TECHNICAL REPORT

ISO/TR 11371

First edition
2013-10-15

Pulps — Basic guidelines for laboratory refining

Pâtes — Lignes directrices pour le raffinage de laboratoire

Reference number
ISO/TR 11371:2013(E)

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Published in Switzerland

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Foreword

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The committee responsible for this document is ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 5.

Introduction

It is well known that the current standardized methods (PFI, Valley, Jokro, …) for refining/beating have only limited value in the evaluation of chemical pulps. They were originally developed for quality control purposes and have no counterpart in real mill operations.

The biggest shortcomings involved are the following:

— refining mode (energy consumption, refining intensity) is different from mill-scale refining processes;

— no possibility to adjust refining parameters for specific pulps;

— no direct measure for specific energy consumption.

These well-known standardized methods have fairly good reproducibility and repeatability and the equipment is easily handled. Nevertheless, many laboratories have replaced these methods by the use of so-called simulating laboratory refiners, which allow the evaluation of pulps for various mill-scale refining applications. No uniform methods for simulating refining have so far been established on an international scale.

Pulps — Basic guidelines for laboratory refining

1 Scope

This Technical Report gives guidelines for the laboratory refining of various pulps intended for paper production including:

— unifying terms and parameters for the simulation of industrial refining processes and laboratory refiners;

— treating pulp samples in a (semi) continuous operation in contrast to quasi-stationary laboratory beating equipment such as the PFI mill or Valley Hollander;

— evaluation of chemical market pulps under close-to-reality conditions in terms of refining intensity and refining energy consumption;

— optimizing of fibre furnishes in terms of cost, quality, and energy requirements;

— this Technical Report only considers refiners operating at low consistency.

2 Basics of pulp refining

Chemical pulps are seldom suitable for a specific end use as such. Refining is the most important process where the fibre properties are tailored to meet the demands of various paper and paperboard products.

The main target of refining is to improve the bonding ability of the fibres to enhance runnability and to give the paper good printing properties. Other targets can be, for example, to shorten fibres which can be too long, to give good sheet formation or to develop specific paper properties such as porosity or optical properties.

The most common refining method for chemical pulps is to treat the pulp suspension with metallic bars at low consistency. The bars are attached to a stationary element (stator) and to a rotary element (rotor). The pulp fibres pass through the gap between the rotor and the stator receiving impacts with varying number and intensity. In industrial refiners, the refining elements (fillings) can be disks, cones, or cylinders.

The fibres are affected by refining in several ways; the most common ones are as follows:

— cutting of the fibres;

— formation of fines by removing parts from fibre walls;

— external fibrillation giving the fibres a “hairy” look;

— internal changes in the fibre wall (internal fibrillation, swelling, or delamination);

— straightening or curling the fibre;

— creating or removing kinks, nodes, or microcompressions in the fibre wall;

— dissolving or leaching out colloidal material into the water phase;

— redistribution of hemicelluloses in the fibre wall from the interior to the exterior parts;

— formation of a gelatinous layer at the fibre surfaces.

As a result, the fibres become more flexible and conformable and their bonding area is increased. This is reflected in the pulp and sheet properties as follows:

— water removal in sheet forming is decreased (drainage resistance increased);

— strength properties promoted (tensile properties, burst, Z-directional strength, fracture toughness are increased);

— tear strength is increased or decreased depending on fibre characteristics and the extent of refining;

— structural properties (bulk, air permeability, and absorbency) are decreased;

— optical properties (light-scattering ability, opacity) are decreased, brightness only slightly.

3 Terms, abbreviation and definitions

The refining is affected by machine, refiner fillings, and process parameters listed in 4.1–4.3.

3.1 Machine parameters

Term	Abbreviation	Unit	Definition
Installed motor power	P_m	kW	Installed motor power of refiner main drive
Total load power	P_{tot}	kW	Measured power requirement of the refiner, with the fillings applied, under refining conditions, in the presence of a fibre suspension – constant gap
No-load power	P_0	kW	Power requirement for friction and pumping. Measured in water or fibre suspension in defined conditions for flow and open gap
Net refining power	P_{net}	kW	Difference between total load power and no-load power
Refiner rotational speed	n	1/min, 1/s	Revolutions of the refiner rotor per minute/second
Average peripheral velocity	v	m/s	Velocity of the rotor at the outer diameter of the refining zones of the refining elements at a defined refiner rotational speed. Sometimes defined as the velocity of a point at half-length of the refining zones of the refining elements at a defined refiner rotational speed.

