Faculty of Mechanical Engineering, Institute of Wood and Paper Technologies, Professorship of Paper Technology

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Application of high-power ultrasound in fibre suspensions to increase the strength of paper

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DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Agenda

- Introduction
- Theory
- Ultrasound equipment
- Ultrasound treatment of virgin wood fibres
- Ultrasound treatment of recycled fibres
- Measuring of cavitation

Introduction

Å The most important objective of refining is to improve the binding ability of fibres and thus the tensile strength of the paper made from them.

Å The desired improvement is in the first place a function of the fibresô additional specific surface generated through refining.

Å Refining, however, is the most energy intensive sub-process in stock preparation lines of paper mills. And it is ï almost inevitably ï accompanied by fibre cutting which results in higher drainage resistances as well as in losses in tear strength.

Å Fibres from lower grade recovered papers as frequently used for the manufacture of packaging papers would particularly suffer from these impacts because such papers usually require a certain level in tear strength.

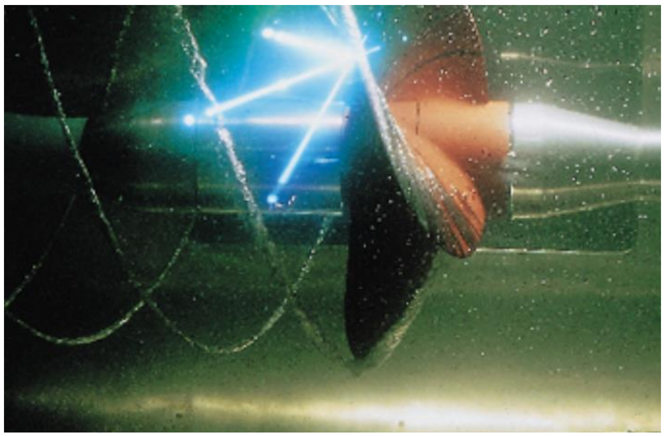
Å In order to nevertheless meet given strength requirements the addition of starch or synthetic dry strength additives might be necessary.

Å It would be by far more preferable if a process were available which would allow a gentle treatment of the fibres at low energy demand.

Å The ultrasound treatment of fibre suspension could offer a corresponding alternative.

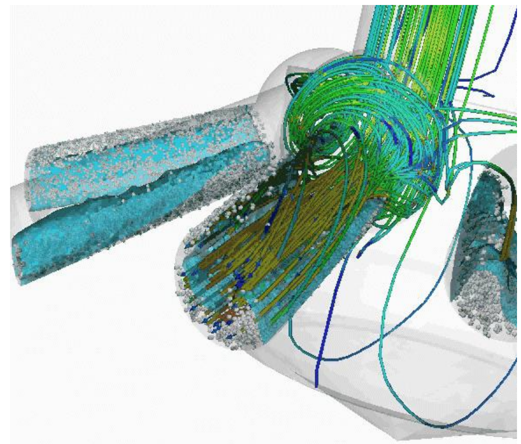
Theory - Cavitation

Cavitation at a running ship propeller



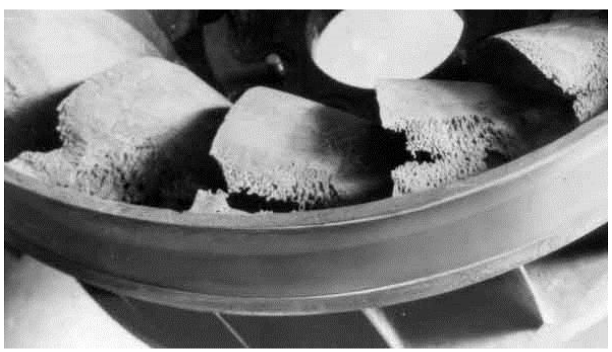
Source: Pelz, F., Ludwig, G., Kompaktkurs ñKavitationò, Institut für Strömungs-mechanik TU Dresden, 2011

Cavitation inside the fuel valve of a Diesel engine



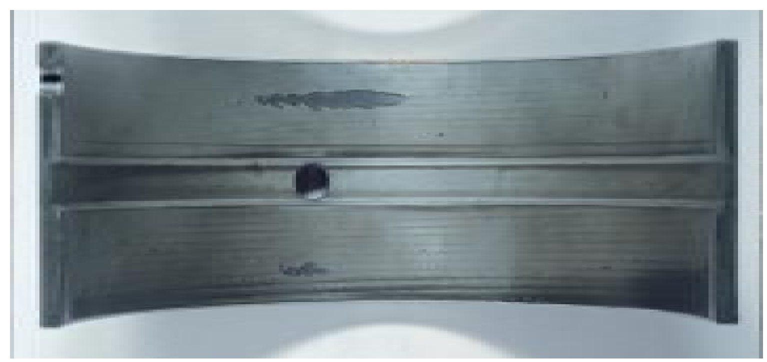
Source: Fluid Research, http://www.fluid-research.com, 2013

Cavitation at pump impeller



Source: Brennen, C.H., Cavitation and bubble dynamics, 1995

Cavitation at journal bearing (inside the oil film)



Source: Miba Gleitlager AG ï Lager-schäden, 2013

Theory - Cavitation

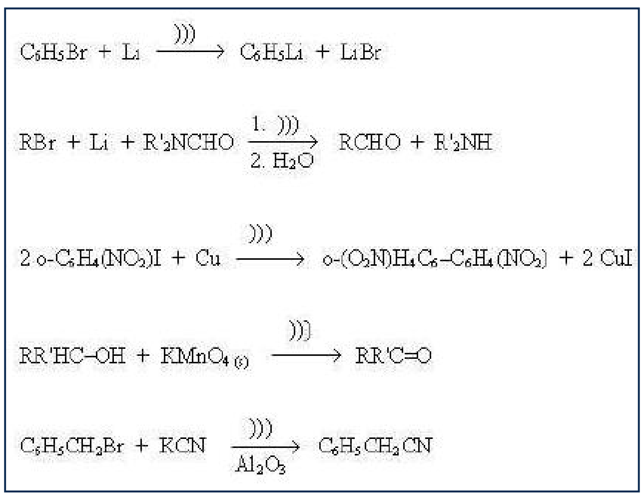
Effects of cavitation

Å Temperature: >> 1000 K

Å Pressure: >> 100 bar

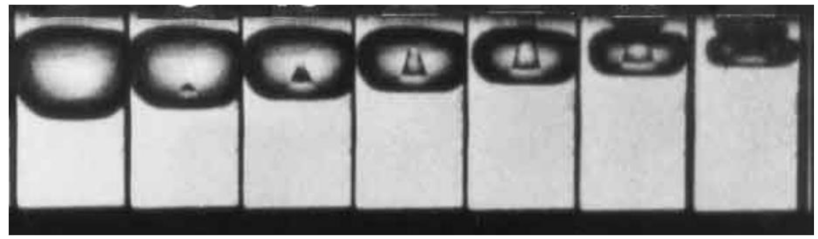
Å Speed of micro jet: >> 100 km/h

Chemical reactions and formations of radicals



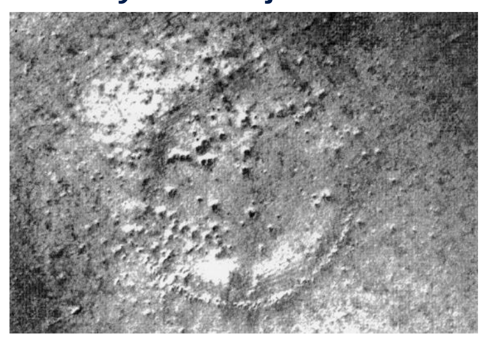
Source: Suslick, S., The chemistry of ultrasound, http://www.scs.illinois.edu

Development of micro jet in a bubble



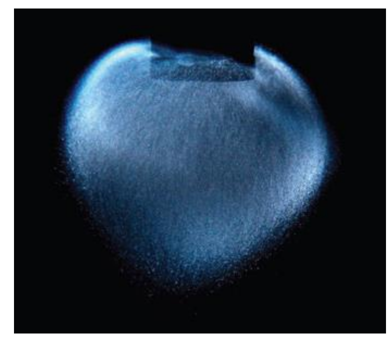
Source: Brennen, C.H., Cavitation and bubble dynamics, 1995

Erosion on aluminium foil by micro jets



Source: Düx, P., et. al., Von der Kavitation zur Sonotechnologie, 2000

Sonoluminescence from ultrasound



Source: Suslick, K., Inside a collapsing Bubble: Sonoluminescence, 2007

Theory – Ultrasound

Sound

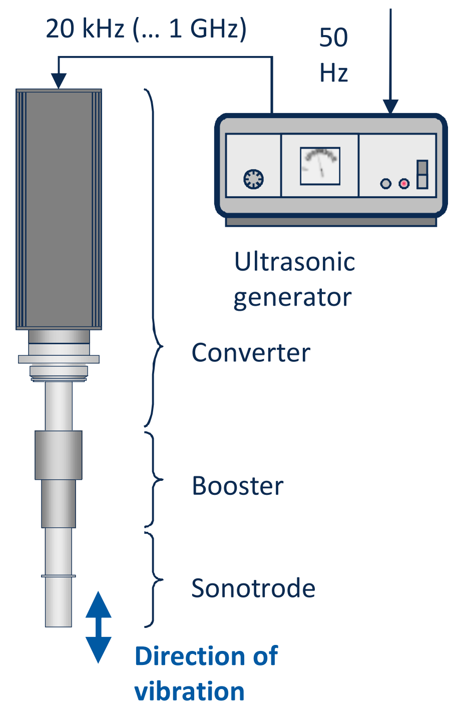
Vibrations	Frequency range
Infrasound (not audible)	< 16 Hz
Sound (audible)	16 Hz - 20 kHz
Ultrasound (not audible)	20 kHz - 1 GHz
Hypersound (not audible)	> 1 GHz

