TECHNICAL SPECIFICATION

ISO/TS 11371

First edition
2023-07

Pulps — Guidelines for using laboratory refiners to simulate industrial low consistency refining

Pâtes — Lignes directrices relatives à l'utilisation de raffineurs de laboratoire pour simuler le raffinage basse consistance industriel

Reference number
ISO/TS 11371:2023(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

This first edition of ISO/TS 11371 cancels and replaces ISO/TR 11371:2013, which has been technically revised.

The main changes are as follows:

— the focus lies exclusively on simulating industrial refining with laboratory refining;

— the basics of refining are further elaborated;

— Clause 3 has been updated;

— the refining procedures have been reviewed and detailed;

— the clause on pulp preparation and the two annexes have been removed.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

It is well known that the current standardized method (PFI mill method) for beating has only limited value in the evaluation of pulps. It was originally developed for quality control purposes and has no counterpart in real mill operations since the fibre property development is based on a different principle.

The biggest shortcomings are the following:

— The refining principle is different from mill-scale refining processes (controlled by energy consumption, refining intensity);

— No possibility to adjust refining parameters for specific pulps;

— No direct measure for specific energy consumption;

— Not consistent and correct usage of terms.

This well-known standardized method has good reproducibility and repeatability and the equipment is easy to handle. Nevertheless, many laboratories have replaced this method by the use of refiners enabling them to simulate industrial refining and to allow the evaluation of pulps for various mill-scale refining applications.

The objective of this document is to address the related topics by providing a common basis with regard to refining parameters, definitions, and procedures.

Pulps — Guidelines for using laboratory refiners to simulate industrial low consistency refining

1 Scope

This document provides guidelines for the laboratory refining of various pulps intended for paper production including:

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

— Treatment of pulp samples in a (semi) continuous operation in contrast to the batch operation of laboratory beating equipment such as the PFI mill;

— Evaluation of fibres for papermaking, in particular chemical market pulps, under close-to-reality conditions in terms of refining intensity and refining energy consumption.

This document only considers refiners operating at low stock concentration, i.e. 3 % to 5 %.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Machine parameters

3.1.1
total load power
P_{tot}
power provided to the refiner during refining of a fibre suspension to modify fibre properties and overcome friction and the pumping effect

Note 1 to entry: It is expressed in kW.

3.1.2
no-load power
P_0
power required to overcome friction and the pumping effect measured in water or fibre suspension (at refining stock concentration) in defined conditions for flow and open gap

Note 1 to entry: It is expressed in kW.

3.1.3
net refining power
P_{net}
difference between total load power and no-load power

Note 1 to entry: It is expressed in kW.

3.1.4
refiner rotational speed
n
revolutions of the refiner rotor per minute or per second

Note 1 to entry: It is expressed in 1/min or 1/s.

3.1.5
tangential speed
v
speed of the rotor at the outer diameter of the refining zones of the refining elements at a defined refiner rotational speed

Note 1 to entry: It is expressed in m/s.

3.1.6
average tangential speed
$\bar{v}$
tangential speed of a point at half-length of the refining zones of the refining elements at a defined refiner rotational speed

Note 1 to entry: It is expressed in m/s.

3.2 Refiner fillings parameters

3.2.1
filling
exchangeable plates used for fibre treatment (refining), including a stationary element (stator) and a rotating element (rotor) in the form of a disk, cone or cylinder with bars and grooves

3.2.2
rotor
motor-driven (rotating) refiner filling

3.2.3
stator
stationary refiner filling

3.2.4
bar
one of a number of structures of rectangular cross-section on the active surface of the rotor and stator filling

Note 1 to entry: It may be cast, fabricated or machined into the surface of an element. The bars cause the refining of fibres (see Figure 1) and transport of the fibre suspension.

3.2.5
bar width
$b_{r,s}$
width of a single bar at the bar surface (rotor or stator)

Note 1 to entry: It is expressed in mm.

3.2.6
number of stator bars
z_s
total number of stator bars on the refiner filling

3.2.7
number of rotor bars
z_r
total number of rotor bars on the refiner filling

3.2.8
average rotor bar angle
α_r
angle formed between the rotor bars and the radius for disc fillings

Note 1 to entry: It is expressed in °.

3.2.9
average stator bar angle
α_s
angle formed between the stator bars and the radius for disc fillings

Note 1 to entry: It is expressed in °.

3.2.10
average cutting angle
ϕ
sum of the average rotor bar angle and the average stator bar angle

Note 1 to entry: It is expressed in °.

3.2.11
cutting edge length
C_{EL}
CEL
total length of all bar edges at a defined refiner rotational speed

Note 1 to entry: It is expressed in km/s.