3.2 Refiner fillings parameters

Term	Abbreviation	Unit	Definition
Refiner fillings			Tools used for pulp refining, including a stationary element (stator) and a rotating element (rotor) in the form of a plate or cone with bars and grooves
Rotor			Motor-driven (rotating) element of refiner fillings
Stator			Stationary element of refiner fillings
Fillings segment			Removable or exchangeable part of rotor or stator
Bar			Element cast, fabricated or machined onto the fillings surfaces which provide for pulp refining and transport of fibre suspension
Bar width	*bw*	mm	Width of a single bar on bar top
Number of bars			Total number of bars on the refiner fillings (rotor or stator)
Fillings sector			Area of refiner fillings segment – the sector or cluster angle, in which the bars/grooves are paired. Many sectors added to one another make a full disc.
Bar angle		°	Arithmetic average of the minimum and maximum angle between the middle line of a certain bar and radial lines over the start and end point of the bar
Average cutting angle		°	Sum of the average rotor bar angle and the average stator bar angle
Cutting edge length	*CEL*	km/rev, km/s	Total length of all bar edges in kilometers either per revolution in the running refiner or per second in the running refiner at a defined refiner rotational speed
Cutting length factor	*CLF*	m/s/rpm	Total length of all bar edges in meters per second in the running refiner at a refiner rotational speed of 1 rpm
Grooves			Channels between bars
Groove width	*gw*	mm	Width of the groove, synonymous with bar spacing
Groove depth		mm	Distance between the upper edge of the bar and base plate/base cone surface
Bar material and sharpness			There are various types of plates (cast, fabricated, and machined) having different metallurgy (supplied by the manufacturer). Bar sharpness greatly affects the refining result and should be checked regularly.

3.3 Refining process parameters

Term	Abbreviation	Unit	Definition
Refining gap		mm, µm	Distance between the top surface of rotor and stator bars
Refining time		min, s	Period of time from the start of refining to sampling or interval between two samplings
Flow	*f*	l/h, l/min, l/s	Fibre suspension flow through the refiner
Refining intensity	*I*		Various ways to describe (see formulas)
Specific (net) energy consumption	*SRE*	kWh/t	Net refining energy consumption related to the oven-dry mass of fibres treated

3.4 Definition of refining intensity

The refining result achieved for a pulp depends on many factors as mentioned earlier. Several models and theories, the first ones dating back to over a century, have been developed to describe the refining action. Usually they are based on describing refining by two factors: specific energy and refining

intensity. The specific energy is relatively easily measured but varying approaches have been used to describe the intensity.

3.4.1 Specific edge load (SEL)

The specific edge load theory published by Brecht et al. (see Reference [2]) is based on the idea that all the refining energy is transferred to the fibres by the bar edges. The parameters calculated are the net energy consumption, SRE [Formula (1)], and specific edge load describing the intensity, SEL [Formula (2)].

$$SER = \frac{P_{tot} - P_0}{f \times c} = \frac{P_{net}}{f \times c} \tag{1}$$

where

SRE specific refining energy (kWh/t o.d.);

P_{tot} total load power (kW);

P_0 no-load power (kW);

P_{net} net refining power (kW);

f flow (m^3/h);

c consistency (t/m^3).

$$SEL = \frac{P_{tot} - P_0}{n \times Z_r \times Z_{st} \times l} = \frac{P_{net}}{n \times CLF} = \frac{P_{net}}{CEL} \tag{2}$$

where

SEL specific edge length (J/m);

P_{tot} total load power (kW);

P_0 no-load power (kW);

P_{net} net refining power (kW);

n rotation speed (revs/s);

Z_r number of rotor bars;

Z_{st} number of stator bars;

l bar length (km);

CEL cutting edge length (km/s);

CLF cutting length factor (km/rev).

The specific edge load is still the most common way to describe refining intensity. It is a “machine intensity”, well known to work well when identical refiners are compared with the same pulps and refining conditions. It is in essence the energy per unit bar length per bar crossing.

