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EXPERIMENTAL INVESTIGATION OF DIFFERENT REFINING STAGES INFLUENCES ON OPTICAL AND ULTRASONIC SIGNALS IN PAPER PULP SUSPENSIONS

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An important parameter to control in papermaking is the fibre mass fraction in the pulp suspension. Poor control of the mass fraction leads to an unstable process that compromises the production, quality and the energy efficiency in the pulp mill. Using optical or ultrasound measurement techniques can obtain estimation of the mass fraction. Refining is an important operation in preparing the fibres for the paper machine. Refining influence the properties of the fibre by crushing the fibre, roughens the fibre surface and occasionally cut fibres and removes parts of the outer fibre wall leading to an increasing amount of short fibres (fines). Since refining is used to give the fibres desirable properties, its impact on the fibres with respect to light and sound is investigated. Two different types of chemical pulp is considered; bleached hardwood and unbleached softwood pulp. A freeness tester was used for verify the changes in fibre properties at four different refining levels. The result shows that for unbleached softwood pulp the used measurement techniques are influenced by refining. For bleached hardwood pulp the influence of refining intensity on the tested measurement techniques either were not observable or minor. The results indicate that refining can potentially influence accurate consistency estimation for unbleached softwood pulp but for bleached hardwood pulp the influence is believed to be minor using the investigating measurement techniques.

INTRODUCTION

The papermaking process is today a fully automated process. This has put high demand on the sensors for controlling the papermaking process in order to produce the desired paper quality. Also have the demands for an environmentally friendly process and effective use of raw materials and energy increased the complexity of controlling the process. By improving the process control, the demands for efficiency and quality can be met.

An important control parameter in the papermaking process is the mass fraction or consistency of cellulosic materials in the pulp suspension [1]. Poor control of the mass fraction leads to an unstable process that compromises the production, quality and the energy efficiency in the pulp mill. Today, consistency is estimated with mainly three different techniques, shear force sensors, microwave sensors and optical sensors. It is believed that no commercial product uses ultrasound to measure pulp consistency. Although, Löfqvist [2] showed that ultrasound have the potential to estimate consistency. In Törmänen et al. [3] a method based on a combination of optical and ultrasonic techniques was proposed. They showed that short fibre fragments (fines) are the predominant source for optical scattering. Further, the long fibres are the predominant source for attenuation of ultrasonic waves. By combine the two techniques the mass fraction of fines and the mass fraction of fibres in a pulp sample could be determined, respectively.

The different sensor techniques have their advantages and disadvantages. Different process treatment and location in the process chain favour different sensors. All sensors used today estimate the consistency by measure something that relates the measured signal to the consistency. The calibration is recognised as the key to accurate consistency measurements [1], [4]. Optical sensors can be accurate with proper calibration [5]. However, optical sensors are sensitive to pulp composition [1]. Changing the properties of the pulp compared to the calibration samples, might compromise the consistency estimation.

Manufacturing of paper involves different treatment on the pulp suspension. The refining process is an important operation in preparing the fibres for the paper machine. The degree of beating or refining of the fibres influence the elastic properties of the fibre by split and crush the fibre. Refining also roughens the fibre surface, creating hair-like fibrils, which increase the specific surface area of the fibre. Further, refining also occasionally cut fibres and removes parts of the outer fibre wall leading to an increasing amount of fines in the suspension [6].

The motivation for this study is to examine the influence of refining on light and sound waves and thereby compromise accurate consistency control based on the investigated measurement techniques.

EXPERIMENTAL METHODS

This study concern two different measurement techniques, optical and ultrasound. The examined optical properties are light intensity and the time-of-flight of the received light pulse that has travelled through the pulp sample. The examined ultrasonic property is the attenuation of a sound pulse that has travelled through the pulp sample.

Light pulses propagating through random inhomogeneous medium are temporally divided into ballistic, snake and diffuse components [7]. Depending on the number of scattering particles one or the other components is dominating. In a turbid sample, where multiple scattering occur, diffusion light will dominate. The propagation time for a photon through a medium is due to number of scattering events and speed. With increasing scattering events in the medium the photon density reduces and the probability for a photon to be absorbed increases. These two factors decrease intensity as the light propagates through the medium. Hence, both time-of-flight (TOF) and light intensity for a propagating pulse is affected by number of scattering events in a low absorbing highly scattering medium.

