Ultrasonic measurement of gaseous air in pulp suspensions

Matti Karras, Tapio Pietikäinen, Helena Kortelainen, and Jouni Tornberg

The method has been tested in the laboratory and in several paper mills. Tests prove that a commercial meter can be developed to control the feed of chemical defoamer in paper machines.

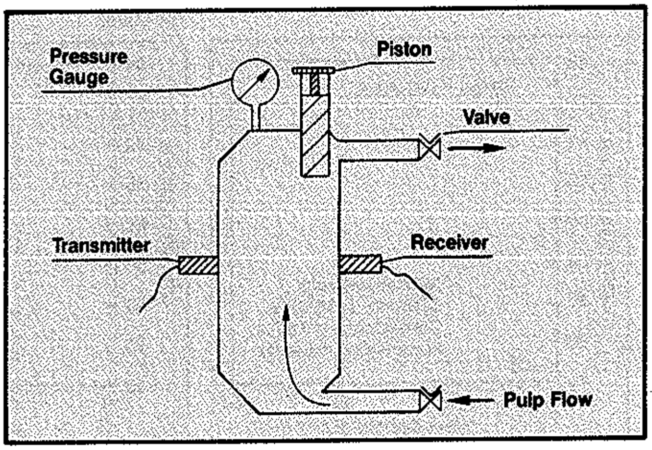
It is well known that entrained air in a pulp suspension can cause difficulties in the papermaking process. The most severe consequences of disturbances caused by entrained air include decreased wet-web strength, retarded drainage (*1-4*), and losses in pumping capacity (*3*). In short, a high level of entrained air in a pulp suspension can limit the production capacity of a paper machine.

The amount of entrained air in a pulp suspension normally is controlled through the use of mechanical deaerators and chemical defoamers. Defoamers are surface-active chemicals that operate by reducing the stability of air bubbles and foam, causing them to collapse and coalesce (*4, 5*). However, these chemicals are expensive, and an overdosage can reduce tensile strength of paper (*6*) and cause formation of deposits on the paper machine (*7, 8*). The economical use of defoamers has been hampered by the lack of an on-line device for measuring air content. The most commonly used laboratory device for measuring air content is based on the compressibility of air. Air pressure is either increased or decreased, and the change in volume is measured (*9*).

This paper is based on a discovery made in the laboratory during experiments involving ultrasonic interaction in a pulp suspension. Large air bubbles were observed to have only a modest effect on the attenuation of ultrasonic transmissions, while entrained air produced a far more dramatic response. In the case of entrained air, the water–air interface scatters sound strongly. This occurs because of the considerable difference between the acoustic impedances of water (1.5×10^6 kg/m^{2}s) and air (4.3×10^2 kg/m^{2}s). The entrained air attaches to the fiber flocs in the suspension and scatters sound effectively. The inertia of loose bubbles, on the other hand, is too low for agitation by acoustic waves. Loose bubbles do not scatter sound effectively.

Karras, a professor at the University of Oulu, and Pietikäinen, a research associate, work in the electronic measurement laboratory at the University of Oulu, P.O. Box 191, SF-90101, Oulu, Finland. Kortelainen, an application engineer, and Tornberg, research manager, work at Kajaani Electronics Ltd., P.O. Box 177, SF-87101, Kajaani, Finland.

