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Pulps — Basic guidelines for laboratory refining

Pâtes — Lignes directrices pour le raffinage de laboratoire

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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)].

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

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).

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

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).

$$SSL = = \frac{SEL}{IL} \qquad (3)$$

where

SSL specific surface load (J/m2);

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).

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

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).

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

where

MEL modified edge load [J/m]

bw bar width [mm]

gw groove width [mm]

ϕ cutting angle [°]