The ultrasonic attenuation is due to absorption and scattering of the sound waves as they propagate through the medium [8]. Absorption is the conversion of sound energy to other forms of energy (heat). Scattering is the reflection of the sound in directions other than its original direction of propagation. The sound attenuation in a pulp suspension is a function of frequency. The frequency-dependent attenuation in this study is calculated as:

$$\alpha_s(f)=\ln[|P_w(f)|/|P_s(f)|]/(2d) + \alpha_w(f) \quad (1)$$

where $\alpha_s(f)$ is the attenuation in the suspension, d is the distance between the transducer and the steel reflector, $|P_w(f)|$ is the amplitude in the frequency domain of the water reference echo, $|P_s(f)|$ is the amplitude in the frequency domain of the sample echo and $\alpha_w(f)$ is the attenuation in pure water and is assumed to be $25\cdot10^{-15}\ f^2$, where f is the frequency [8].

EXPERIMENTS

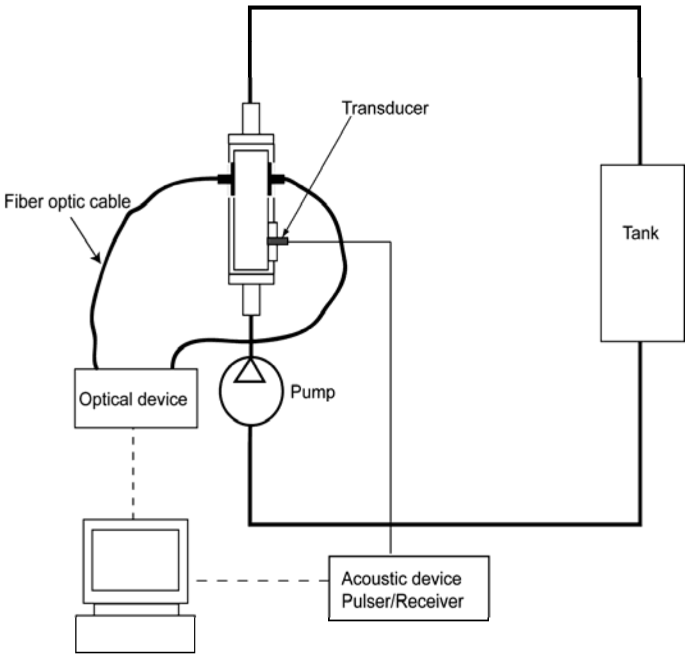

Fig. 1 Illustration of the experimental set-up

The measurement cell is designed to allow measurements of the two techniques simultaneously. Figure 1 shows an illustration of the measurement cell and also the experimental setup. The inner dimension of the measurement cell is 10×3×3 cm.

The light was generated and measured by a custom designed LIDAR system CMP3 from Noptel Oy, Finland. The light was coupled to the measurement cell by optical fibres with a 0.39 NA and a core diameter 600 µm. The light is directed onto the incident window of the cell, containing the flowing pulp. The light beam that emerges on the opposite side passes a parallel plane window and is directed onto an optical fibre, which is connected to the optical device. The optical device register both intensity and time-of-flight (TOF) of the receive light. The device is connected to a computer for storing of the measured properties. The wavelength of the light is 905 nm. With a repetition rate of 4000 Hz the average of 1024 measurements was captured and stored in the computer. The procedure was repeated 200 times to improve the statistical significance of the measurement. In this study we present TOF as the remaining time in picoseconds, after the TOF value for pure water is subtracted. The received light intensity is presented as voltage.

The ultrasound wave was measured in a pulse-echo setup. The propagating ultrasonic wave is travelling through the suspension and reflected back at a polished steel reflector and thereafter captured by the transducer. A PZT transducer from Panametrics, Waltham, USA generated the ultrasound signal, with a center frequency of 15 MHz. The transducer was excited and amplified by a dual pulser/receiver model DPR500 from JSR Ultrasonics, NY, USA. The captured ultrasonic signal from the pulser/receiver was digitised with an oscilloscope card (CompuScope 12400 from GageScope) sampling at 100 MHz with a 12 bit resolution. For each pulp sample, 200 ultrasonic pulses were recorded and averaged using an averaging procedure that reduces timing jitter [**9**]. A digital thermometer monitored the temperature in both the water and the room. The temperature range in the pulp samples during the course of experiments was 19.60 ± 1.5°C. The travelling distance for the ultrasonic wave was calculated from the theoretical speed of sound in water given by the pure water sample temperature [**10**] and the time-of-flight of the ultrasonic wave that has travelled back and forth once respectively twice in the cell using cross-correlation technique. The distance *d* was found to be 29.7 mm.

The pulp was delivered by Smurfit Kappa Kraftliner, Piteå, Sweden. Two different types of chemical pulp were considered; bleached hardwood and unbleached softwood pulp aimed for kraftliner production. The pulp samples stems from before between and after three refiners connected in series, resulting in four different refining intensity levels. From each refining level pulp samples of four different mass fractions were mixed. The mass fraction ranged from 0.3 % to 1.3 % for unbleached softwood pulp and 0.25 % to 1.5 % for bleached hardwood pulp. Altogether, a set of 16 pulp samples with four refining levels and four mass fraction levels for each pulp type was investigated.

