length, mm	25	24 – 32	24 – 26	24 – 26
Active Alkali, % NaOH	17.5	17 – 19	21	21
Active Alkali, g/L NaOH	134	129 – 135	140	140
Sulphidity, %	32	< 30	35	35
Steam Usage LP/MP, MJ/t	1450 Digester only	< 6 t steam/t Total mill	700/1900 Digester only	700/1350 Digester only
Yield, % OD	55.8	44 – 46	47	52
Kappa Number	18	17 – 18	26	15
Dilution Factor	1.0	< 2.5	2.5	2.5
Black Liquor Solids, %	15.0	16 – 17	15.4	14.8

tion is used to supply pulp to the several APP paper machines in China.

Arauco Valdivia

Celuloso Arauco y Constitución's pulp mill in Valdivia, Chile, started up in February 2004 and produces 550,000 tonnes of pulp annually. Valdivia is a 'swing' mill producing both radiata pine (60% of production) and ecualyptus pulp. The mill design was based on a maximum capacity rate of 1,700 ad tpd for pine and 1,900 ad tpd for eucalyptus. *E. nitens* (70%) and *E. globulus* are the eucalyptus species pulped.

The pulping line consists of ten SuperBatch-K digesters of 400 m^3 capacity followed by 4 stages of washing and screening (Fig. 3). Oxygen delignification is in two stages with 60% of delignification occurring in the first reactor. The ECF bleach sequence is D (Eop) D D. The mill is located in an environmentally sensitive area. Very low loadings to the recipient waters are a key requirement and are achieved by a combination of state-of-the-art technology and internal measures. Effluent treatment consists of primary, secondary, and tertiary treatment stages followed by disk filtration to minimise suspended solids levels prior to discharge.

INNOVATIONS AND TRENDS IN FIBRE LINE TECHNOLOGY

Pulping

State-of-the-art cooking includes both continuous and batch processes utilising low cooking temperatures and optimised alkali profiles. Continuous cooking has predominated over the last decade, and typically consists of two vessels for softwood and one or two vessels for hardwood. With segregation of chips by species the norm, the chip feed is of uniform quality and thus results in reduced processing upsets. Lower cooking temperatures (145-153°C) are typically used with kappa numbers in the range 26-35 for softwoods, 17-22 for birch, and 15-18 for eucalypts.

The pulping equipment and process details for each of the fibre lines are summarised in Table I.

Both Veracel and Hainan Jinhai operate continuous pulping systems. Veracel's low level – Lo-Solids cooking system consists of an hydraulic impregnation vessel and a steam-phase digester. The main objective of the Lo-solids cooking is to increase the selectivity of the cook through low and uniform radial cooking temperatures and a uniform alkali profile. Cellulose dissolution is minimised in the principal and residual delignification phases, and relatively high yields of around 55% OD are achieved.

The Compact Cooking process at Hainan Jinhai is producing in excess of 3,000 tonnes/day. Chips of uniform size and thickness are fed via a Compact feeder to the liquor impregnation vessel. The digester is of massive scale at 12.5 m diameter, with a retention time of about 6 hours. Cooking is at lower temperature with a low energy and alkali demand giving milder cooking conditions and pulp of good strength.

Arauco Valdivia operates the modified batch cooking process SuperBatch-K. The 'K' refers to a modification of the liquor displacement system to mitigate the earlier problems with calcium complex formation