1. The on-line meter for measuring gaseous air in pulp suspensions.

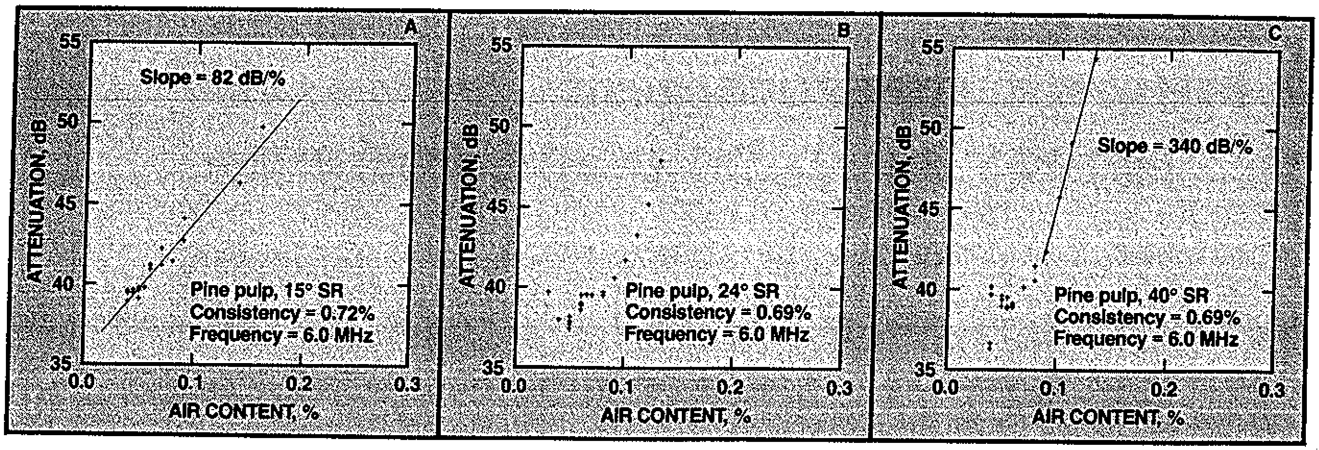


Experimental construction of the meter

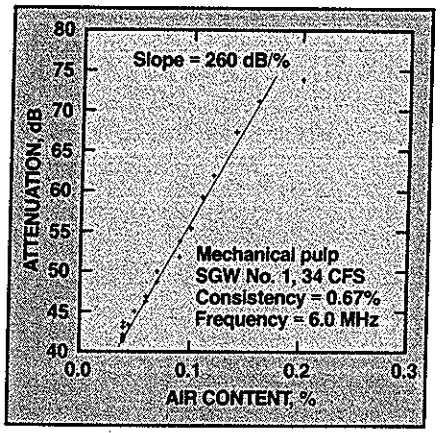
The structure of the on-line meter used in this study to measure gaseous air in suspension is illustrated in **Fig. 1**. The instrument comprises a pressure vessel, an air-compression gauge, a piston for the 0.5-bar compression, a displacement indicator at the piston shaft, and two Krautkrämer clamp-on transducers (type MB2S-N/2.0 MHz). The transducers, which function as a transmitter/receiver pair (distance 90 mm), are used to determine attenuation. The meter is designed for air contents up to 1%, and it operates in consistencies below 1.5%, which are typical in the short-circulation portion of a paper machine.

The quantity of air in the pulp suspension flowing through the meter is monitored continuously with ultrasonic attenuation. The compression gauge is used for intermittent calibration. During the laboratory portion of this research, Krautkrämer immersion transducers (type H5K/6.0 MHz) were used. The on-line measurements in the mills, however, were carried out using a 2-MHz frequency. The continuous wave transmitter used was a YEAUSU FT-757GX. The output of the receiving transducer was measured with a radio-frequency millivoltmeter (Rohde & Schwarz type URV5), and the measured data from the radio-frequency millivoltmeter were col-

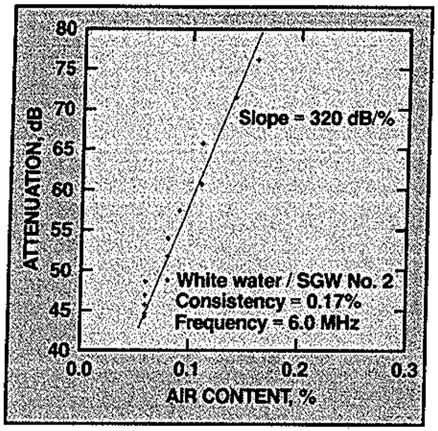
2. Ultrasonic attenuation as a function of air volume in pine pulp suspensions at three different levels of Schopper-Riegler freeness. A: unbeaten pulp at 15°SR. B: pulp beaten to 24°SR. C: pulp beaten to 40°SR.



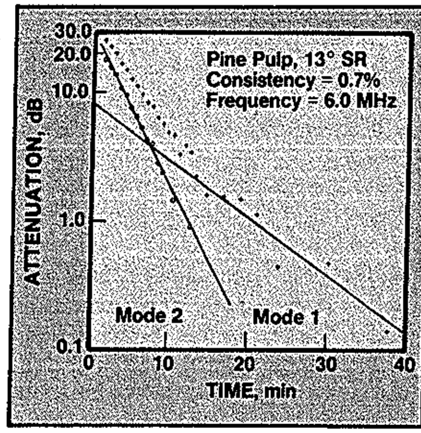
3. Ultrasonic attenuation as a function of air volume in SGW pulp suspension.