The rate of drainage, which is related to the work done on the fibres during refining was measured in a laboratory at the pulp mill with a freeness tester and is presented in MSR (Modified Shopper-Riegler) values. Freeness testing is a standard method for determines the degree of refining of pulp. The relation between refining intensity and MSR, is that increased refining intensity give a increased MSR value. In this study the MSR values ranged from 18 (unrefined) to 37 after the last refiner for unbleached softwood pulp. For bleached hardwood the MSR value increased from 31 (unrefined) to 54 after the last refining level.

RESULTS

UNBLEACHED SOFTWOOD PULP

Figure 2 shows the received light intensity converted into millivolt at different consistency levels as a function of MSR, i.e. refining intensity, for unbleached softwood pulp. The standard deviation of each measurement is shown as error bars in the figure.

The trend in all mass fraction levels is that the amplitude decreases with increasing refining. Figure 3 shows TOF plotted against MSR at the different consistency levels. The trend is that the propagation time for the light pulse in the suspension increases with refining intensity. In the mass fraction level 0.3 %, the trend is not observable as the values are within the uncertainty of the measurements.

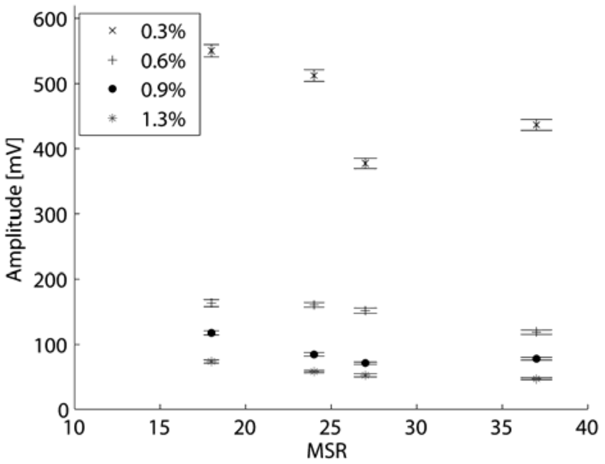

Fig. 2 Received light intensity as function of MSR at different consistency levels for unbleached softwood pulp

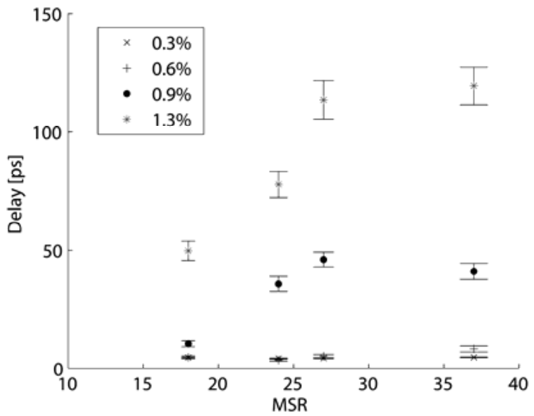

Fig. 3 Time-of flight as function of MSR at different consistency levels for unbleached softwood pulp

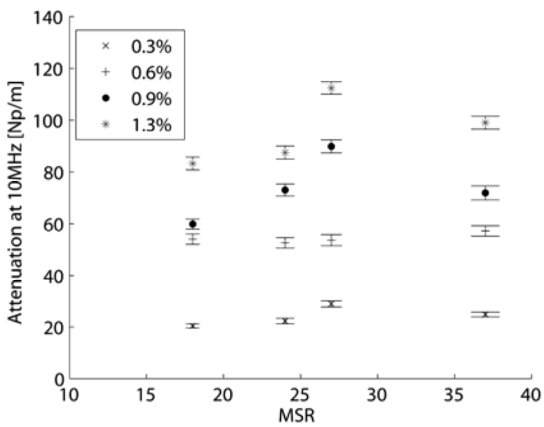

Fig. 4 Ultrasonic attenuation at 10 MHz plotted against MSR at different consistency levels for unbleached softwood pulp

Figure 4 shows the ultrasonic attenuation in Neper/m at 10 MHz for unbleached softwood pulp. A trend is noticed, sound attenuation increases weakly with refining intensity. But the results also show a large variation between the measurements, especially in pulp samples at higher consistency levels and refining intensities. It is believed that it is caused by inhomogeneity in the pulp suspension, likely due to floc formation in the suspension. During the experiment it was noted that floc formation was more evident in high-refined pulp samples and at higher consistencies levels. These flocs cause variations in the received signal since the floc represents a locally higher concentration of fibres blocking the optic or acoustic signal path. Further, in the area close to the flocs there will be a locally lower concentration of fibres. Although, steps were taken to reduce floc formation, it is believed that the measurements were conducted on a pulp consistency other than the expected. The floc formation in pulp suspension is well known and has been discussed by others [**1**], [**11**] as a source of error.