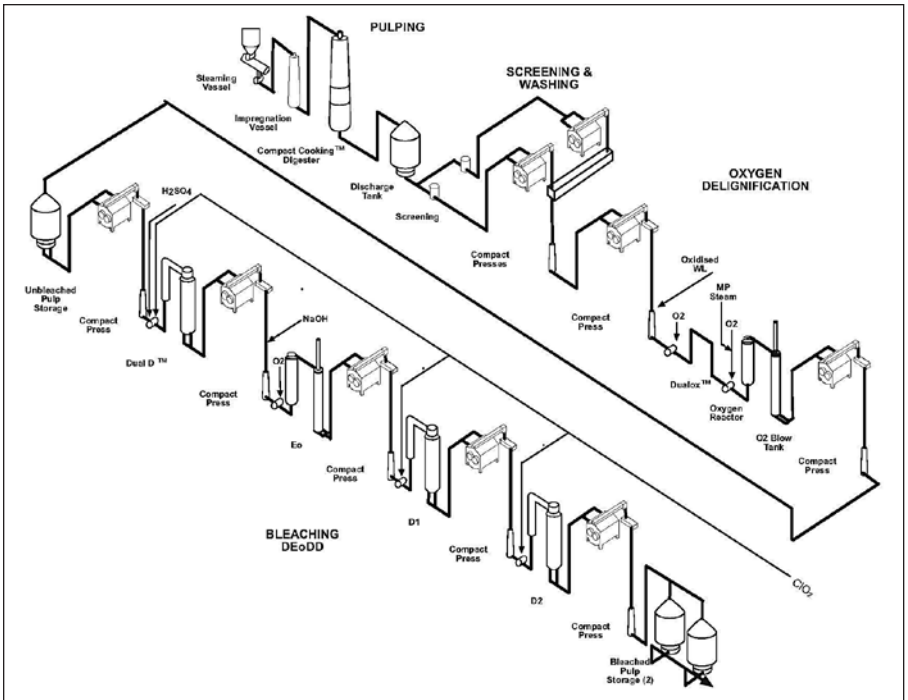


Fig. 2. APP Hainan Jinhai bleached hardwood fibre line.

TABLE II. Oxygen delignification key parameters

Parameters	Veracel	Hainan Jinhai	Arauco Valdivia	
Supplier	Andritz	Kvaerner Dualox	Metso OxyTrac	Metso OsxyTrac
Number of Vessels	2	2	2	2
Capacity, ad tpd	3,200	3,020	1,527	1,680
Wood Type	Eucalyptus	Euc & Acacia	Pine	Eucalyptus
Knots, %	1.0	< 0.7	1.0	1.0
Screen Rejects, %	0.2	< 0.5	0.5	0.5
Consistency, In	11.0	10 – 11	11	11
Oxygen, %	1.6	1.8	2.1	1.1
NaOH, %	1.6	2.0	2.6	1.6
MgSO4, %	–	≤ 0.2	0.2	0
Viscosity, In, dm3/kg	1250	≤ 1300	1030	1150
Viscosity, Out, dm3/kg	1150	≤ 1050	844	923
Viscosity, Loss, dm3/kg	100	250	186	227
Dilution Factor	1.0	2.5	2.5	2.5
Incoming Kappa	16.5	17 – 18	26	15
Kappa Out	10	10 – 12	10	9.5
O_2 Yield Loss, %	(3.0)	(1.5 – 2.0)	–	–
Brown Stock Washing	2 DDs	3 presses	3 presses	3 presses
Post O_2 Washing	2 DDs	2 presses	2 presses	2 presses

Note: 1. ( ) design
2. All chemicals as % actual chemical on bleached pulp basis.

in the front-end liquor systems and evaporation. Throughout the cooking cycle all liquors are pumped into the bottom of the digester and liquor is displaced through the screens located in the upper part of the digester.

Displacement cooking claims to provide optimal cooking conditions for the duration of the cook resulting in retention of fibre strength and pulp of uniform quality. At Valdivia MP steam is used to reach the cooking temperature of 150-160°C. Kappa targets for pine and eucalyptus are 26 and 15, respectively.

Washing and screening

Atmospheric diffusion washers and drum washers common in 20th century mills are replaced by presses and multi-stage DD washers that achieve high equivalent displacement ratios (EDRs). Veracel has two parallel pressurized diffusers after the digester followed by 2-stage drum displacement (DD) washers prior to oxygen delignification. Arauco Valdivia uses a dewatering press, with 2.5-3.0% feed consistency and two displacement wash presses with 6-8% feed consistency. The dewatering press is fed directly with screen accepts, and the press filtrate is cooled before entering the filtrate tank to return it to optimum temperature for the digester displacement liquor and to enhance soap separation in the liquor tank.