3.2.12
cutting length factor
C_{LF}
CLF
total length of all bar edges for one complete rotation of the rotor

Note 1 to entry: It is expressed in m·min/s.

3.2.13
grooves
channels between bars

3.2.14
groove width
g
distance between two bars (rotor or stator)

Note 1 to entry: It is expressed in mm.

3.3 Process parameters

3.3.1
refining gap
distance between the top surfaces of rotor and stator bars

Note 1 to entry: It is expressed in mm or µm.

3.3.2
refining time
period of time from the start of refining to sampling or interval between two samplings

Note 1 to entry: It is expressed in min or s.

3.3.3
stock concentration
c
ratio of the oven-dry fibre mass that can be filtered from a stock sample, to the mass of unfiltered sample

Note 1 to entry: It is expressed in %.

3.3.4
flow rate
f
fibre suspension flow rate through the refiner

Note 1 to entry: It is expressed in l/h, l/min, l/s or m^3/h.

3.3.5
mass flow rate
F
fibre mass flow rate through the refiner

Note 1 to entry: It is expressed in kg/s or t/h.

3.3.6
refining intensity
I
how force is transferred to the fibre

Note 1 to entry: See Clause 5.

3.3.7.1
net specific refining energy
S_{RE}
SRE
<continuous process> net refining power per oven-dry mass flow rate of fibre

Note 1 to entry: It is expressed in kWh/t or kJ/kg.

3.3.7.2
total specific refining energy
S_{RE}
SRE
<continuous process> total refining power per oven-dry mass flow rate of fibre

Note 1 to entry: It is expressed in kWh/t or kJ/kg.

3.3.7.3
net specific refining energy
S_{RE}
SRE
<batch process> product of the net refining power and the time for which it is applied per oven-dry mass of fibre

Note 1 to entry: It is expressed in kWh/t or kJ/kg.

3.3.7.4
total specific refining energy
S_{RE}
SRE
<batch process> product of the total refining power and the time for which it is applied per oven-dry mass of fibre

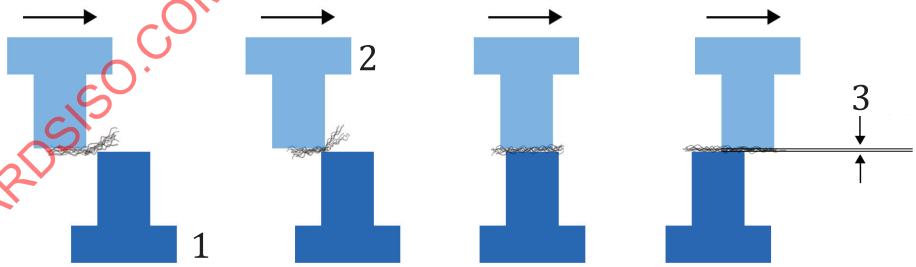
Note 1 to entry: It is expressed in kWh/t or kJ/kg.

4 Basics of pulp refining

Fibres usually need treatment to meet the required paper or board quality. Refining is the most important process step for achieving this, which it does by modifying the fibre properties.

The main purpose of refining is to improve the bonding ability of the fibres. Depending on the product, this is required to increase strength, enhance runnability, increase stiffness, improve printing properties, modify porosity or increase transparency, or a combination of these. It can also be used to improve sheet formation by reducing the length of fibres, which are too long, or to modify some other paper property.

The most common refining method for chemical pulps is to treat the pulp suspension at low stock concentrations using metallic bars according to the bar-to-bar principle (Figure 1). The bars are attached to elements knows as fillings, a stationary element (stator) and a rotary element (rotor). The pulp fibres pass through the gaps between the rotor and the stator bars receiving impacts, which can be varied in number and intensity. In industrial refiners, the refiner fillings can be disks, cones, or cylinders.



Key
1 stator
2 rotor
3 refining gap

Figure 1 — Bar-to-bar refining principle

Refining affects fibres in several ways. The most common effects are as follows:

— External fibrillation;

— Internal fibrillation (changes in the fibre walls, swelling, and delamination);

— Cutting of the fibres;

— Fines generation by removing parts from fibre walls;

— Straightening of the fibres;

— Creating or removing kinks, nodes, or micro compressions in the fibre walls;

— Dissolving or leaching out colloidal material into the water phase.

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

— Rate of water removal during sheet forming is decreased (drainage resistance increased);

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

— Tearing resistance 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 and lightness only slightly)

5 Refining intensity

5.1 General

The refining result achieved for a pulp depends on many factors as mentioned earlier. Several models and theories, the first ones dating back more than a century, have been developed to describe the refining action. Usually they describe refining by two factors: specific refining energy and refining intensity. The specific energy is relatively easily measured but varying approaches have been used to describe the intensity.