3.4.2 Specific surface load (SSL)

The specific surface load theory developed by Lumiainen (see Reference [3]) is based on the idea that, in addition to bar length, bar width also affects the refining result. The energy is transferred to pulp fibres not only during the short edge-to-edge contact phase but also during the edge-to-surface phase. The specific surface load (SSL) value is obtained by dividing the specific edge load (SEL) by the bar width factor, length of the refining impact (IL), see Formula (3).

$$SSL = = \frac{SEL}{IL} \tag{3}$$

where

SSL specific surface load (J/m^2);

SEL specific edge load (J/m);

IL bar width factor (m).

The bar width factor is calculated from the bar width and the angular setting of the bars, see Formula (4).

$$IL = \frac{w_r + w_{st}}{2} \times \frac{1}{\cos(\frac{\alpha}{2})} \tag{4}$$

where

IL bar width factor (m);

w_r rotor bar width (m);

w_{st} stator bar width (m);

α average intersecting angle (°).

The specific surface load theory works better than the specific edge load theory when similar refiners with varying fillings are compared. Both theories still have weak points, but both offer practical tools in selecting fillings and other refining parameters.

3.4.3 Modified edge load (MEL)

Meltzer et al. developed the modified edge load theory (see Reference [4]), where the traditional specific edge load was corrected by factors taking the bar and groove width and cutting angle into account. The modified edge load (MEL) is calculated according to Formula (5).

$$MEL = \frac{bw + gw}{bw} \times \frac{1}{2\tan\varphi} \times SEL \tag{5}$$

where

MEL modified edge load [J/m]

bw bar width [mm]

gw groove width [mm]

ϕ cutting angle [°]

3.4.4 C-factor theory

The C-factor theory developed by Kerekes (see Reference [5]) is probably the most comprehensive one to date. As for other theories, it is based on the assumption that the specific refining energy can directly be related to the number of impacts and to the intensity of each impact, see Formula (6).

$$E = N \times l \tag{6}$$

where

E specific refining energy

N number of impacts

l specific energy/impact

The C-factor represents the capacity of the refiner to impose impacts on pulp fibres passing through. It links the power input and the pulp mass flow rate to the average number and intensity of impacts imposed on fibres, see Formulae (7) and (8). The calculation of the C-factor includes the geometry of fillings (bar/groove length, height, and width and cutting angle), refiner speed, refining gap, consistency, fibre length, and coarseness.

$$N = \frac{c - factor}{F} \tag{7}$$

$$I = \frac{P_{net}}{c - factor} \tag{8}$$

$$S = \frac{I}{l \times w} \tag{9}$$

where

N number of impacts;

F pulp mass flow;

I energy (intensity) of impact;

P_{net} net refining power;

S specific intensity;

l average fibre length;

w fibre coarseness.

The calculation of the C-factor and refining parameters includes various equations specific for conical and disk refiners, not presented here.

4 Laboratory refining procedures

Various types of pulp are evaluated by laboratory refining. Each pulp type has its own requirements for pulp preparation and refining procedure.

Main pulp types and their properties affecting pulp quality:

A Chemical pulps

Fibre raw material origin (sw, hw, non-wood)

Pulping process (kraft, sulphite, organosolv)

Bleaching [elemental chlorine free (ECF), total chlorine free (TCF)]

Drying (sheeted or flash dried)

B Mechanical and chemi-mechanical pulps

Fibre raw material origin (sw, hw, non-wood)

Chemical pre-treatment

Defibration process [groundwood (GW), pressure groundwood (PGW), thermomechanical pulp (TMP)]

Bleaching

Drying

C Recycled pulps

Fibre composition

Filler content

Processing conditions

D Synthetic pulps

Chemical pulps are the most common pulps for low-consistency (LC) refining in laboratory/pilot scale. Pulps entering the testing laboratory can be as follows:

Laboratory pulps

— never dried at low or medium consistency

— centrifuged to 20 % to 30 % consistency

— dried at the laboratory (90 % dry solids)

Mill pulps

— never dried

— wet pressed

— machine dried

— flash dried

4.1 Pulp preparation

Present standard methods for disintegration cannot be used as such before the actual refining trials. The pulp quantity for wet disintegration (ISO 5263) is too small for a refining trial. Moreover, the consistency (1,5 %) is clearly below the normal range of industrial LC refining which is typically 4 % to 5 % . For practical reasons, it would be best to carry out the disintegration in a pulper connected to or near to the refiner.