Ultrasound

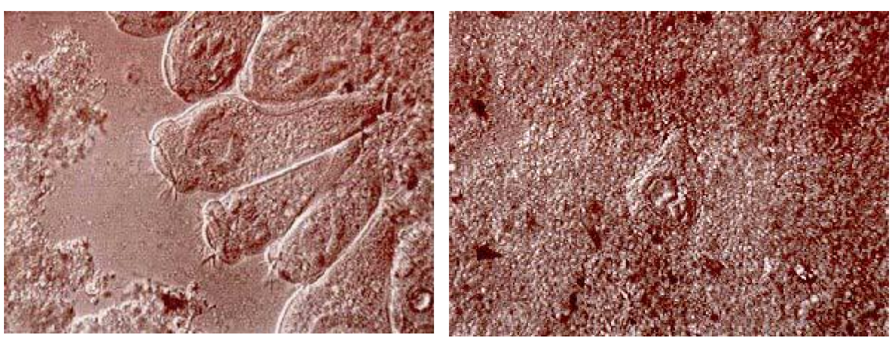
Å High frequency mechanical waves above the human limit of audibility

Å Ultrasound can propagate in gases, liquids and solids

Å In liquids already low intensity ultrasound can induce **acoustic cavitation**



Sewage sludge disinte-gration



Source: Eder, B., Großtechnische Untersuchungen zur Klärschlamm-minimierung, 2002

Measuring of cavitation - Optical

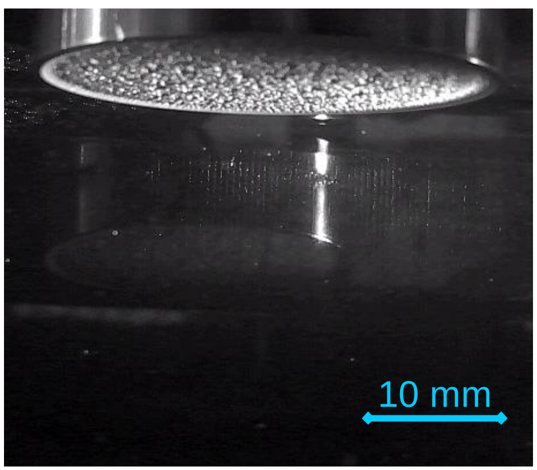
Cavitation field

Å Ultrasound UIP 1000, Hielscher Ultrasonics GmbH, Sonotrode BS2d34, (D = 34 mm)

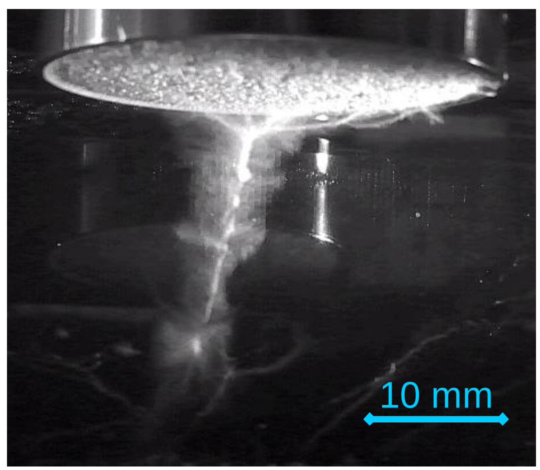
Å Medium: water, Immersion depth Sonotrode: 10 mm, Temperature: 20°C

Å Motion Analysing Microscope: Keyence VW 6000, Optical unit: Keyence VH-Z00R, RZ5ï 50x, scattered light

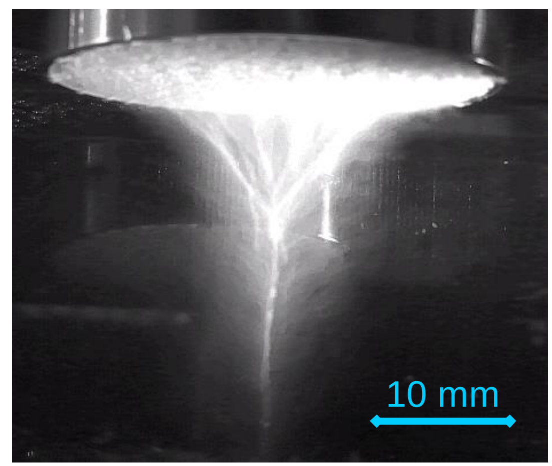
Amplitude (pkpk) 0 µm
Intensity 0 W/cm²



Amplitude (pkpk) 10 µm
Intensity 10 W/cm²



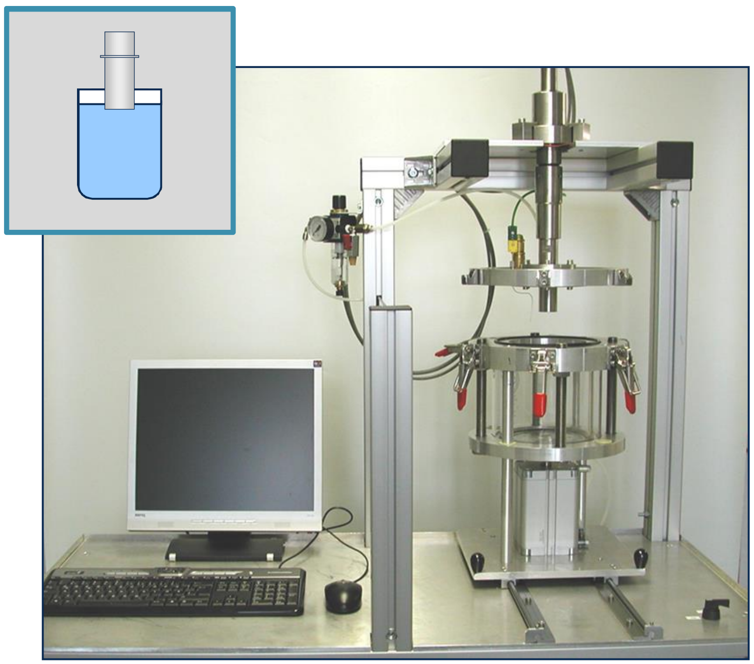
Amplitude (pkpk) 28 µm
Intensity 30 W/cm²



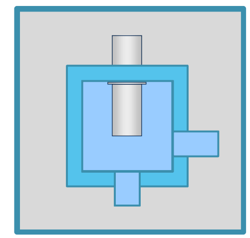
Ultrasound equipment

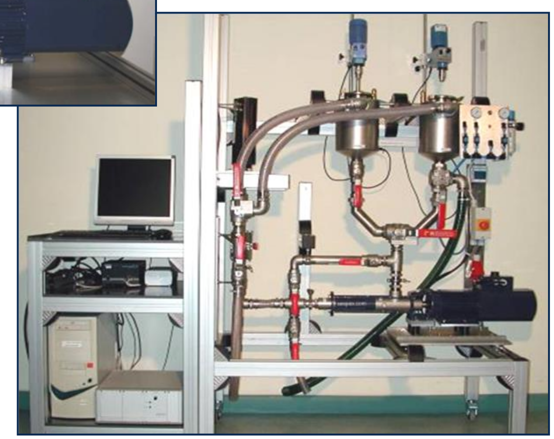
Laboratory plant

Discontinuous ultrasonic treatment (Batch-cell)



Continuous ultrasonic treatment (flow cell) (UDA-PTS, UDA-PPT)





Ultrasound equipment

Continuous ultrasonic treatment (flow cell) for the exposure of fibre suspensions to ultrasonic waves

Parameters of the ultrasonic flow system:

Å Frequency: 20 kHz

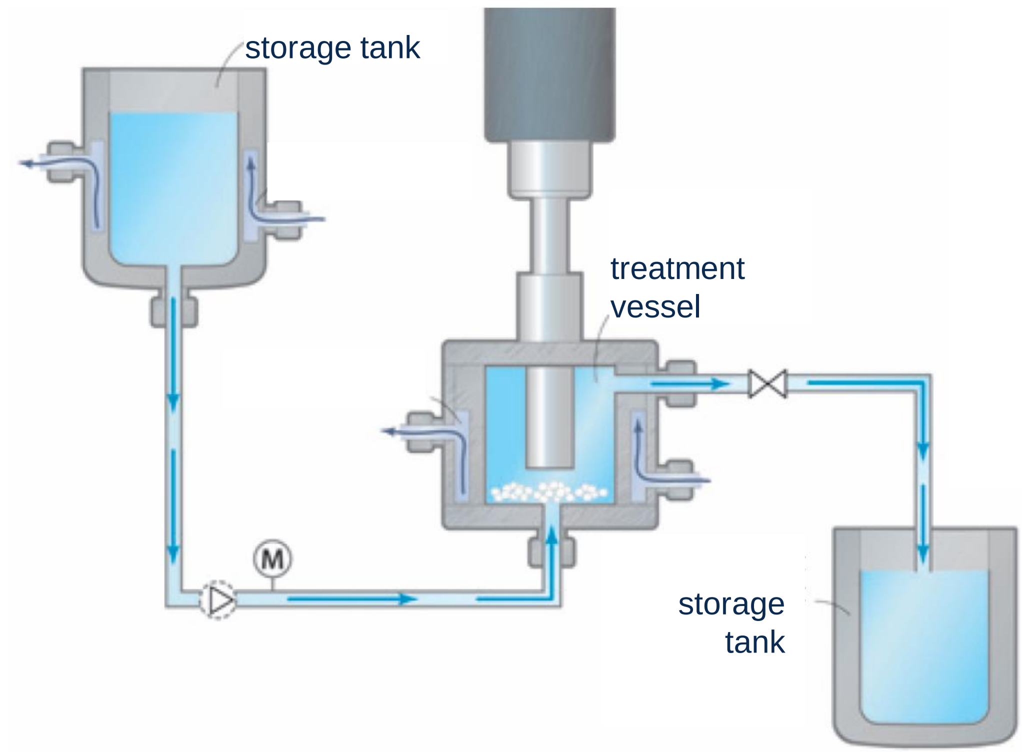
Å Amplitude: 2é 160 µm (pk to pk)

Å Power: max. 1000 W gross

Å Sound intensity: 4é 440 W/cm^2

Å Sonotrode Ø: 10, 18, 22, 34, 40 mm

Å Pressure: 0é 5 bars



Source: Ingo Jänich, Ultraschall+Technologien, 2009

Refining equipment

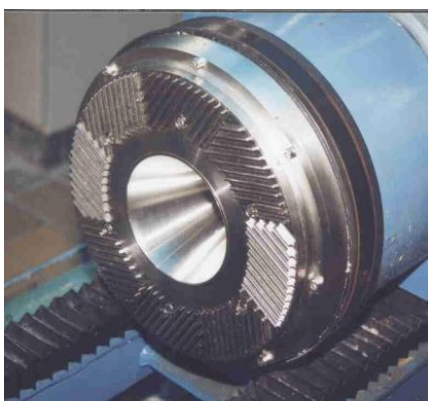
Pilot refiner of PTS

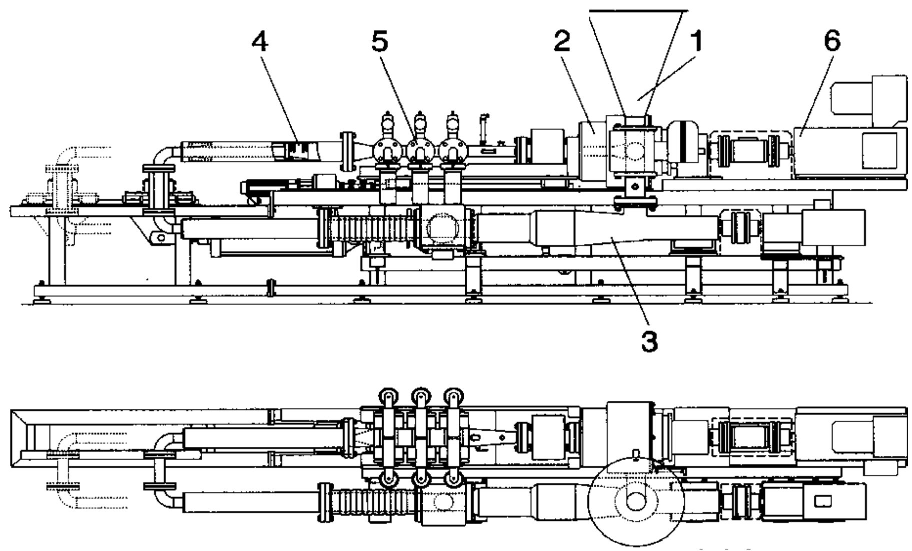
Å Fillings: disc or conical (Ø 300 mm)

Å Specific edge load: 0,5é 5 Ws/r

Å Motor drive: max. 2000 RPM

Å Stock consistency: max. 8%





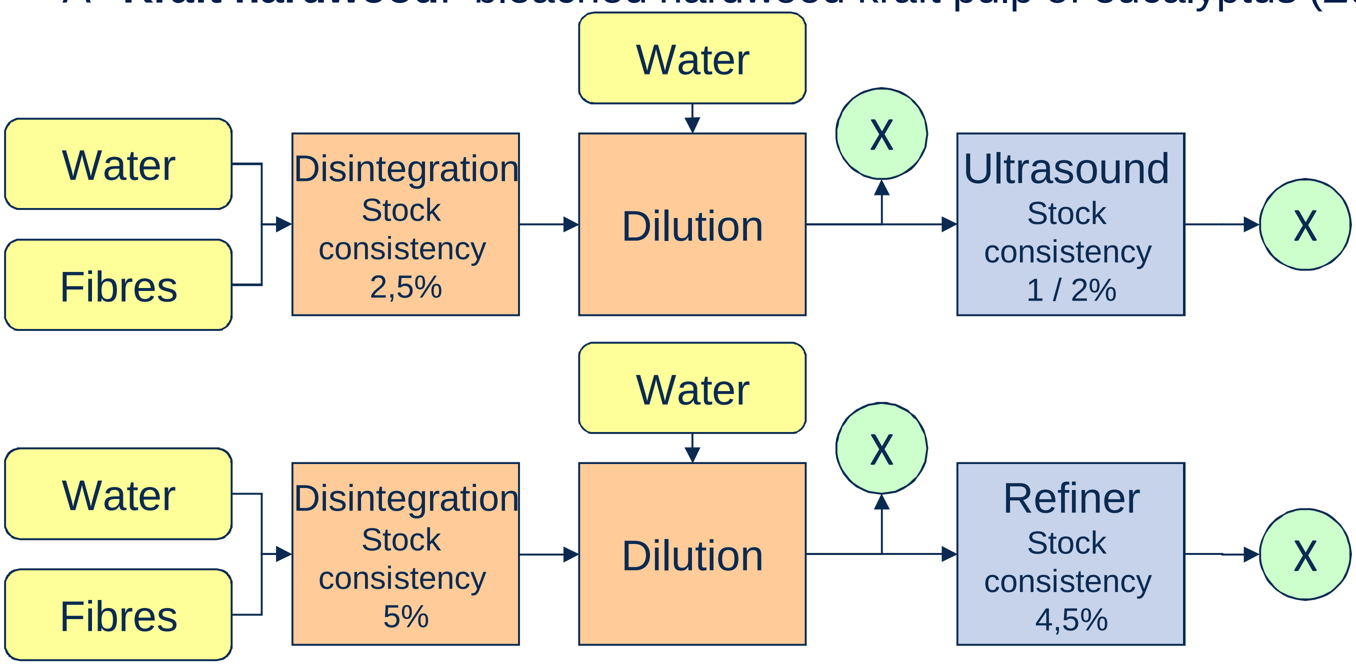
1	Pulp tank	4	Volume adjustment
2	Refiner	5	Samples
3	Pump	6	Motor drive

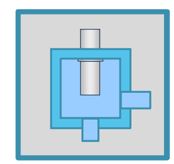
Methods – Virgin wood fibres

Experimental design ï Ultrasound treatment vs. refining in a disc refiner

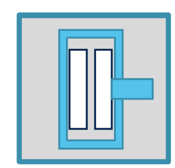
Å **Kraft softwood**: bleached softwood kraft pulp consisting of 80% spruce (*Picea abies*) and 20% pine (*Pinus sylvestris*)

Å **Kraft hardwood**: bleached hardwood kraft pulp of eucalyptus (*Eucalyptus globulus*)





