

Measuring dispersed air in newsprint pulp suspensions

Michael J. Ajersch, Robert H. Pelton, and Alex K. T. Chan

McMaster Center for Pulp and Paper Research, Department of Chemical Engineering,
McMaster University, Hamilton, ON, Canada L8S 4L7

Stuart R. Loewen

Abitibi-Price Inc., 2240 Speakman Dr., Sheridan Park, ON, Canada L5K 1A9

ABSTRACT *Two techniques for using a vibrating U-tube densitometer to measure the amount of dispersed air in newsprint pulp were investigated in the laboratory and in a pilot-plant setting. In the first technique, stock density is monitored as a function of time. Density variations are attributed to changes in the content of dispersed air. With this method, the absolute volume fraction of air can be calculated if the density and the concentration of fiber and fillers are known. The second technique involves measuring stock density at two pressures, permitting direct calculation of dispersed-air content. The air contents calculated using this technique correlated well with measured air contents from a commercial PAM (process air measurement) sensor over a range of 0–5% by volume. Data from both instruments showed that the air content fluctuated by as much as ± 0.5 volume percent within a 10-s interval in the pilot flow loop.*

KEYWORDS

Air content
Measurement
Pilot plants
Slush pulps

An overview of the last 40 years of papermaking literature reveals sporadic activity on the subject of dispersed air in newsprint manufacture. Much of the early work focused on identifying problems associated with dispersed air and reducing the level of dispersed air by mechanical means. More recently, research has been driven by the availability of new techniques for measuring air content together with the perception that dispersed air remains a problem in many paper machines. The literature on the effects of air in papermaking was reviewed 16 years ago by May and Buckman (1), and to a large extent, the subject has not developed much in the intervening years.

Despite the information in the literature, we are left with many questions, including: What are typical values for air content at the

various locations in a modern paper machine; in what form is the air present; and most importantly, does it matter? The work presented here is the first report from a research project aimed at answering these questions. The specific objectives were to develop and verify robust instrumentation for studying dispersed air in newsprint machines.

Techniques for measuring air

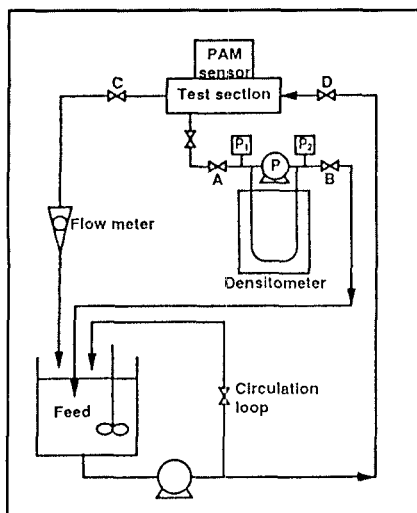
Many techniques have been described for measuring dispersed air in wood pulp suspensions (2). The procedure described in TAPPI Useful Method 653 consists of measuring the density of a pulp suspension and comparing it with the density measured after removing the dispersed air (and probably the dissolved air) by boiling. Densities are determined

by weighing a pulp-filled glass container of known volume. Woodworth (2) claims that the method requires 2–3 h to complete and that a precision of $\pm 0.1\%$ is possible with a skilled operator.

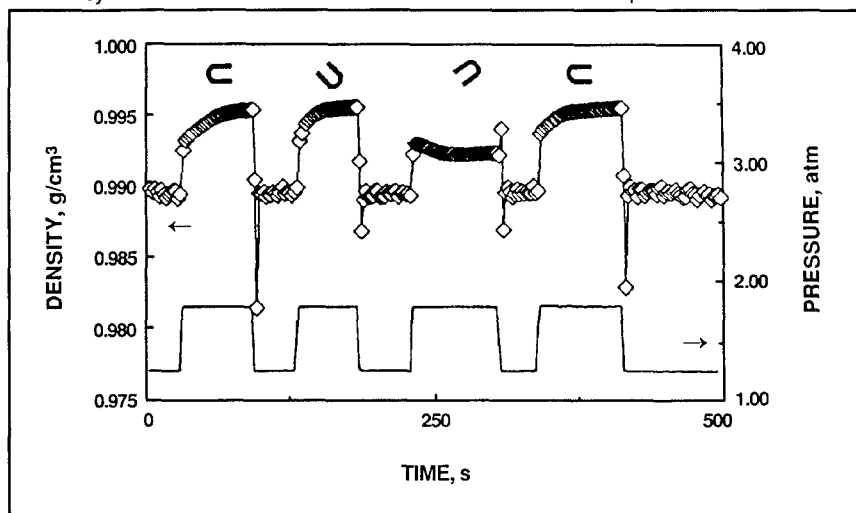
Two recent works describe a dispersed-air sensor based on ultrasonic attenuation (3, 4). The main disadvantage of the ultrasonic system is that the relationship between attenuation and bubble properties is complex. That is, many small bubbles will give different results than will a few large bubbles at the same total concentration of dispersed air. This situation necessitates frequent calibration by a secondary manual compression procedure.