The pulp preparation method for refining should include a specification of the following items:

— Soaking before disintegration (optional, depending on pulp type and d.s.);

— Disintegration (construction of the disintegrator, consistency, time, temperature);

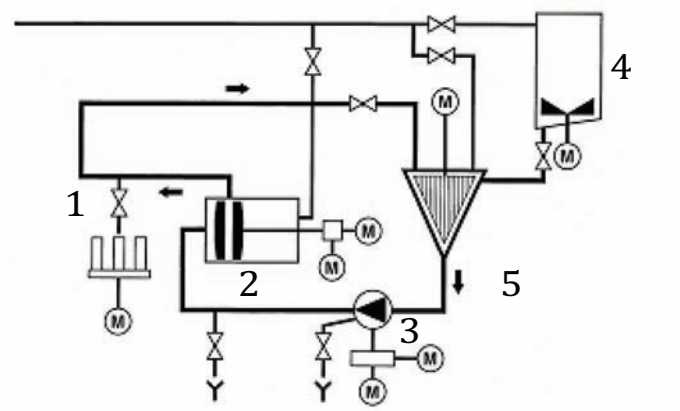
— Dwelling time after disintegration;

— Water requirements (distilled/deionized, tap, adjusted conductivity, or pH adjustment);

— pH adjustment.

4.2 Refining system

An example of a typical refining system with pulp circulation is shown in Figure 1.



Key

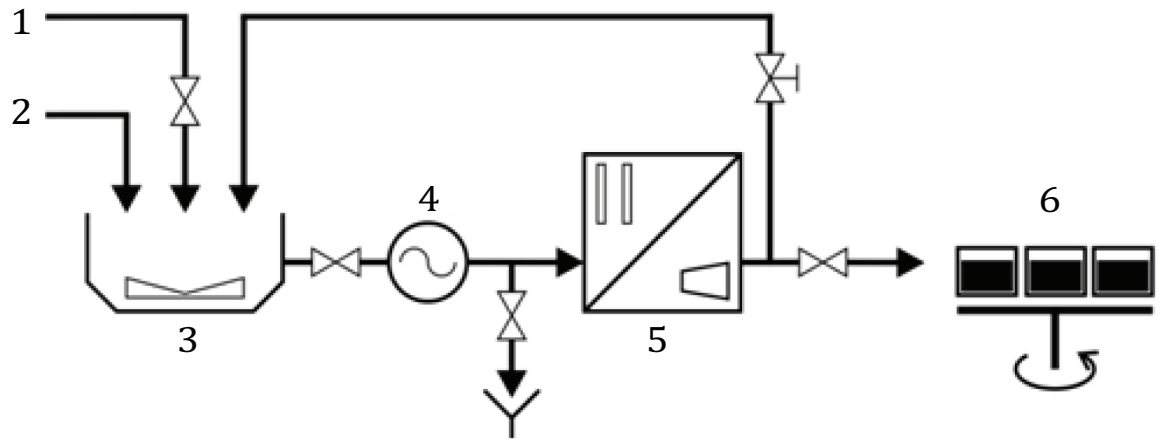
1 sampling
2 refiner
3 pump
4 pulper
5 process display

Figure 1 — An example of a typical refining system with pulp circulation (M →motor)

It consists of a pulper, infeed chest, recirculation pump, the refiner itself, and a sampling device with a rotating weighing table.

NOTE 1 Variation on this system might also include a stratifying infeed chest to minimize mixing of stock with successive passes through the refiner.

NOTE 2 A technical change has been made to the latest version of the refining system; the pulper also functions as the chest where the pulp can be mixed during the refining trial. The configuration is shown in Figure 2.



Key

1 water
2 furnish
3 pulper/chest
4 pump
5 refiner
6 sampling device with balance

Figure 2 — Alternative configuration of the refining system

In a normal trial, the disintegrated pulp to be refined is introduced into the infeed chest. The refining is started by circulating the pulp suspension in the system with the fillings in the "open" position, during which the no-load power is measured. When the refining starts, the net power needed for a predetermined specific edge load (SEL) is determined by adjusting the plate gap. The sampling system takes pulp samples automatically at predetermined specific energy consumption (SRE) levels. The samples taken are weighed for the correct timing of taking the next sample.