Intensity 135 W/cm² (HW)
Iintensity 90 W/cm² (SW)
Amplitude 125 µm



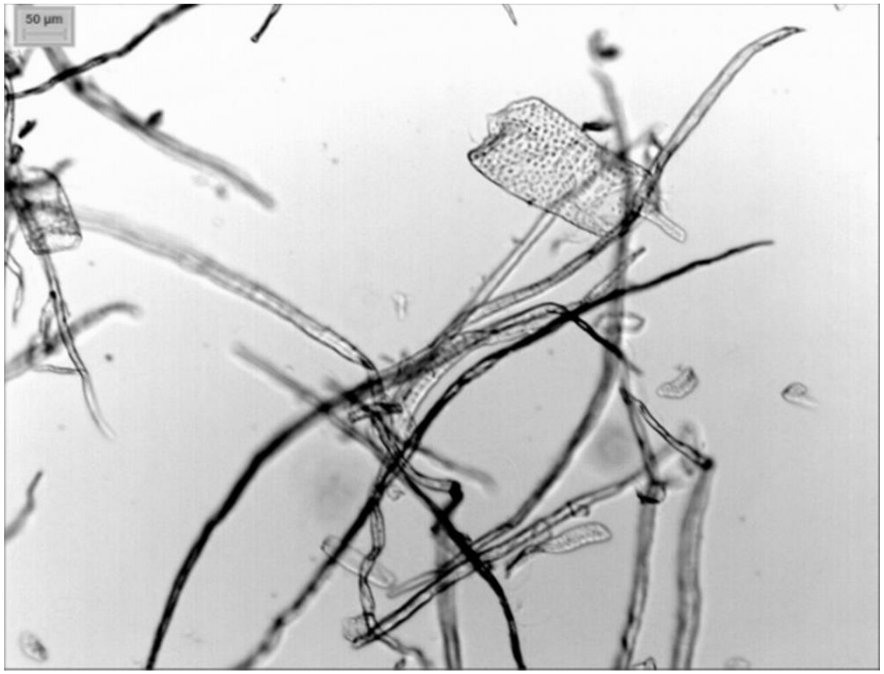
Specific edge load 1,0 Ws/m

X → Pulp: Drainage resistance, Water retention value WRV, FiberLab, Intrinsic viscosity (DP), Light microscopy
→ Paper sheets (Rapid-Köthen, 80 g/m²): Strength properties, SEM, Porosity (DSC)