Commercial instruments that monitor dispersed air by measuring the compressibility of the pulp are supplied by PAPEC (Sumner, WA).

1. Full-scale pilot flow loop used to compare the densitometer and the PAM sensor



2. Stock density and pressure as functions of time for a newsprint pulp. (Results obtained in bench-top flow loop.) Regions of high pressure correspond to density measurements on stagnant pulp; regions of low pressure correspond to density measurements on flowing pulp. The "U" symbols denote the orientation of the U-tube in the vertical plane.



Information about pulp compressibility is converted to air content using Boyle's gas law (5). Automated and manual versions of these instruments are available. In this report, wherein we examine the use of a U-tube densitometer to measure dispersed air in a newsprint pulp, the automated PAM (process air measurement) instrument was used as a benchmark for the densitometer results.

Domtar was assigned patents for sensors using automated densitometers to measure fiber length (6), pulp specific surface area (7), and the air content of pulp (8). Densitometers are robust, inexpensive, and very accurate. Since we report densitometer results in this work, it is instructive to review the transformations necessary to convert densities to air contents.

The density of a pulp suspension is given by the following mass balance equation.

$$\rho_{\text{stock}} = (\rho_{\text{pulp}}\phi_{\text{pulp}}) + (\rho_{\text{air}}\phi_{\text{air}}) \quad (1)$$

where

- ρ_{stock} = measured stock density
- ρ_{air} = density of dispersed air
- ρ_{pulp} = density of fiber, filler, and water
- ϕ_{air} = volume fraction of dispersed air
- ϕ_{pulp} = volume fraction of fiber, filler, and water

However, because

$$\rho_{\text{air}}\phi_{\text{air}} \approx 0$$

Eq. 1 can be simplified to

$$\rho_{\text{stock}} = \rho_{\text{pulp}}\phi_{\text{pulp}} \quad (2)$$

In addition,

$$1 = \phi_{\text{pulp}} + \phi_{\text{air}} \quad (3)$$

To obtain the fraction of dispersed air, ϕ_{air} , from the measured density, ρ_{stock} , more than one density measurement is required, since there are too many unknowns in Eqs. 2 and 3. The usual approach is to increase or decrease the system pressure and *immediately* measure a second density before significant mass transfer of air between phases occurs. Thus if two measured densities, $\rho_{\text{stock } 1}$ and $\rho_{\text{stock } 2}$, are measured at two pressures, P_1 and P_2 , the volume fraction of dispersed air at P_1 is obtained using Eq. 4.

$$\phi_{\text{air } 1} = \frac{(\rho_{\text{stock } 2} - \rho_{\text{stock } 1})}{\{\rho_{\text{stock } 2} [1 - (P_1/P_2)]\}} \quad (4)$$

Equation 4 was derived assuming that:

- The gas phase obeys the ideal gas law
- The liquid phase is incompressible (i.e., ρ_{pulp} is independent of P)
- There is no mass transport between vapor and liquid phases.

The Domtar patent describes the following four steps.

1. A pulp sample is isolated in the densitometer.
2. Density is measured at the system pressure.
3. Pressure in the densitometer is lowered by expansion of a piston.
4. Density is determined again.

A key feature of this design is that the pulp remains stagnant during the density measurement.

In this work, we show that air content can be reliably measured by densitometry. However, we were unable to obtain reliable density measurements on stagnant pulp samples in our densitometer because of bubble coalescence and convection. Herein, we demonstrate new densitometer-based techniques that alleviate this problem.

Experimental

Density was measured with an Anton-Parr Model DPR 417 NYEK densitometer, which included a temperature sensor and an mPDS 4000 data-acquisition computer. Data were stored in a personal computer that was interfaced with the data-acquisition computer. The minimum inner diameter of the densitometer U-tube was 6.6 mm. Specifications for the factory-calibrated densitometer were for an accuracy of ± 0.0001 .

g/cm³ and a reproducibility of ± 0.00001 g/cm³.