The system should include an automatic break-up to prevent bar contact (power limit) and an emergency stop button. The system shall have enough circulating pulp suspension for stable refining action. The maximum number and size of samples taken shall be adjusted accordingly.

In many cases, the refined pulp remaining in the system is needed for further studies. It should be possible to empty the system conveniently with minimal pulp losses before careful rinsing.

An advanced refiner system includes several types of fillings (disk, conical) which are easily interchangeable.

4.3 Measurements

At the beginning of the refining trial, after the disintegration, the following parameters shall be measured (or adjusted):

— consistency by adjusting the suspension volume/weighed o.d. pulp;

— temperature;

— conductivity;

— pH;

— no-load power with pulp suspension;

— pulp flow;

— system pressure;

— rotational speed of the rotor;

— rotor position (actual plate gap difficult to measure), optional;

— seal water addition.

The parameters should be monitored during the trial and collected automatically. An example of a test report from refining is shown in Annex 1.

4.4 Sample evaluation

The samples taken are prepared and tested preferably according to ISO standards using the latest version of this Technical Report. The following procedures and analyses are recommended (for bleached kraft pulps):

Preparation of laboratory sheets	
Disintegration	ISO 5263
Sheet forming	ISO 5269
Pulp properties	
Drainability, CSF	ISO 5267-2
Drainability, SR number	ISO 5267-1
Water retention value, WRV	ISO 23714
Fibre properties	ISO 16065-1, ISO 16065-2, ISO/TR 13159
Fines content (DDJ)	SCAN-CM 66
Sheet properties	
Testing conditions	ISO 186
Grammage	ISO 536
Tensile properties	ISO 5270, ISO 1924
Zero span tensile index (rewetted)	ISO 15631
Tear index	ISO 5270, ISO 1974
Internal bonding strength	Tappi T 569
Burst index	ISO 5270, ISO 2758
Apparent bulk density	ISO 5270, ISO 534
Air resistance, Gurley	ISO 5270, ISO 5636-5
Roughness, Bendtsen	ISO 8791-2
Optical properties	
ISO brightness	ISO 2470-1
Light scattering coefficient, light absorption coefficient	ISO 9416
Opacity	ISO 2471
Colour CIE L*, a*, b*	ISO 5631-1

An example of a report on testing is shown in Annex 2.

4.5 Parameters

The use of simulating type refiners with the specific edge load theory includes a large number of parameters to be specified. These include refiner parameters, fillings parameters, process parameters, and pulp suspension parameters. Examples of the most common conditions for laboratory refiners used for low-consistency refining of kraft pulps are shown in the table below.

Refiner parameters		**Range**	**Preferred**
Average peripheral rotational velocity of rotor	m/s	10-30	15-25
Rotational speed	rpm	1 500-2 500	2 000
Fillings parameters			
Bar width	mm		
Sw pulps conical		3-5	4
Sw pulps, disk		3-5	4
Hw pulps, disk		2-3	2,5
Hw pulps low intensity		1	
Groove width	mm		
Sw pulps conical		9-12	10
Sw pulps, disk		3-6	4
Hw pulps, disk		2-5	3
Hw pulps low intensity		1,2	
Cutting angles		10-60	
Process parameters			
Specific edge load	J/m		
Sw pulps conical		1-4	2,5
Sw pulps, disk		1-4	2,5
Hw pulps, disk		0,2-1	0,3-0,5
Hw pulps low intensity		0,05-0,2	0,1
Specific refining energy	kWh/t		
Sw pulps		0-400	
Hw pulps		0-200	
Suspension parameters			
Consistency	%	3-6	4
Starting temperature	°C	20-50	20-30
pH		variable	7
Conductivity of filtrate	mS/m	0-100	40-70

4.6 Maintenance

The system includes various technical components, the operation of which shall be monitored during the trials and checked periodically. It is important to follow the instructions of the machine supplier.

For a smooth and continuous operation, you need to have a quick access to technical support from electrotechnical, instrument, and IT experts.