Hainan Jinhai uses Compact Press™ technology throughout the fibre line. Two wash presses in parallel follow the screening stage and pulp then passes to a third press prior to oxygen delignification.

Deknotting and screening can be carried out either before oxygen delignification, as in the case of Arauco Valdivia and Hainan Jinhai, or after, as for Veracel. Veracel claims advantages in screening after oxygen delignification - less foaming making the pulp easier to screen, higher yields due to breakdown of shives, smaller and cleaner rejects, and advantages in the heat balance between the cooking and oxygen stages.

For all three mills deknotting and primary screening occur in a single stage. Valdivia has 4 parallel DeltaCombi™ units for knot separation and a blower system for returning the knots to the digester chip bin. This knots return system has caused process instability, especially during eucalyptus campaigns, and is being modified to inject knots directly into the digesters. Veracel operates two parallel ModuScreen units for knots separation and primary screening, followed by washing and return of knots to the digester.

Screening is either 3-stage (Veracel) or 4-stage (Valdivia) and the options with rejects are to recycle, as in the case of Veracel where they are cleaned, washed and returned to the oxygen delignification stage, or landfill them.

Oxygen delignification

Oxygen delignification is carried out at medium consistency and in two stages by all three mills. This is a significant difference to mills of the previous decade where oxygen delignification was typically one stage.

The bulk of the delignification occurs

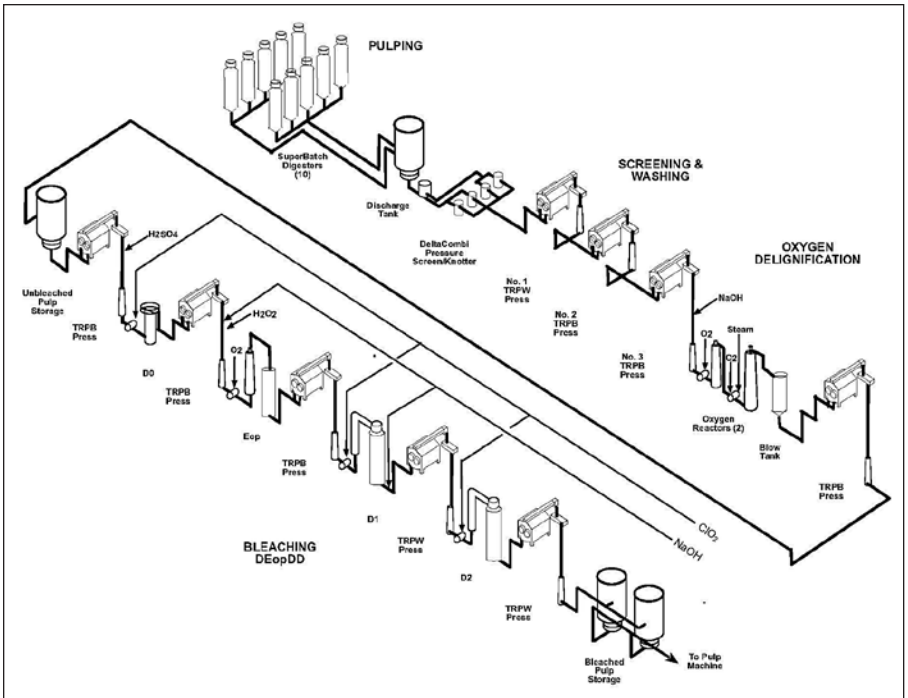


Fig. 3. Arauco Valdivia bleached fibre line.