4. Ultrasonic attenuation as a function of air volume in white water of LWC paper machine.



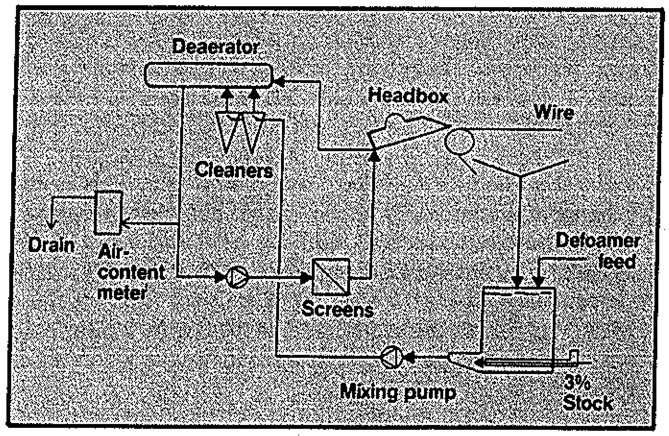
5. Recovery rate of the ultrasonic attenuation in pine pulp suspension after saturated aeration under continuous mixing.



lected via an IEEE-488 bus interface to an ABC-80 microcomputer.

The meter has been tested both in a laboratory aerator vessel and in several field tests on paper machines. The laboratory was equipped with an aerating and circulating pump and an LC-100 consistency transmitter from Kajaani Electronics Ltd. In laboratory tests, the suspension was first aerated using a porous air-feeder, and air was entrained by using a centrifugal pump to circulate the aerated suspension in and out of an open tank. The meter was then filled with continuously flowing suspension from the tank, and aeration was interrupted when the ultrasonic attenuation reached saturation point. Finally, attenuation vs. air volume was monitored while the air was escaping from the open tank, with only the mixing on.