4.7 Quality assurance

The refiner shall be regularly checked to maintain refining action and specific energy levels.

Measurement of no-load power with water should be a routine operation each time the refiner is started. After repair or change of fillings, the rotor position shall be calibrated with pulp suspension.

NOTE The calibration system is usually automatic and gives a pulp sample at fixed SRE (50 kWh/t). The drainage properties (CSF/SR) of the pulp sample are analysed.

Stability of the refining action shall be checked regularly by reference refining trials using standard reference BSKP and BHKP dried pulps which have been stored long enough for stabilization of their physical properties.

After refining these pulps in standard conditions, the essential pulp/sheet properties are tested using several methods. It is recommended that quality monitoring cards are used for: Fibre length, Fines content, Drainability (CSF/SR, WRV), Tensile properties, Tear index (BSKP), Bulk, Internal bond, and Scattering coefficient.

Quality monitoring faces challenges because of the experimental variation of

— homogeneity of the reference pulp,

— pulp preparation (soaking, disintegration, dwelling time),

— refiner (power control, condition of the fillings),

— sampling,

— preparation of laboratory sheets, and

— test methods for various properties.

The refining action changes over time in many cases due to the condition of the fillings. It can be changed by

— mechanical damage (bar contact, foreign objects),

— corrosion,

— wear of the bar and smoothness of its surface, and

— rounding of the bar edge.

5 Summary and guidelines

Simulating type refining is very difficult to standardize. It is more like a research tool for the optimization of refining for a specific pulp and end use. It is of course possible to define conditions for quality control type of laboratory refining. This kind of standard should, however, give different conditions (fillings parameters, specific edge load, SRE levels) for at least softwood and hardwood pulps because of their varying refining response. It is also questionable if this kind of standard would be optimal for benchmarking type of refining trials due to the variability in fibre characteristics within a pulp type.

Instead of a standard, the following guidelines on simulation type refining are given:

— refiner system based on the use of SEL/SRE, more advanced refining theories can be applied (and integrated to the control system);

— adjustment of conductivity to >40 mS/m to avoid fluctuations in drainability (SR, CSF);

— examples of parameter values for refining of softwood and hardwood pulps from 4.5;

— instructions on quality monitoring to maintain refining action and specific energy levels;

— test report forms as in Annexes 1 and 2;

— more detailed information on the refiner and fillings, extractable from the system can be given if needed (not in every day operation).

Annex A
(informative)

Trial Report

Date							
Work no.				**REFINER**			
Trial no.							
Fillings							
Type		Code		Cutting edge length km/s			
Pulp							
Name							
Quantity g.o.d.							
Disintegration							
Suspension volume	l						
Consistency	%						
Time	min						
Starting temperature	°C						
Water used							
Conductivity	mS/m						
pH							
Machine/process parameters							
Flow	l/min						
Rotational speed	rpm						
No load power (pulp)	kW						
Specific edge load	J/m						
Process data from trial							
Sample no.		1	2	3	4	5	6
Refining time:	min, s	0,0					
Sample: wet mass	g						
o.d. mass	g						
Remain mass quant	g						
Temperature:	°C						
Inlet pressure:	bar						

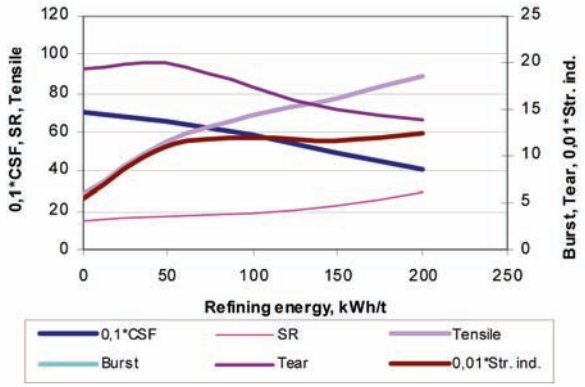
Total load power:	kW						
Net refining power:	kW						
Spec. edge load:	J/m						
Rotor position:	mm						
Total spec. energy:	kWh/t						
Net refining energy:	kWh/t						
Pulp drainage data							
CSF	ml						
SR							
WRV	g/g						