TABLE III. Bleaching key parameters

Parameters	Veracel	Hainan Jinhai	Arauco Valdivia	
Sequence	Dhot (Eop) D P	Dhot (Eop) D D	Dh (Eop) DD	Do (Eop) DD
Rate, ad tpd	3,100	3,000	1,527	1,680
Wood	Eucalyptus	Euc & Acacia	Pine	Eucalyptus
Washing	4 DDs	4 presses	5 presses	5 presses
Incoming Kappa	10	10 – 12	10	9.5
Stage 1 H_2SO_4 %	0.2	0.3 – 0.5	0	0
ClO_2 %	0.59	0.5 – 1.0	0.92	0.77
Stage 2 NaOH %	0.85	1.5	1.5	1.2
O_2 %	0.18	0.4	0.4	0.13
H_2O_2 %	0.20	0.2 – 0.3	0.3	0.28
Stage 3 ClO2 %	0.20	0.4 – 0.5	0.57	0.49
H_2SO_4 %	0.20			
Stage 4 ClO2 %	–	0.2 – 0.3	0.19	0.18
H_2O_2 %	0.1			
NaOH %	0.24			
Antichlor	metabisulphite	–	$NaHSO_3$	$NaHSO_3$
Shrinkage, %	(2.5)	(< 3.0)	(2.8)	(2.7)
Brightness, % ISO	90.4	88 – 90	> 90	90.1

Note: 1. All chemicals as % actual chemical on bleached pulp basis.
2. ( ) design

in the first reactor, which is typically run at lower temperature and higher pressure than the second reactor. Veracel runs its first reactor at a temperature of 92-96°C, a pressure of 6-8 bar, with the addition of 60-70% of the alkali and oxygen charge. Valdivia adds all chemicals to the first reactor. Typically, the retention time in the first tower is about half that of the second tower. Veracel operates the second reactor at a temperature of 98-100°C and a pressure of 3-5 bar. Oxygen delignification at the Hainan Jinhai mill is the two-stage Dualox™ process.

The degree of delignification varies between 60% for softwood, and 40% for hardwoods. A significant portion of the hardwood kappa number is hexeneuronic acid which lowers the overall degree of delignification compared to softwoods. Valdivia's kappa targets are 12 and 9.5 for softwood and hardwood, respectively, to preserve pulp strength and pulp yield.

Bleaching

The three mills have similar four-stage, ECF bleaching sequences (Table III), which are similar to that used in the 1990s. The original bleach sequence of Veracel was A/D0 (Eop) D P which was modified after start up to Dhot (Eop) D P. This resulted in a significant reduction in chemical consumption.

Veracel's bleach plant operates with upflow towers in all stages followed by a DD washer after each tower. The washing is counter current with filtrate from the pulp machine being used for washing on the final DD washer. Veracel, like the other two mills, has very low bleach chemical consumption.

Arauco Valdivia's bleaching sequence is a conventional ECF sequence, D (Eop) D D. The first bleaching tower is upflow, with a top scraper and a dropleg to the MC pump standpipe. The three other towers are upflow-downflow, with MC bottom. The upflow section of the Eop tower is a pressure vessel. Mixers are all dynamic type SMD-300 in all stages. Washing is with wash presses.

The two first stages have displacement presses and the last two stages have simpler dewatering presses. Hot water is used for Eop washing, and pulp machine filtrate is used before the last D stage press. A minor amount of cold water may be added to the dilution before the first D stage for temperature control. The excess filtrates, both acid and alkaline, are filtered before they are sewered. To decrease emissions of COD, BOD and colour from the bleach plant, it is possible to recycle the alkaline filtrate from the Eop stage and use it for washing prior to the first bleaching stage.

At Hainan Jinhai, the DualD bleaching process D (Eop) D D also has a hot chlorine dioxide first stage. As with the other two mills there are upflow/downflow towers in each D stage. Wash presses follow each bleaching stage. Brightness is in the range 88-90% ISO.

To achieve consistent quality and cost efficiency the bleach plants have a high level of on-line instrumentation that allows tracking, analysis and optimal control of the bleaching process. Standard deviation of the final brightness is less than +0.5% ISO.

PERFORMANCE

The real measure of the success of these three mills is reflected in their overall performance – market, business and environmental performance. Control of the processes is excellent, product quality meets

TABLE IV. Fibre line performance

Parameters	Veracel	Hainan Jinhai	Arauco Valdivia	
Wood Species	*E.urograndis*	*Acacia E. grandis*	*P. radiata*	*E. Nitens E. globulus*
Digester				
Kappa Number	18	17 – 18	26	15
Kappa Std. Deviation	0.5		2.0	
Oxygen Delignification				
Delignification, %	38	30 – 44	61.5	37
Kappa Number	10.0	10 – 12	10	9.5
Kappa Std. Deviation	0.5		1.25	0.85
Washing Loss as kg COD/ADt	10.0	< 3	6	6
Bleaching				
Brightness, % ISO	90.4	88 – 90	89.3	90.1
Viscosity In, dm3/kg	1100		844	923
Viscosity Out, dm3/kg	880	700	737	833
Viscosity Loss, dm3/kg	220		107	110
Final Product				
Brightness, % ISO	90.4	88 – 90	90.3	90.6
Dirt, ppm	0.3	< 5[1]	0.7	0.9

Note: 1. Hainan dirt count units are mm^2/m^2.