Results – Virgin wood fibres

Light microscopy of pulp suspension

Eucalyptus, untreated

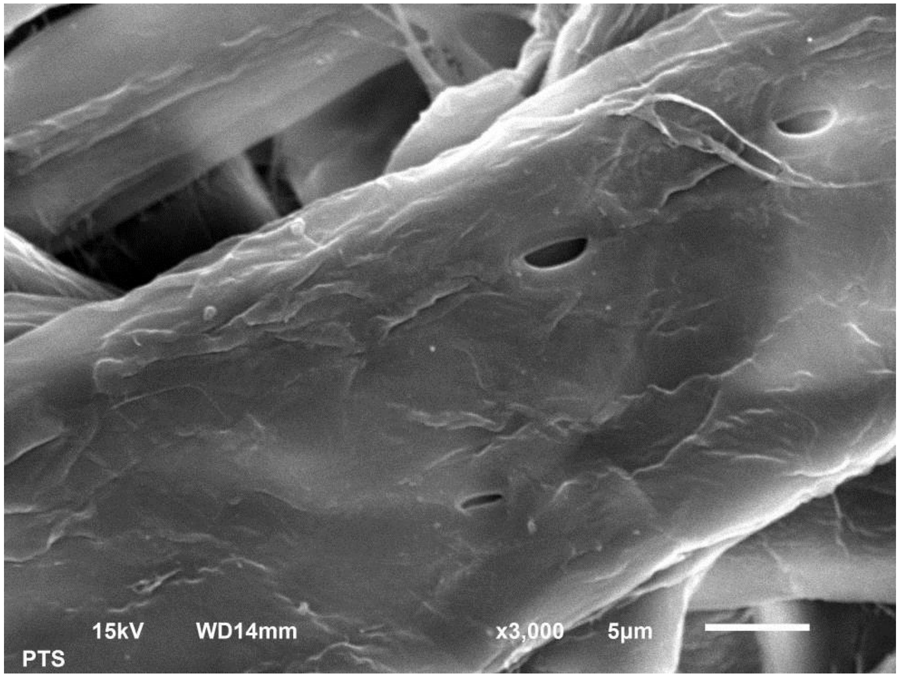


Eucalyptus, Ultrasound treatment

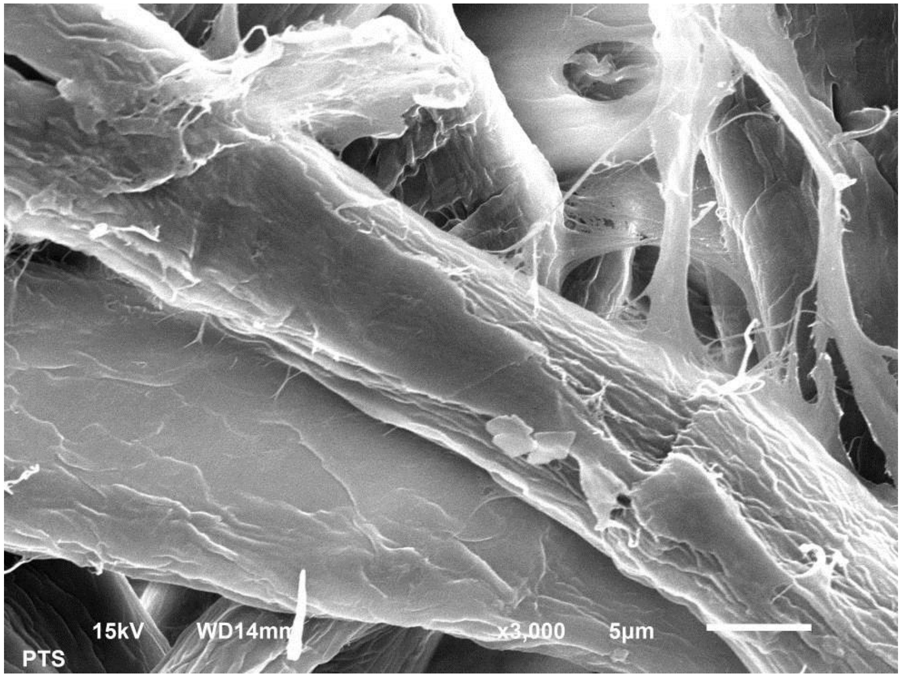
Results – Virgin wood fibres

Scanning Electron Microscopy of Rapid-Köthen sheets

Eucalyptus, untreated

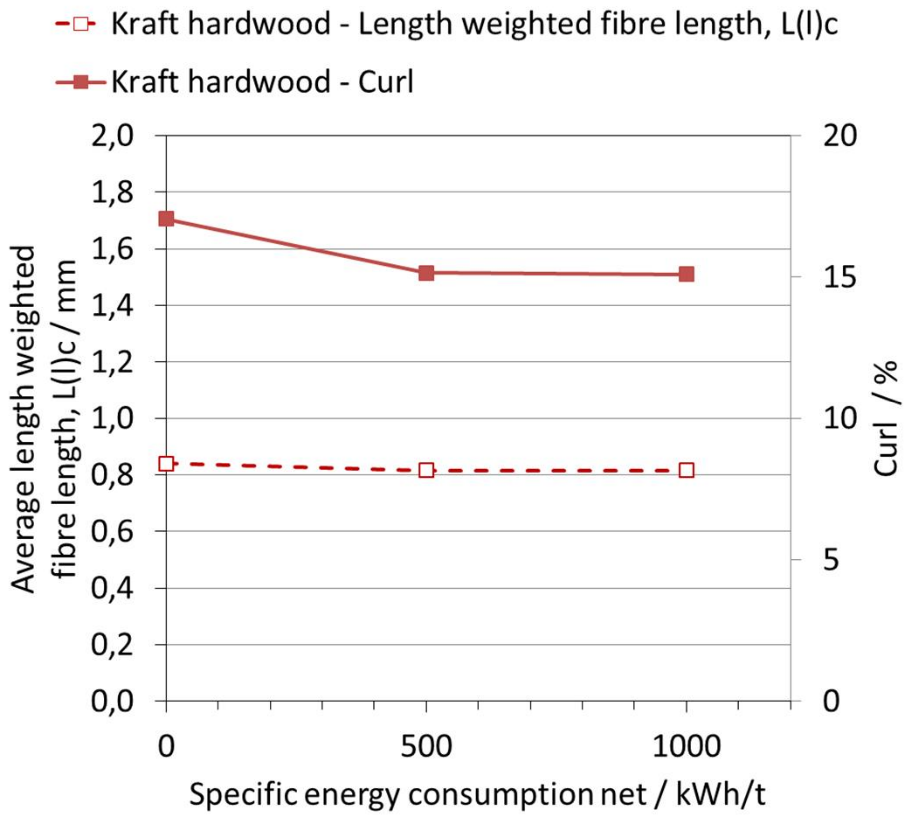


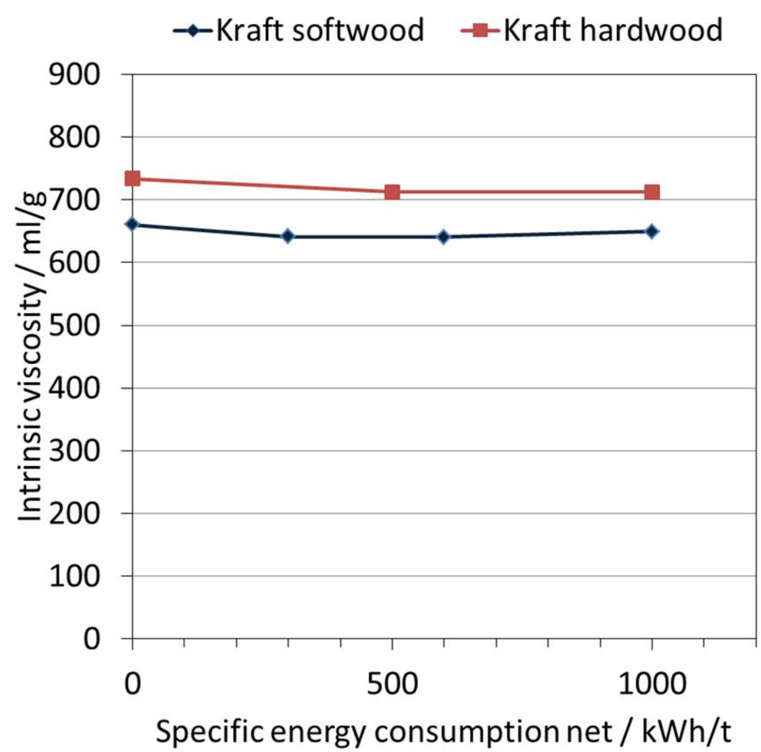
Eucalyptus, Ultrasound treatment



Results – Virgin wood fibres

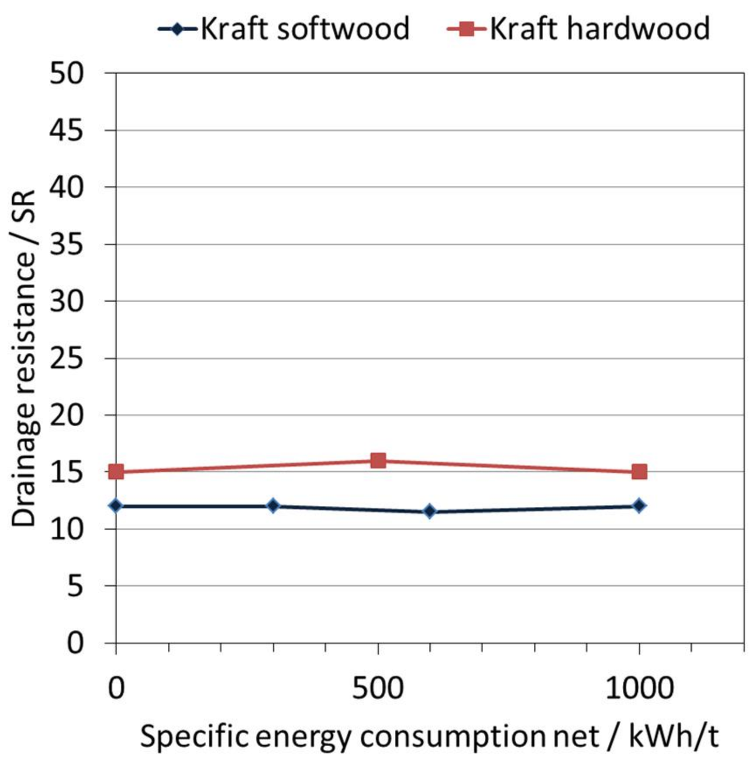
Ultrasound treatment

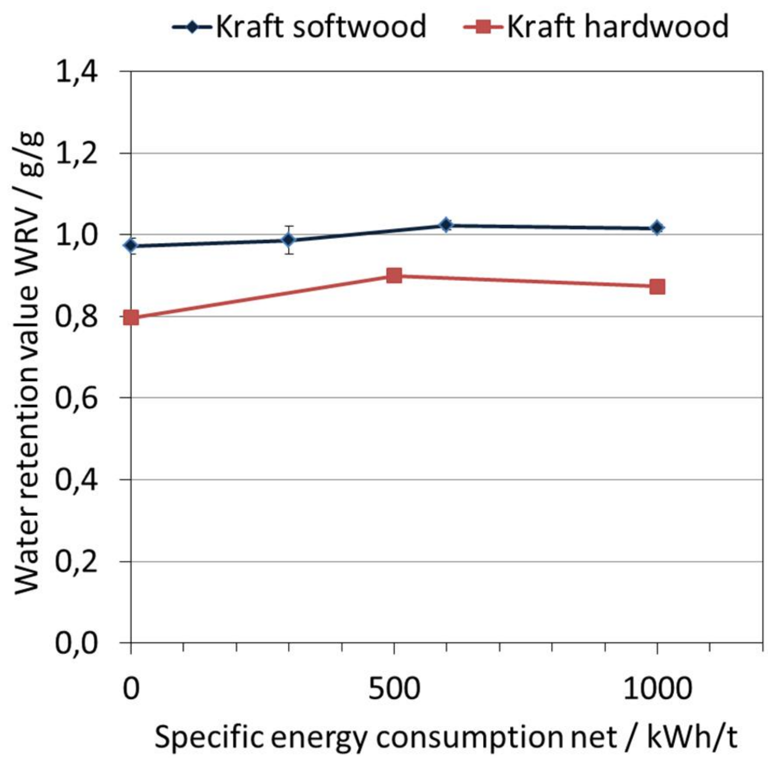




Results – Virgin wood fibres

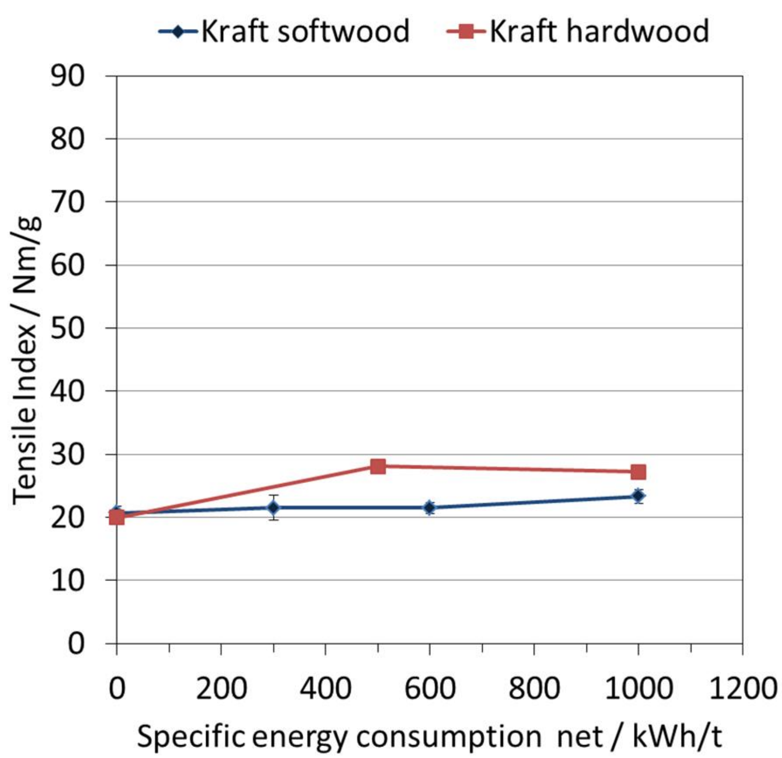
Ultrasound treatment



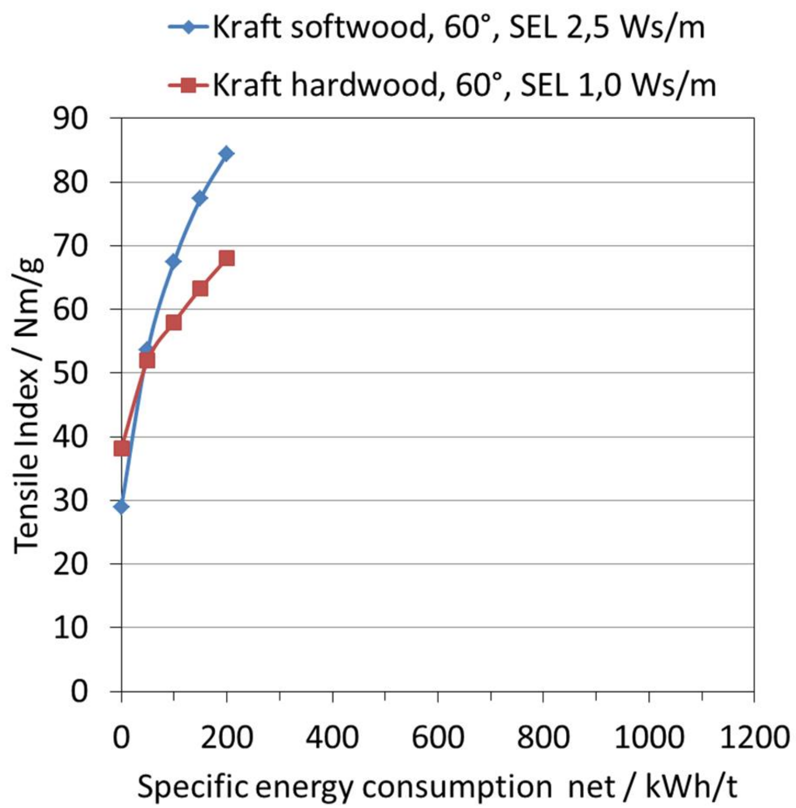


Results – Virgin wood fibres

Ultrasound treatment



Treatment in pilot disc refiner



Results – Virgin wood fibres

Conclusions

Å Water retention values of both, softwood and hardwood pulp are slightly higher after ultrasound treatment while drainage resistance is not changed.