6. Location of the air-content meter in the short circulation of a paper machine.



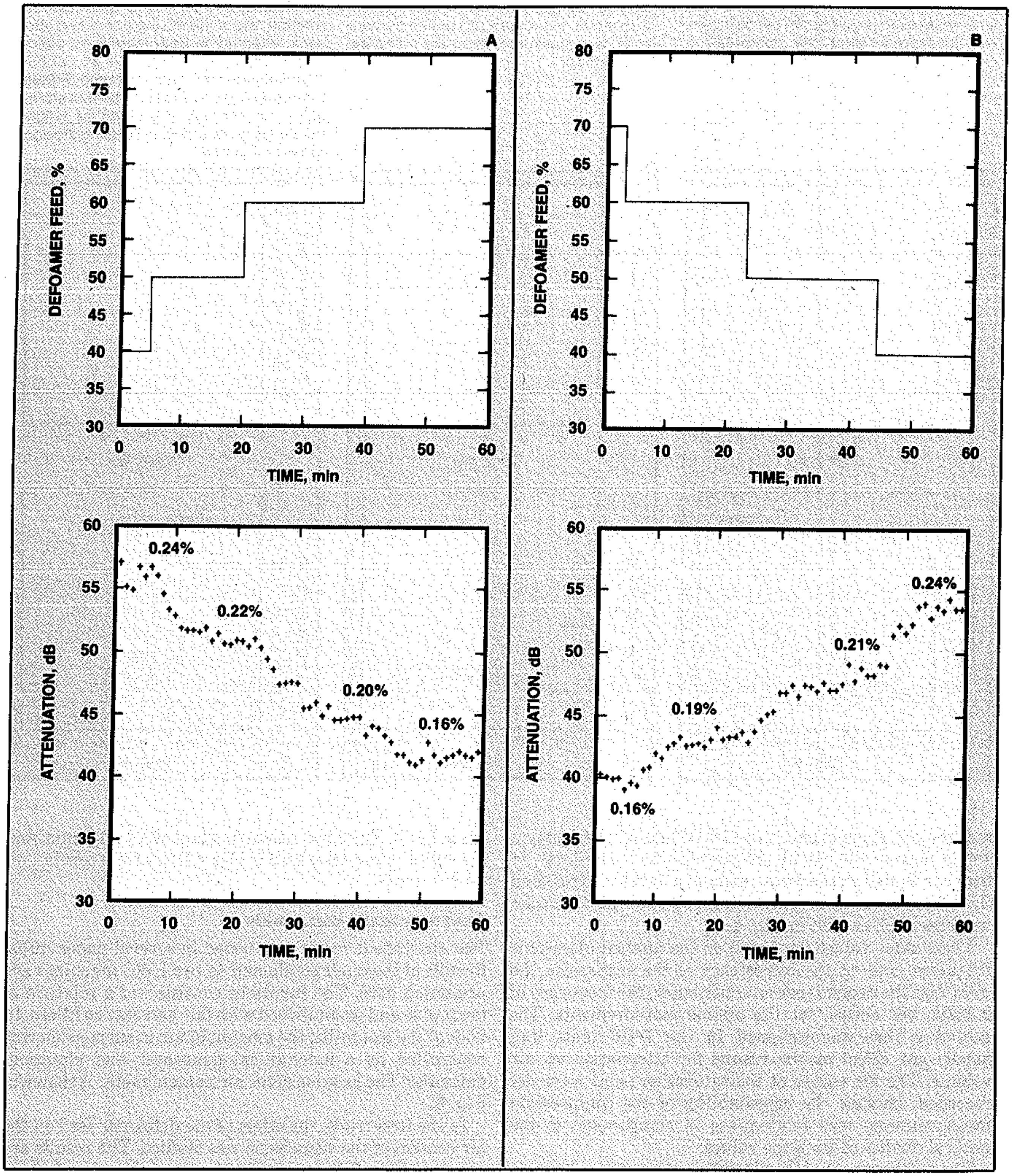
Measurements

Laboratory measurements

The ultrasonic beam is attenuated both by absorption and by scattering. The amount of scatter can be estimated by measuring both the linearly transmitted intensity and the sidewardly scattered intensity from the central volume of the meter cylinder.

The ratio of the scattered and the linearly penetrated intensities is the estimate of the scattering efficiency of the central volume, free of absorption. Scattering was almost isotropic. The ratio of scattered and linearly transmitted sound varied from -50 dB in an airless suspension to -15 dB in a saturation-aerated suspension. In the beginning of the work, it became evident that the scattering dominated over the absorption. Thus in this research, only the attenuation of the linearly penetrating beam was recorded. (Attenuation was recorded in decibels compared with the

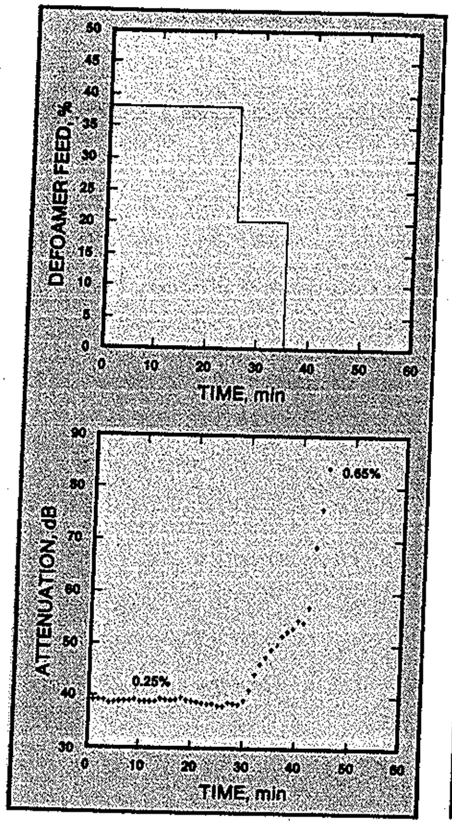
7. Effect of a stepwise change in defoamer feed on ultrasonic attenuation and air content. Top: Stepwise change of defoamer feed. Bottom: Simultaneous change in ultrasonic attenuation. Air content, expressed as volume percentages, was measured using the compression method.



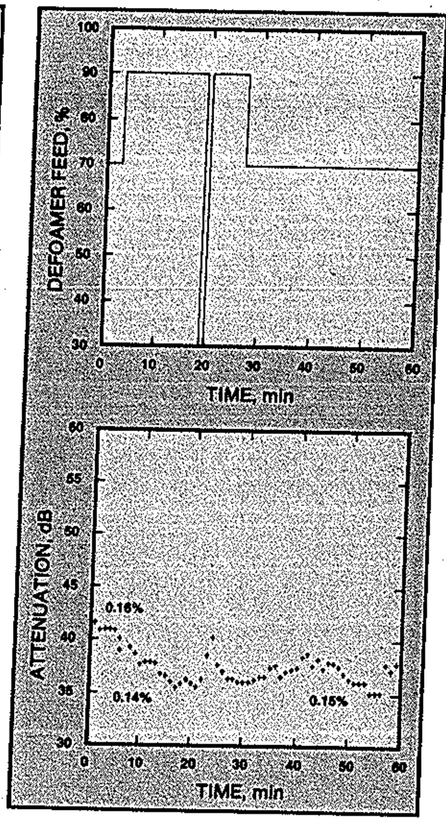
transmitted intensity.)