5.2 Specific Edge Load (SEL)

The specific edge load theory[3] 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 specific refining energy, S_{RE}, as given in Formula (1) and specific edge load, S_{EL}, as given in Formula (2) describing the refining intensity.

$$S_{RE} = \frac{P_{tot} - P_0}{f \cdot c} = \frac{P_{net}}{f \cdot c} \tag{1}$$

where

S_{RE} is the net specific refining energy (SRE) (kWh/t o.d.);

P_{tot} is the total load power (kW);

P_0 is the no-load power (kW);

P_{net} is the net refining power (kW);

f is the flow rate (m^3/h);

c is the stock concentration (%).

For a disc element, calculating the cutting edge factor, C_{LF}, by breaking the disc into N radial regions of length Δr

$$S_{EL} = \frac{P_{tot} - P_0}{n \cdot z_r \cdot z_s \cdot l} = \frac{P_{net}}{n \cdot C_{LF}} = \frac{P_{net}}{C_{EL}} \quad (2)$$

where

S_{EL} is the specific edge load (J/m);

P_{tot} is the total load power (kW);

P_0 is the no-load power (kW);

P_{net} is the net refining power (kW);

n is the rotational speed (1/min);

z_r is the number of rotor bars (-);

z_s is the number of stator bars (-);

l is the bar length (m);

C_{EL} is the cutting edge length (km/s);

C_{LF} is the cutting length factor (m·min/s).

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 refiners are compared with the same pulps and refining conditions. It is in essence the energy per unit bar length per bar crossing.

5.3 Specific Surface Load (SSL)

The specific surface load theory[4] 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, S_{SL}, value is obtained by dividing the specific edge load, S_{EL}, by the bar width factor, I_L,, as given in Formula (3).

$$S_{SL} = \frac{S_{EL}}{I_L} \quad (3)$$

where

S_{SL} is the specific Surface Load (SSL);

S_{EL} is the specific Edge Load (SEL);

I_L is the bar width factor (m).

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

$$I_L = \frac{b_r + b_s}{2} \cdot \frac{1}{\cos\frac{\phi}{2}} \quad (4)$$

where

I_L is the bar width factor (m);

b_r Is the rotor bar width (m);

b_s is the stator bar width (m);

ϕ is the average cutting 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.

5.4 Modified Edge Load (MEL)

The modified edge load theory[5] corrected the traditional specific edge load by factors taking the bar and groove width and cutting angle into account. The modified edge load, M_{EL}, is calculated as given in Formula (5) assuming the same filling design for rotor and stator.

$$M_{EL} = \frac{b+g}{b} \cdot \frac{1}{2 \cdot \tan\alpha} \cdot S_{EL} \tag{5}$$

where

M_{EL} is the modified edge load (MEL) (J/m);

b is the bar width (mm);

g is the groove width (mm);

α is the average bar angle (°).

5.5 C-Factor Theory

The C-Factor theory[7] is probably the most comprehensive one to date. As 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 according to Formula (6).

$$E = N \cdot I \tag{6}$$

where

E is the specific refining energy (kJ/kg);

N is the number of impacts per mass of pulp (1/kg);

I is the energy/impact (kJ).

The C-Factor, 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 N, see Formula (7), and intensity, I, of impacts, see Formula (8) imposed on fibres. The calculation of the C-Factor includes the geometry of fillings (bar/groove length, height, and width and cutting angle), refiner speed, refining gap, stock concentration, fibre length, and coarseness. Based on the intensity, I, of impacts one can also derive the Energy, S, per mass of a single fibre according to Formula (9).

$$N = \frac{C_{factor}}{F} \tag{7}$$

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

$$S = \frac{I}{l_F \cdot w} \tag{9}$$

where

N is the number of impacts (-);

F is the pulp mass flow rate (kg/s);

I is the energy/impact (kJ);

P_{net} is the net refining power (kW);

S is the energy per mass of a single fibre (kJ/kg);

l_F is the average fibre length (mm);

W is the fibre coarseness (µg/m).

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

6 Pulp types and properties

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

Main pulp types and their properties affecting pulp quality:

A Chemical and semichemical pulps

Fibre raw material origin (softwood, hardwood, non-wood)

Pulping process (kraft, sulphite)

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

Drying (sheeted or flash dried)

B Mechanical, thermomechanical and chemi-thermomechanical pulps

Fibre raw material origin (Softwood, hardwood, non-wood)

Chemical pre-treatment

Bleaching

Drying

C Recycled pulps

Fibre composition

Filler content

Processing conditions

Chemical pulps are the most common pulps for low-consistency (LC) refining in the laboratory or in a pilot scale refiner. Pulps can enter the testing laboratory in different conditions. This is considered in the pre-treatment prior to refining.