Å A significant external fibrillation typical after refining pulp in a disc refiner can not be observed after ultrasound treatment.

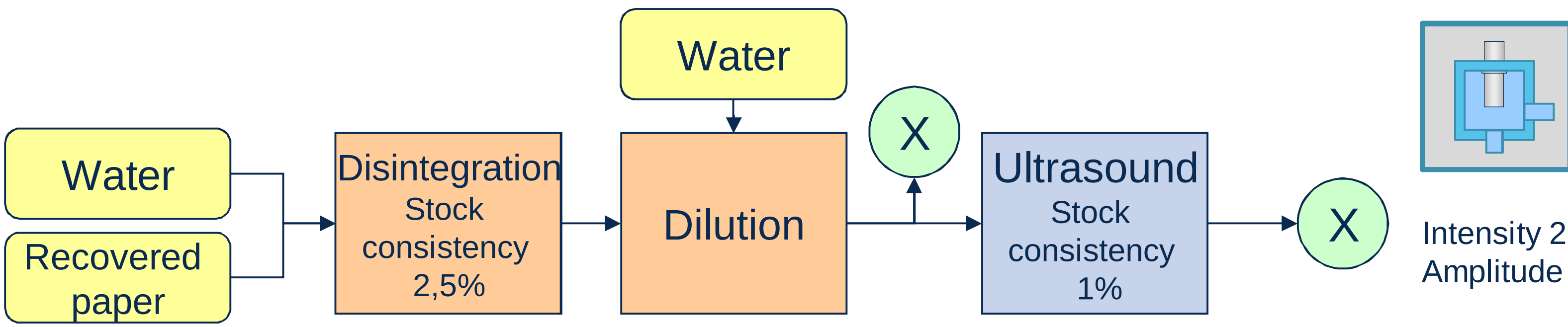
Å The increase in tensile strength after ultrasound treatment is - compared to the treatment in refiners - far less for the same specific energy consumption.

Å Tensile strength after ultrasound treatment increases by 40 % for hardwood kraft pulp (SEC 500 kWh/t) and by 12% (SEC 1000 kWh/t) for softwood kraft pulp.

Methods ï Recycled fibres for packaging paper

Experimental design - Ultrasound treatment

Å **Recovered paper mixture** (grades 1.02, 1.04 (EN 643))

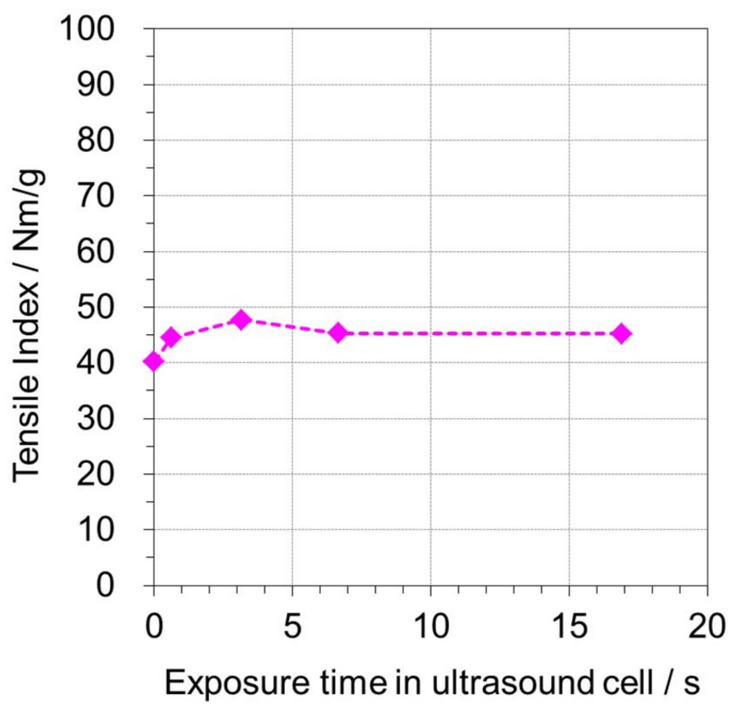


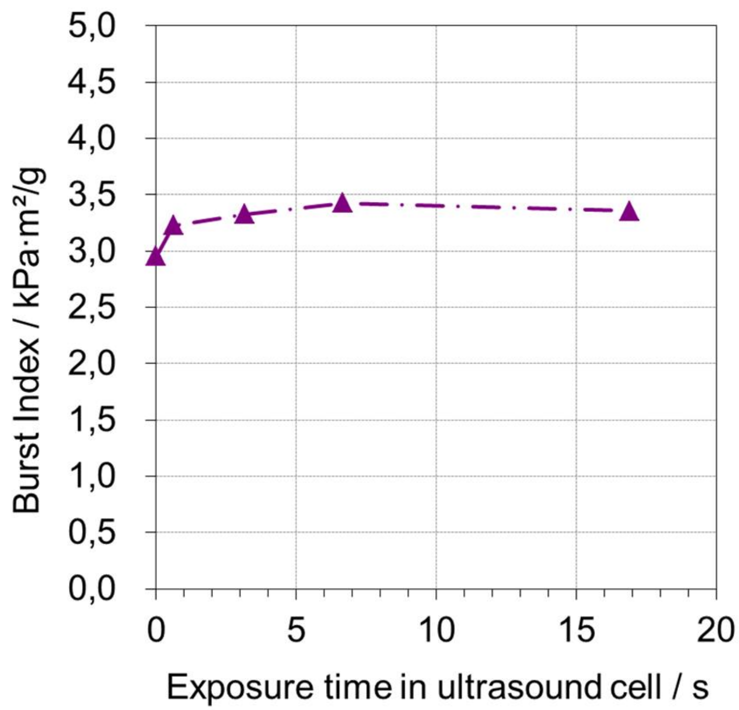
Intensity 28 W/cm²
Amplitude 61 µm

X → Pulp: Drainage resistance, FiberLab, Water retention value WRV
→ Paper sheets (Rapid-Köthen, 80 g/m²): Strength properties