Attenuation of ultrasonic transmission as a function of air volume in the pulp was measured in a variety of pulp suspensions. **Figures 2a, 2b, and 2c** show the results for pine pulp suspensions at three different levels of Schopper-Riegler (SR) freeness. The data points for unbeaten pine pulp (15°SR) formed a line with a slope of 82 dB/1% air. Beating added another strongly attenuating component to the results, as seen in Fig. 2c, where the data points form a line with a slope of 340 dB/1% air for the pulp beaten to 40°SR. It is interesting to observe that when beating is increased, a larger fraction of entrained air becomes strongly attenuating. This strongly attenuating fraction of entrained air is called mode 2, while a weaker attenuating fraction is called mode 1.

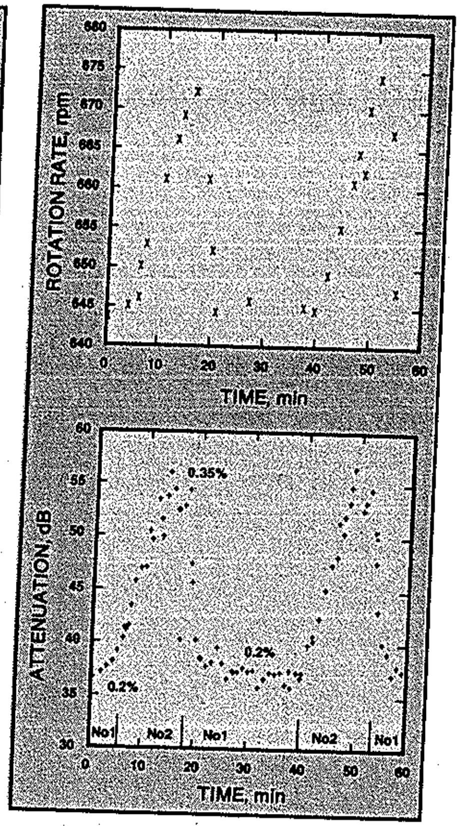
Figure 3 illustrates the results obtained with a



8. Effect of a two-stage cutoff of defoamer feed on the air content in LWC machine. Top: Defoamer feed. Bottom: Simultaneous change in ultrasonic attenuation. Air content, expressed as volume percentages, was measured using the compression method.



9. Effect of slight overdosage of defoamer followed by a 1-min cutoff of defoamer feed. Top: Defoamer feed. Bottom: Simultaneous change in ultrasonic attenuation. Air content, expressed as volume percentages, was measured using the compression method.



10. Results of mill trials during which the regularly used defoamer was replaced with another defoamer that was still in the development stage. The results show that rotation rate of the mixing pump and ultrasonic attenuation both increased, indicating an increase in the pulp's air content. Top: Rotation rate of mixing pump. Bottom: Simultaneous change in ultrasonic attenuation. Air content, expressed as volume percentages, was measured using the compression method.

mechanical, stone groundwood (SGW) pulp, where only a single slope of 260 dB/1% air was observed. Similarly, in tests conducted on the white water of a lightweight-coated (LWC) paper machine, only a single slope of 320 dB/1% air was observed, as seen in **Fig. 4**.

These slope values depended on the applied ultrasonic frequency and on the consistency of the suspension. To minimize the dependence on consistency, the frequency of 2 MHz was chosen for the on-line measurements. The added fillers encountered in the field tests had hardly any effect on the results for attenuation vs. air volume. The air values at the saturation point were not recorded, because the repeatability of the compression measurements was inadequate in comparison to the general quality of the slope values.

The recovery rate of the ultrasonic attenuation during a prolonged slow mixing after saturated aeration was studied in detail. An example is shown in **Fig. 5**, where the recovery of the attenuation in the bleached pine pulp is analyzed in two components, with time constants of 9.6 ± 1.0 min and 3.4 ± 0.2 min. The higher time constant belongs to mode 1, the lower to mode 2. The recovery rate of air from other suspensions was found with just single time constants. For a birch pulp (consistency × 1.0%, 40°SR), the time constant was 9.7 ± 1.0 min, while the SGW pulp described in Fig. 3 had a time constant of 9.8 ± 1.0 min, and the white water described in Fig. 4 had a time constant of 6.4 ± 1.0 min.