TABLE V. Environmental parameters

Parameters	Veracel	Hainan Jinhai	Arauco Valdivia
Flow, m3/day	72,000	60,400	50,000
Primary Clarifier, # x m^3	1 x 25,080	Yes	1 x 5,000
Bio-Treat Type	activated sludge	Anaerobic & aerobic	ASB
Secondary, m^3	2 x 14.26	Yes	2 x 44,750
Sec Clarifier, # x m^3	–		2 x 8,700
Tertiary, m^3		Yes	2 x 590
Spill Containment	by area		by area
Emergency Basin, m^3	60,000		130,000
Nutrients Applied	N_2 as urea		
Cooling Towers	1		2
Final Effluent Parameters			
BOD, kg/adt	0.30		0.07
COD, kg/adt	6.7	< 3	1.5
TSS, kg/adt	0.67		0.23
AOX, kg/adt	0.06		0.03
Colour, kg/adt	520 mg/L		0.55
Temperature, °C	35		28.5

Note: 1. Hainan Jinhai figures from reference (3)
2. Arauco Valdivia data corresponds to official data from 2007

market standards, and environmental performance is among the best in the world. All three mills are low cost producers. Table IV outlines key parameters that are commonly used to measure the performance of each unit operation.

All mills have modern technology and good process control which results in minimal cellulose degradation and optimal fibre yields, low variability in process parameters and product quality, and minimum energy and chemical consumption. Mills typically produce one prime grade of pulp only, which eliminates grade switching and maximizes productivity.

Environmental performance

The mill effluent treatment systems and final effluent parameters are shown in Table V.

Veracel operates within the best environmental practices expected of a modern pulp mill. Effluent is treated in an activated sludge process and solid wastes are used to produce organic compost. The 2007 environmental performance figures show the consistent operation of the mill within its permitted discharge levels, internal targets and best available technology (BAT*) guidelines (Table VI).

The mill is believed to be amongst the best in the world in terms of effluent and air emissions, operating at approximately 50-75% of the legal limits. Water consumption is in the range of 22-24 m^3/tonne of pulp, with BOD and COD limits set at 0.3-0.4 kg/tonne and 5 kg/tonne, respectively. Veracel is probably the only mill that discharges its effluent upstream of its intake, which is a requirement of the mill's operating licence. Atmospheric emissions are permanently monitored. There is one common stack for all air emissions.

Emission control technology includes high efficiency electrostatic precipitators, an odorous gases (NCG) collection system, and stripping of foul condensates which are collected and burnt in the boilers. There is an odour perception network of 23 inhabitants in neighbouring communities.

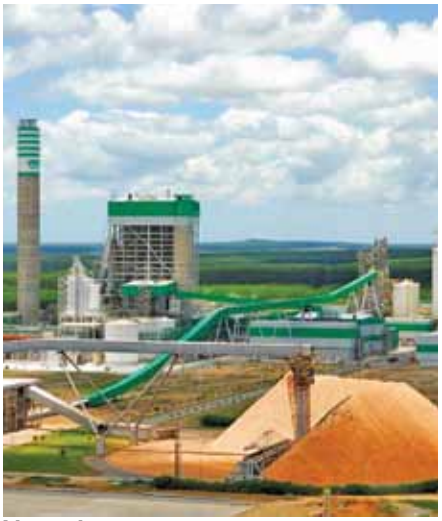
The Arauco Valdivia mill is located in an environmentally sensitive area, and based on some benchmarking of its permit, have some of the most stringent effluent limits for bleached kraft pulp mills anywhere. Valdivia has three permits that cover all parameters. The mill is in compliance with its permit targets.