Results – Recycled fibres for packaging paper

Ultrasound treatment

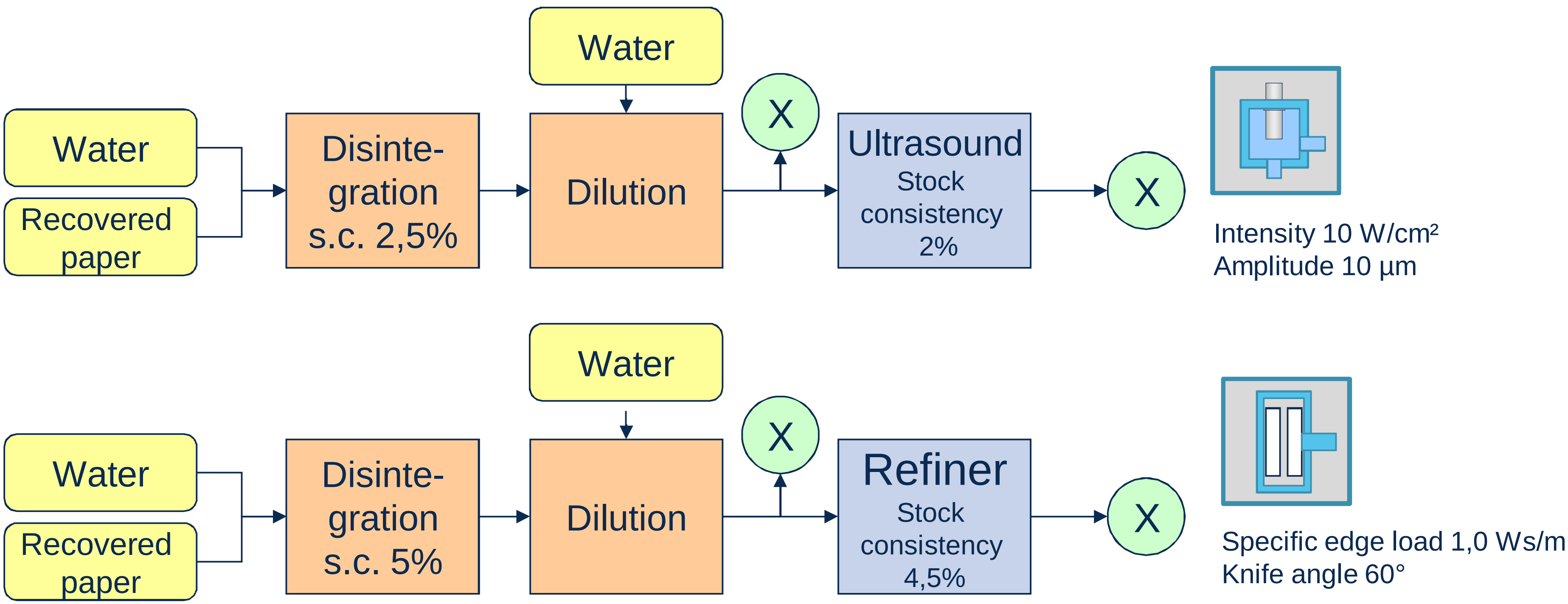




Methods ï Recycled fibres for packaging paper

Experimental design - Ultrasound treatment vs. refining in disc refiner

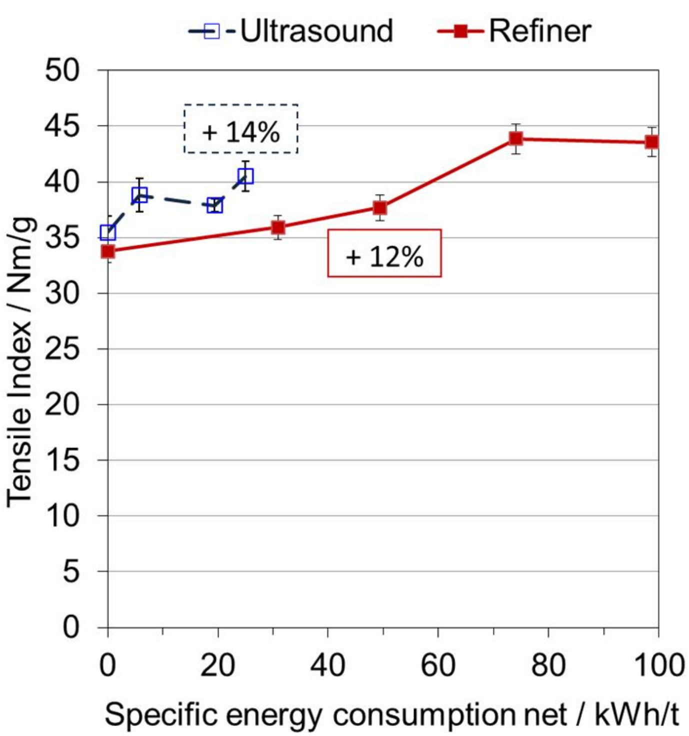
Å **Sample material: mixture of grades 1.02 and 1.04 (acc.to EN 643))**

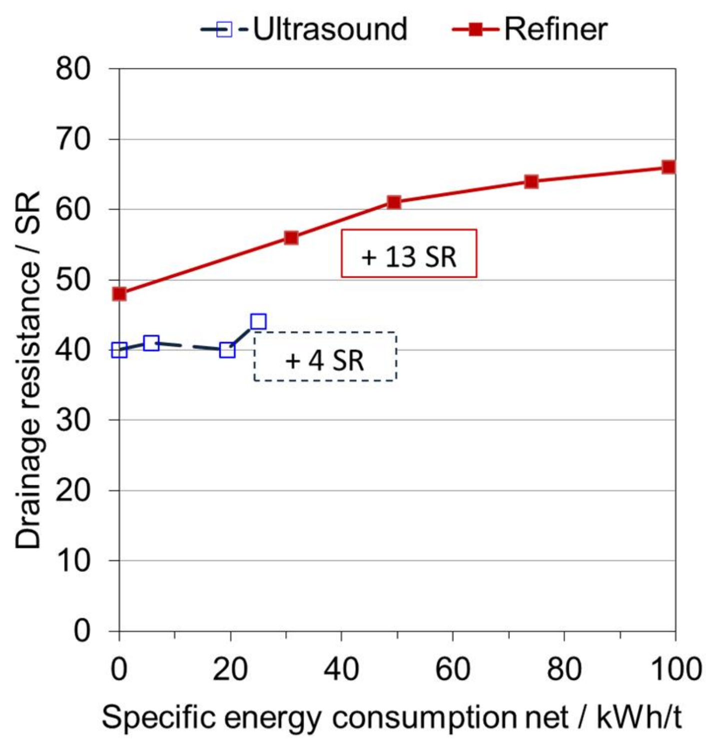


X → Pulp: Drainage resistance, FiberLab, Water retention value WRV
→ Paper sheets (Rapid-Köthen, 80 g/m²): Strength properties

Results – Recycled fibres for packaging paper

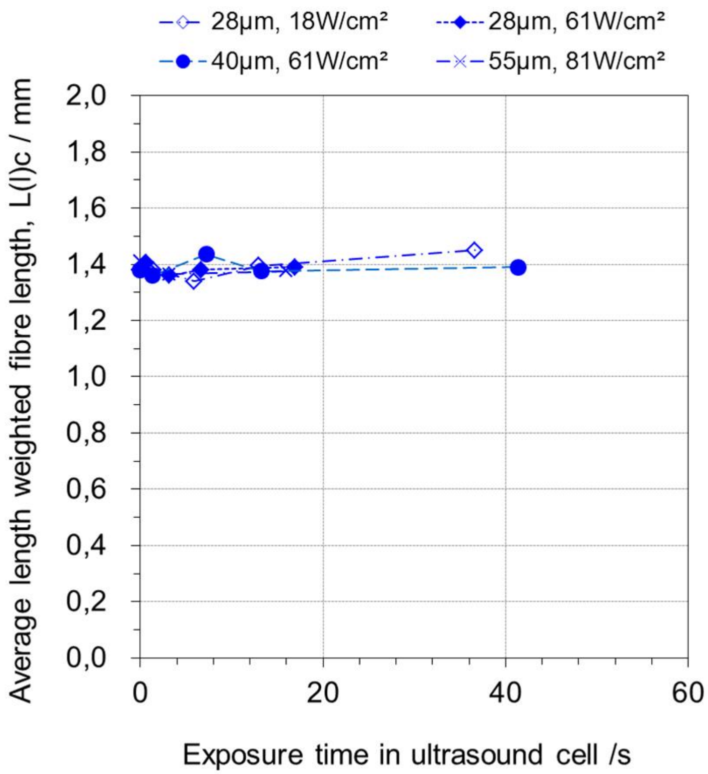
Ultrasound treatment vs. refining in disc refiner





Results – Recycled fibres for packaging paper

Fibre length



Conclusions

Å Ultrasound treatment of suspended fibres from recovered paper (mixture of 1.02, 1.04) can increase the tensile strength of paper sheets by 14% at a specific energy consumption of < 50 kWh/t and an increase in drainage resistance of 4 °SR.

Å To achieve a similar increase in tensile strength, a conventional disc refiner needs more specific energy and increases the drainage resistance by up to 13 °SR.

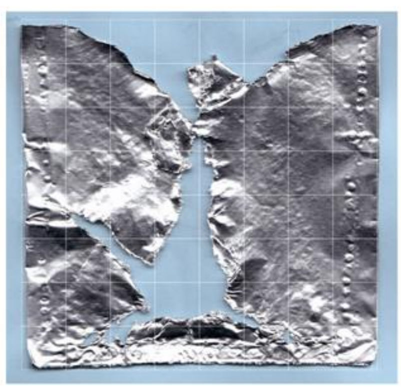
Å Virtually no losses in fibre length are observed after ultrasound.

Characterizing cavitation intensity

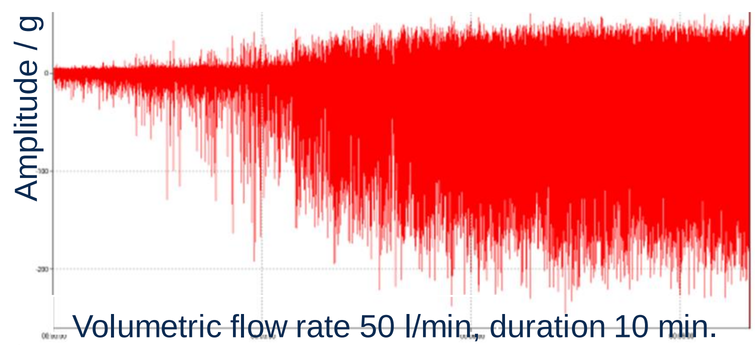
Detection of radicals

- Transformation of potassium iodide (KI) to elementary iodine / tri-iodide (I_2/I_3Z) by radical (OHÅ) during cavitation / ultrasound treatment
- Colourless KI-solution turns yellow
- Measurement of elementary iodine / tri-iodide (I_2/I_3Z) by extinction (350 nm) with photometer

Aluminium foil



Acoustic measurement with acceleration sensor



Characterizing cavitation intensity - Aluminium foil

Experimental design

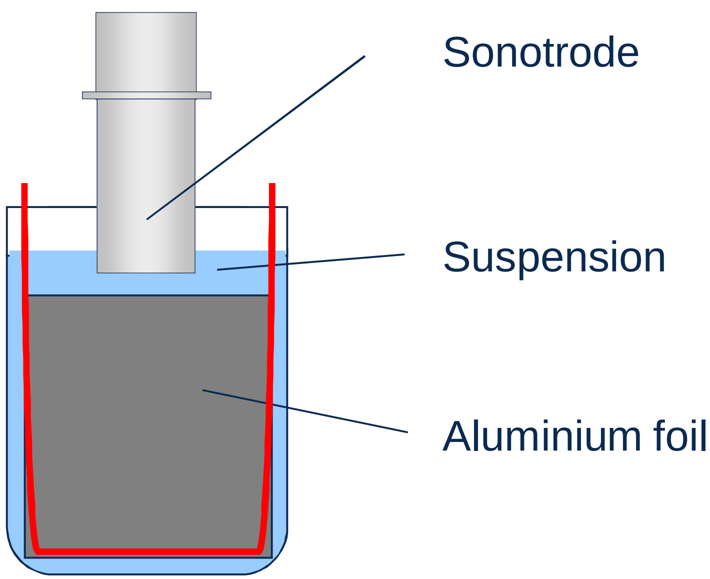
Å Laboratory device: Discontinuous ultrasound treatment (Batch-cell)