Laboratory pulps:

— Never dried at low or medium stock concentration;

— Centrifuged to 20 % to 30 % stock concentration;

— Dried in the laboratory (90 % solids).

Mill pulps:

— Never dried;

— Wet pressed;

— Machine dried;

— Flash dried.

7 Laboratory refining procedures

7.1 Refining parameters

The use of simulating laboratory refiners requires 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 Table 1.

Table 1 — Refining parameters

Refiner parameters		**Range**	**Recommended**
Average tangential speed	m/s	15 to 25	15 to 25
Refiner inlet pressure (controlled)	bar	0,5 to 1,5	1,0
Fillings parameters			
Bar width	mm		
Softwood pulp		3 to 5	3
Hardwood pulp		2 to 3	2
Average cutting angle	°		
Softwood pulp		10 to 60	50 to 60
Hardwood pulp		10 to 60	30 to 40
Process parameters			
Specific edge load	J/m		
Softwood pulp		1,0 to 4,0	2,0
Hardwood pulp		0,2 to 1,0	0,4
Net specific refining energy	kWh/t		
Softwood pulp		0 to 400	0-50-100-150-250
Hardwood pulp		0 to 250	0-40-80-120-160
Suspension parameters			
Soaking time before pulping	h	0 to 5	0 to 5[a]

[a] Depending on fibre type and condition.

Table 1 *(continued)*

Refiner parameters		Range	Recommended
Pulping time	min	3 to 15	3 to 15[a]
Pulping temperature	°C	20 to 40	30
Water conductivity	mS/m	0 to 100	ISO 14436 >40 and <150
[a] Depending on fibre type and condition.			

7.2 Pulp preparation

The present standard method (ISO 5263-1) for disintegration cannot be used before trials in a laboratory refiner as the pulp quantity for wet disintegration is too small. For practical reasons, it is best to carry out the disintegration in a pulper near or connected to the refiner (Figure 2).

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

— Soaking time before disintegration (optional, depending on pulp type and dry content);

— Disintegration (construction of the disintegrator, stock concentration, time, temperature, fibre type);

— Swelling time after disintegration;

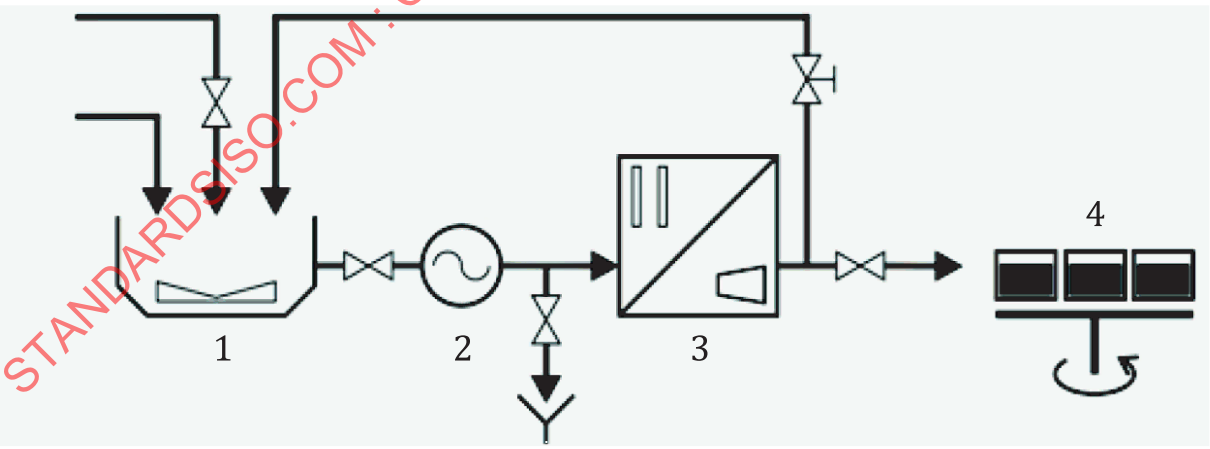
— Water requirements (distilled/deionized, tap, adjusted conductivity, or pH adjustment);

Table 1 contains the recommended settings for pulp preparation.

7.3 Refining system

7.3.1 General

Figure 2 shows a typical refining system with pulp circulation.



Key

1 pulper
2 pump
3 refiner
4 sampling device

The pulper can also function as a recirculation chest.

Figure 2 — Typical refining system