Field tests in the paper mills

The air-content meter was tested in several paper mills. Results of the trials conducted on two LWC machines are presented here. The furnishes consisted of a mixture of kraft pine and groundwood with talc and clay as fillers. In both of the test mills, the amount of air in suspension was controlled by a mechanical deaerator and chemical defoamer. The location of the air-content meter is shown in **Fig. 6**.

In the first trials, the effect of the defoamer feed on the air content of the suspension was studied. The results are shown in **Figs. 7, 8, and 9**. The time lag between defoamer addition and a subsequent change in measurement was about 4 min. Both methods of measuring air content—ultrasonic attenuation and the compression method—responded accurately to the defoamer feed. It is evident from Figs. 7 and 9 that the defoamer dosage was at the optimum level when the feed was about 70% of the maximum. When the defoamer feed was increased higher than 70%, the air content was reduced relatively little. The residual content of gaseous air that could not be removed by the defoamer in this process was about 0.14%.

Ultrasonic attenuation reacts sensitively to small and sudden changes in a pulp's air content. Even a 1-min cutoff of the defoamer feed was observed as an increase in attenuation, as seen in Fig. 9. A two-step cutoff of defoamer feed dramatically increased the air content, as seen in Fig. 8. The process depicted in Fig. 8 was drifting out of control before machine shutdown.

The rotation rate of the mixing pump sometimes is used to estimate pulp air content at a constant production rate. **Figure 10**, where rotation rate and ultrasonic attenuation are both plotted as a function of time, shows the results of a mill trial for a new defoaming agent that was still in the development stage. The new agent was used in place of the regularly used defoamer in two separate trials. The results of each trial were the same: both ultrasonic attenuation and rotation rate of the mixing pump increased, indicating increased air content in the suspension.

Conclusions

When a given volume of air in a pulp suspension is dispersed into small bubbles, these bubbles attach themselves to fibers in the suspension, especially at network junctions. The suspension retains these small bubbles for relatively long periods of time, even under continuous stirring. The presence of these entrained air bubbles in a pulp suspension causes a dramatic increase in ultrasonic attenuation. Because the amount of ultrasonic attenuation is proportional to the surface area of the entrained air bubbles, the quantity of air in a pulp suspension can be monitored continuously by measuring the attenuation of ultrasound in the suspension.

The strongest attenuation (expressed in units of dB/1% air) was found in mode 2 of pine pulp and in the white water of the LWC machine. The strength of the attenuation in these two instances can be explained by the fines contents in the pulp suspensions. The fines become attached to the surfaces of the small bubbles, which increases the inertia and scattering efficiency of the bubbles. The appearance of the steep component (mode 2 in Fig. 5) indicates that the pine pulp suspension contains loose, fine particles. The high decay rate of mode 2 reveals that the bubbles covered with fines are free to stay at the surface of the vessel once they reach it during stirring.

Ultrasonic attenuation responds specifically to the presence of dispersed and entrained air bubbles. Because it is virtually insensitive to the presence of large, loose bubbles, it is an ideal control signal for detecting the harmful fraction of suspension-borne air. Tests conducted on several paper machines indicate that a commercial meter can be developed to control the feed of chemical defoamer. With such a meter in operation, a mill could maintain the air content at low levels without excessive consumption of chemical defoamers. The savings in chemical consumption would easily justify the cost of such a meter.

Literature cited

1. Brecht, W. and Kirchner, U., Wochbl. Papierfabr. 87(8): 295(1959).
2. Brecht, W. and Kirchner, U., Das Papier 15(10a): 625(1961).
3. Sedivy, O., Zellstoff Papier 18(4): 112(1969).
4. May, O., Southern Pulp Paper Mfr. 30(9): 72(1967).
5. May, O. and Buckman, S., Tappi 58(2): 90(1975).
6. Springer, A., Dullforce, J., and Wegner, T., Tappi J. 68(4): 78(1985).
7. Allen, L., Tappi 63(2): 81(1980).
8. Piluso, A., Southern Pulp Paper Mfr. 40(1): 14(1977).
9. Boadway, J.D., Pulp Paper Mag. Can. 57(3):185(1956).

Received for review June 26, 1987.

Accepted August 21, 1987.