These results for unbleached softwood pulp confirm the assumption that refining change the specific surfaces of the fibres and also an increase the amount of small particles (fines) in the suspension.

BLEACHED HARDWOOD PULP

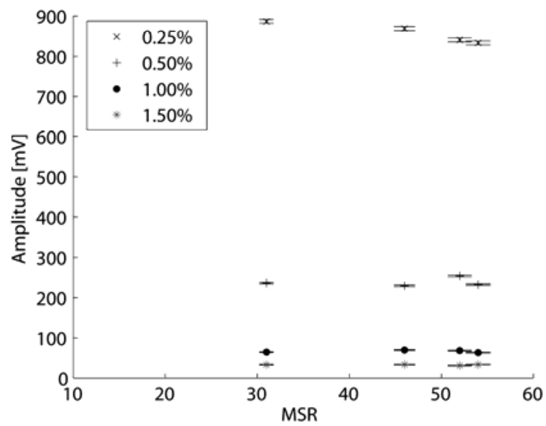

Fig. 5 Received light intensity as function of MSR at different consistency levels for bleached hardwood pulp

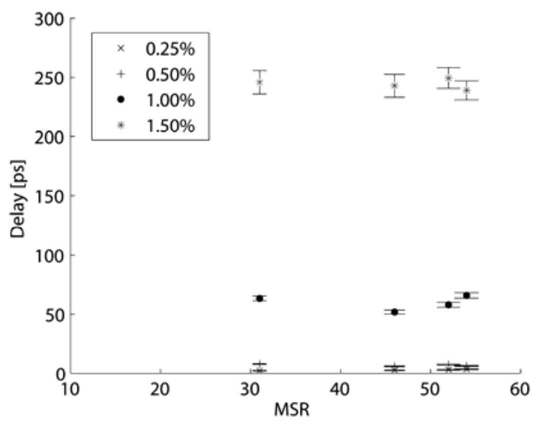

Fig. 6 Time-of flight as function of MSR at different consistency levels for bleached hardwood pulp

Figure 5 shows the received light intensity as a function of MSR. In this case the influence of refining on the amplitude in not apparent or minor. Figure 6 shows the TOF values as function of MSR here the influence of refining intensity are not noticeable. Figure 7 shows the ultrasonic attenuation at 10 MHz plotted against the MSR value. There is no clear indication on the ultrasonic attenuation that the fibres have been affected by the refining intensity.

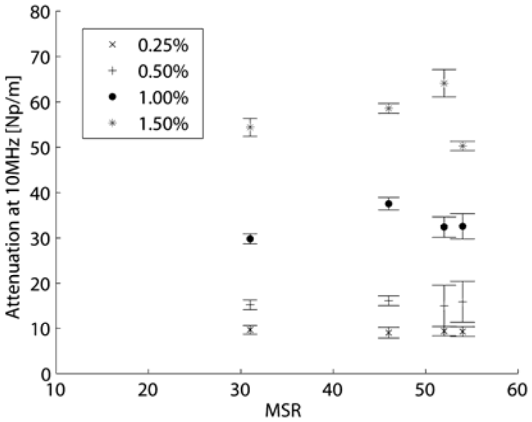

Fig. 7 Ultrasonic attenuation at 10 MHz plotted against MSR at different consistency levels for bleached hardwood pulp

These results indicate that changes in terms of fibre surface development or increasing amount of fines during refining on bleached hardwood pulp are not detectable with the used methods.

CONCLUSION

In this study we have presented experimental results on different refining stages influences on optical and ultrasonic signals in paper pulp suspensions.

The results show that for unbleached softwood pulp the optical amplitude decreases as refining intensity increases. The time-of-flight of the light pulse increases with refining intensity. For the ultrasound attenuation there is a weak trend for increased attenuation as refining intensity increases. For bleached hardwood pulp the influence of refining intensity on the tested measurement techniques was not observable or minor.

The results indicate that refining potentially can influence accurate consistency estimation for unbleached softwood pulp but for bleached hardwood pulp using the investigating measurement techniques the influence is minor or negligible. However, it should be noted that the variation in MSR used in this study is well beyond the normal variation in a pulp mill. Hence, under normal conditions the influence of refining on accurate consistency estimation is believed to be less evident than the results indicate for unbleached softwood pulp.

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