The Valdivia effluent treatment system treats three main mill streams: the low solid sewer which includes bleach plant effluents and excess evaporator condensates; the general mill sewer including effluent from landfill and the woodyard; the storm water system. Key features of the treatment system include:

- a spill pond with spill pumps (130,000 m^3);
- Primary treatment for the main sewer including an automatic screen, primary clarifier, scraper, and fibre sludge pump;
- Neutralisation stage, and cooling towers (two chambers);
- Secondary treatment (two parallel lines)
- aerated basins, nutrient addition, secondary clarifiers, scrapers, and fibre sludge pumps;
- Tertiary treatment (parallel lines) – flocculation chambers, chemical addition (alum, polymer, peroxide), scrapers, and sludge pumps,
- Disc filters (three) in parallel, to reduce

Table VI. Veracel effluent performance compared with permit, BAT and internal targets

Parameters	Units	BAT*	Internal Target	Actual YTD Dec 07 Average
AOX Effluent	kg/adt	<0.25	< 0.15	0.06
COD Effluent	kg/adt	8 – 23	12.0	6.7
BOD5 Effluent	kg/adt	0.5-1.5	0.7	0.31
Suspended Solids	kg/adt	0.6-1.5	1.0	0.67
Water Usage	m^3/adt	-	30	27.7
Effluent Discharge	m^3/adt	30-50	27	24.7
TRS Recovery Boiler as H2S	ppm	-	0.20	0.05
TRS Lime Kiln as H2S	ppm	-	7.0	5.7
Odour Complaints	No.	-	0	11
Colour	mg/l	-	1000	520



Veracel

suspended solids;
• Cooling towers to control the final effluent temperature; and
• Sludge handling system including two belt filter presses for sludge dewatering.

Toxicological studies of acute toxicity (CL50) and chronic toxicity have demonstrated no impact in the recipient (river) environment. No lethal effects were detected for the species *H. gracilicornis, D. obtusa, G.. affinis. y O. mykiis, nor any chronic toxicity in L. valdiviana, S. capricornotum, G. affinis y O. mykiis.*

Hainan Jinhai must also meet strict environmental standards. Effluent treatment is a combination of anaerobic and aerobic in three stages: primary, secondary, and tertiary. Tertiary treatment is based on precipitation. Sludge from the treatment plant is dried and pressed to around 70% moisture and burned in the power boiler. All non-condensable gases from the fibre line are collected in a closed system and burnt in the recovery boiler. Hainan Jinhai reports an average water consumption of less than 30 m^3/t pulp and a total COD discharge of less than 3 kg/t pulp.

Hainan Jinhai and Arauco Valdivia both use a tertiary flocculation stage to remove additional organic material. This results in very low COD (and AOX) levels in discharged effluent compared to biological treatment alone, but incurs the expense of additional chemicals, and sludge handling and disposal. Sludge disposal options include land application or incineration. The use of additional chemicals may also increase the discharge of inorganic salts in the final effluent.

Tertiary treatment is considered in cases where receiving waters are of poor assimilative capacity, or otherwise restricted, and, as such, is identified as a supplemental or optional technology in recent BKP best technology reviews (Australia, 2004) [2].

Résumé: Nous avons passé en revue la conception et le fonctionnement de trois des plus récentes usines de pâte à avoir été érigées au 21e siècle. Il s'agit des papetières Veracel Cellulose d'Eunapolis au Brésil, une usine brésilienne produisant de la pâte kraft blanchie à partir d'eucalyptus; Hainan Jinhai, de Hainan en Chine, une usine de pâte kraft blanchie de feuillus; et Celulosa Arauco y Constitucion, de Valdivia au Chili, une usine chilienne de fabrication en discontinu de pâte d'eucalyptus et de pin de Monterey. La configuration de chaque ligne de production et les principales caractéristiques des technologies employées font l'objet de discussion. Le communiqué présente des données sur les moyens employés pour maximiser le rendement et réduire l'impact des opérations sur l'environnement.

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