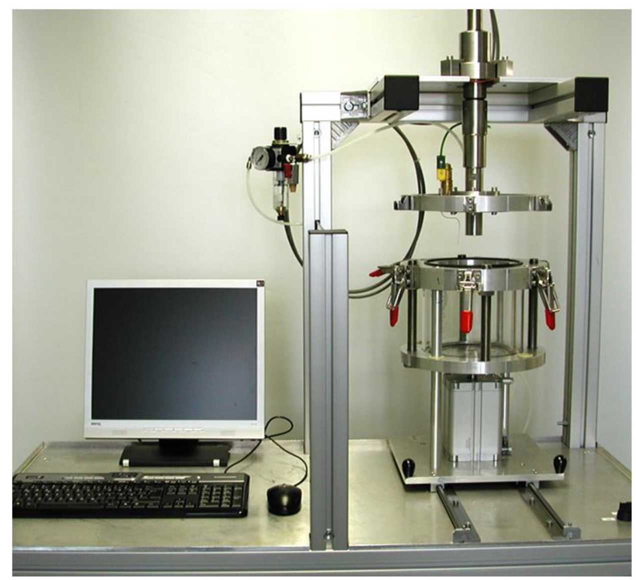
Å Pulp: *Eucalyptus globulus*

Å Pressure: 0 - 5 bar

Å Temperature: 20 - 25 °C

Å Beaker volume: 400 ml





Characterizing cavitation intensity - Aluminium foil

Cavitation index K

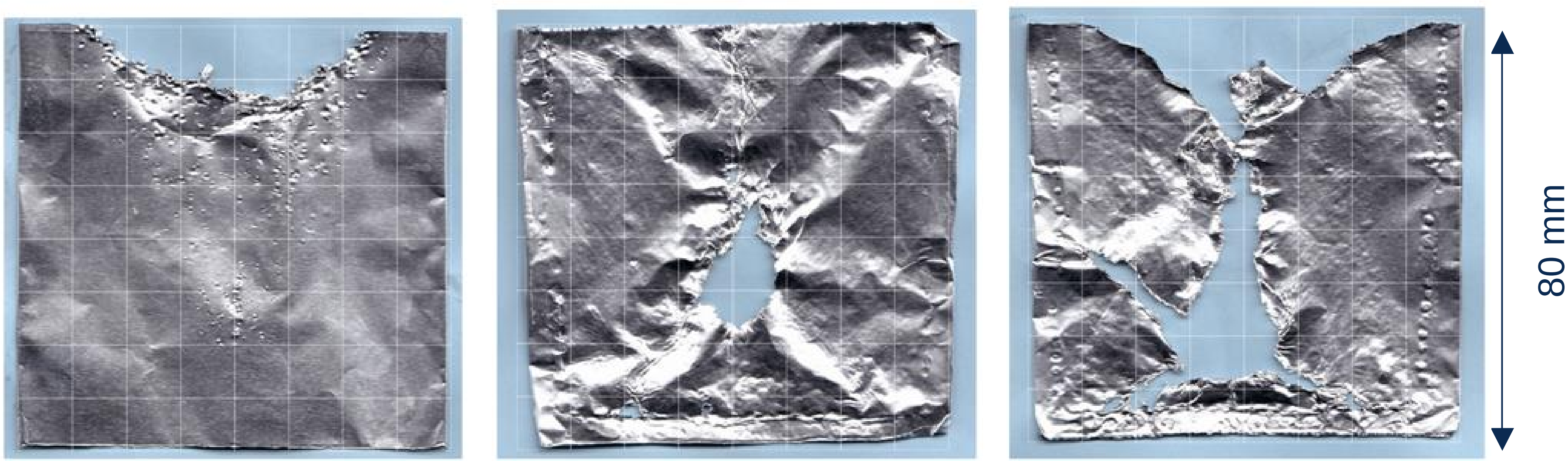
- For a quantitative analysis the aluminium foil is divided into a grid of 64 fields
- H é Number of fields with high erosion
- L é Number of fields with low erosion

$$K = \frac{\sum H + \frac{\sum L}{2}}{64}$$

Cavitation as a function of static pressure:

Sonotrode: BS2d40, Time of exposure: 30 s, Amplitude of sonotrode: 24 µm (pkpk)

Pressure **0 bar** | **2,5 bar** | **5 bar**



Source: Hanke, O., Development of a method to determine the acoustic cavitation in fibre suspension on the basis of specimen; 2012; TU Dresden

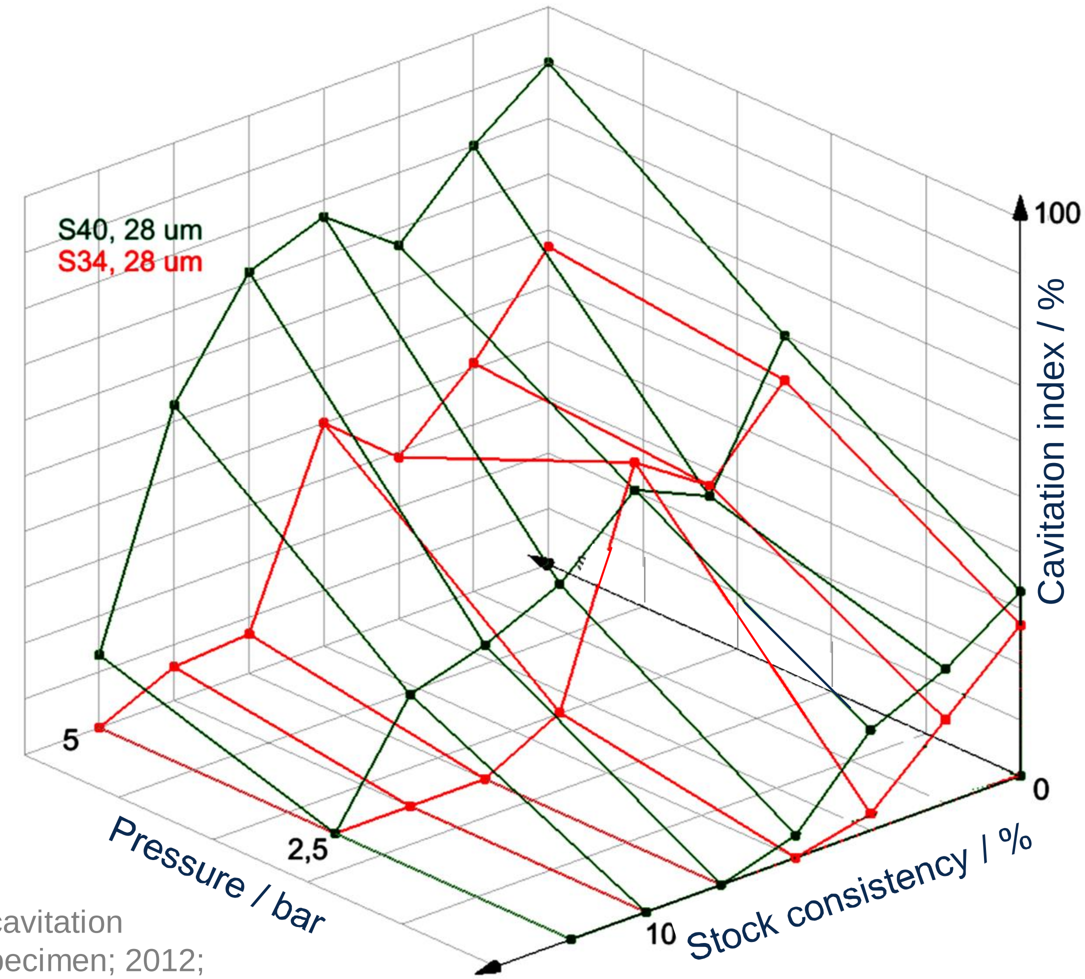
Characterizing cavitation intensity - Aluminium foil

Conclusions

Å The cavitation intensity is controlled by the diameter of the sonotrode, the pressure and the stock consistency of the pulp.

Å At elevated pressure levels cavitation is generated at stock consistencies of up to 100 g/l (10 %).

Å This permits further reductions in specific energy demand.



Source: Hanke, O., Development of a method to determine the acoustic cavitation in fibre suspension on the basis of specimen; 2012; TU Dresden

Conclusions

Virgin wood fibres

Å At a given specific energy input ultrasound treatment generates a far lower increase in tensile strength than refining.

Recycled fibres for packaging paper

Å Ultrasound treatment of suspended fibres including recovered paper (grades 1.02, 1.04) can increase the paper strength by up to 14% with a limited increase in drainage resistance at a specific energy consumption of less than 50 kWh/t.

Å Cavitation can also occur at stock consistencies of up to 10%. Increasing the consistency beyond the normal levels should therefore permit further reductions in specific energy demand.

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