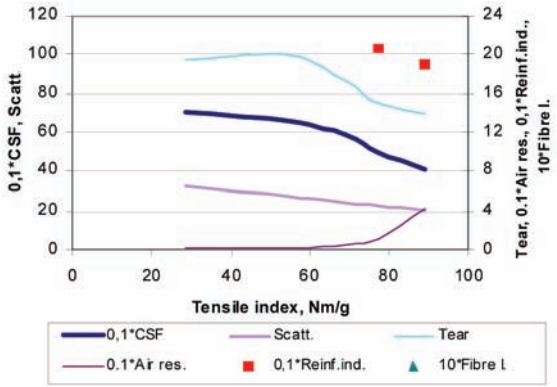
Annex B
(informative)

Report on pulp testing

Report on pulp testing												
Date		**9/30/2012**		**Bleached sw kraft** **Dried mill pulp**					Refiner	**LR1**		
Work no.		**X123_9**							Fillings	**Conical C60**		
Trial no.		**A12**							Specific edge load		J/m	2,5
									Consistency		%	4,0
									Conductivity of filtrate		mS/m	70
	SRE kWH/t	*CSF* ml	*SR* number	*WRV* g/g	L.w. fibre length mm	Coarseness mg/m	Tens.ind. N m/g	T.Stiff.ind kN m/g	Elong. %	Tear ind. mN m^2/g	Burst ind. mN m^2/g	Bulk cm^3/g
	0	700	14,5	1,20	2,50	0,180	28,5	3,85	2,9	19,4	1,9	1,83
	48	655	16,5	1,42	2,48		55,0	5,92	3,4	20,0	4,6	1,56
	99	585	19,0	1,56	2,49		68,9	7,00	3,3	17,3	5,7	1,48
	149	500	23,0	1,70	2,44		77,5	7,65	3,2	15,0	6,2	1,44
	200	410	29,0	1,80	2,42		89,0	8,34	3,3	13,9	6,8	1,40
INTER-POLATED	39	664	16,1	1,37	2,48		50	3,3	1,18	19,9	4,1	1,62
	105	574	19,5	1,60	2,48		70	3,3	1,58	17,0	5,8	1,48
	88	600	18,5	1,53	2,49		65,9	6,77	3,3	17,9	5,5	1,50
	149	500	23,0	1,70	2,44		77,5	7,65	3,2	15,0	6,2	1,44
		400										
	112	564	20	1,61	2,5		71,1	7,16	3,3	16,8	5,8	1,47
			30									
	SRE kWH/t	Density kg/m^3	Air res. (Gurlet) s	Scott bond J/m^2	Scatt. Coeff. m^2/kg	L/abs. coeff. m^2/kg	Opacity %	Brightness %	Strength ind. Tens*Tear	Zero-span (wet) Nm/g		
	0	546	0,9	144	31,9	0,12	73,0	85,3	554	123		
	48	639	2,1	256	27,3	0,11	69,6	84,2	1098	123		
	99	675	4,7	339	24,1	0,11	66,8	83,3	1195	119		
	149	692	12	426	22,5	0,11	65,2	82,8	1162	126		
	200	713	43	517	20,7	0,11	63,1	82,4	1238	126		

Report on pulp testing												
INTER-POLATED	39	621	1,9	235	28,1	0,11	70,3	84,4	995	123		
	105	677	5,6	350	23,9	0,11	66,6	83,3	1190	120		
	88	667	4,2	321	24,8	0,11	67,4	83,5	1174	120		
	149	692	12	426	22,5	0,11	65,2	82,8	1162	126		
	112	679	6,5	361	23,7	0,11	66,4	83,2	1186	121		





Sheet forming	ISO 5269-1	SR number	ISO 5267-1	Tensile properties	ISO 1924-2	Air res/ (Gurley)	ISO 5636-5	Zero span	ISO 15361
Sheet testing	ISO 5270	Freeness	ISO5267-2	Tear	ISO 1974	Scatt. Abs.	ISO 9416		
Testing conditions	ISO 186	WRV	ISO23714	Burst	ISO 2758	Opacity	ISO 2471		
Water	ISO 14487	Fiber length	ISO 16065	Internal bond	Tappi T569	Brightness	ISO 2470		

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ICS 85.040

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