The densitometer and a dispersed-air sensor (PAPEC Model AST-02 PAM) were incorporated into a pilot-plant flow loop, illustrated in Fig. 1. Two Heise model 623 absolute-pressure transducers (P_1 and P_2) were fixed near the inlet and outlet of the densitometer. The tank contained approximately 1600 L of 0.7%-consistency pulp made from diluted chemithermomechanical pulp. The pulp was initially heated with steam, and pulp temperature ranged from 47°C to 58°C. Air was entrained in the pulp by discharging the main recirculation pipe above the surface of the tank. The flow rate through the main return pipe was measured with a magnetic flowmeter and controlled with Valve D. Flow rates were controlled between 100 L/min and 450 L/min.

The pressure at the PAM sensor was measured with the pressure gauge and controlled with Valve C to obtain a constant value of 1.75 atm. The pressure at the densitometer was 1.2 atm, with a pressure drop of approximately 0.05 atm across the densitometer. The pressure corresponding to the density measurements was taken as the average value of the pressure transducers at each end of the U-tube.

A Masterflex peristaltic pump, P, was continuously operated at a flow rate of 0.75 L/min. When Valves A and B were open, Pump P served as a partial bypass to the densitometer. When these valves were closed, pump P recirculated an isolated pulp sample through the densitometer.

Results

Bench-top flow loop

In our initial laboratory studies, pulp was circulated through a 1-gal bench-top flow loop consisting of tubing, a peristaltic pump, and a pulp bucket into which air was sparged. When the system was at steady state, samples were isolated first by closing the downstream valve, B, and then closing the upstream valve, A. Figure 2 shows pressure and the measured stock density as functions of time. The regions of high pressure correspond to density measurements made on stagnant pulp isolated in the densitometer. The regions of low pres-

sure correspond to density measurements made on flowing pulp. The "U" symbols indicate the orientation of the densitometer in the vertical plane.

The pressure increased after closing the downstream valve because the pump continued to operate. The expected increase in density with pressure was observed. However, the detailed behavior of the density curve was dependent on the vertical orientation of the densitometer tube, as seen in Fig. 2. Unexpectedly low density spikes also were observed when the flow was resumed.

We believe that the dependency of density on U-tube orientation was due to convection of bubbles into, or out of, the U tube. Additionally, comparison of the first and last pressure jumps, which were done using the same U-tube orientation, showed that the detailed density/time-response curves of the isolated samples were not reproducible. We believe that the lack of reproducibility was the result of bubble coalescence. These results led us to conclude that density can be measured reliably only on flowing pulp.

Pilot-plant flow loop

The pilot-plant flow loop illustrated in Fig. 1 was used to obtain measurements from the densitometer (stock density) and from the PAM sensor (air content). The results in Fig. 3 show that stock density decreased with increasing air content. The solid line in Fig. 3 is the water density, which was calculated using the measured temperature and applying a density correlation obtained from the literature (9). The dip in air content at 20–25 min was induced by turning off the mixer in the pulp tank.

A simple approach to the analysis of raw density data is to assume ρ_{pulp} in Eq. 2 is equal to the calculated density of water, ρ_{water} . Under this assumption, Eqs. 2 and 3 can be rearranged to give

$$\phi_{\text{air}} = 1 - (\rho_{\text{stock}} / \rho_{\text{water}}) \quad (5)$$

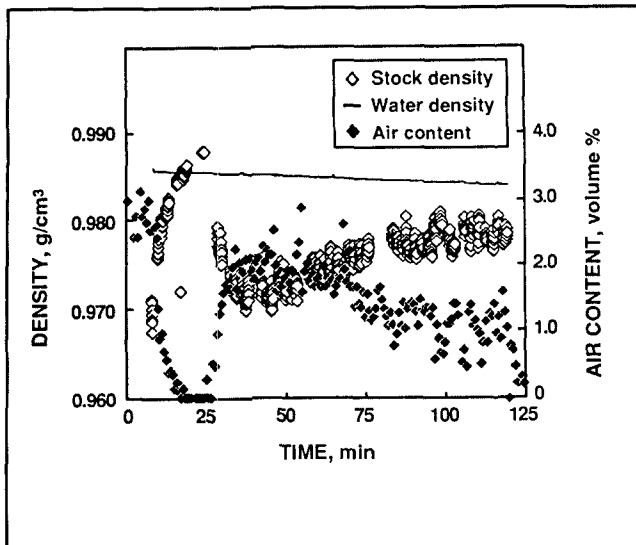
which is plotted against the PAM data in Fig. 4. The correlation coefficient (r^2) for the fitted line was 0.71. Scatter in Fig. 4 is not indicative of poor performance of either instrument, nor does it indicate they were measuring different things. The scatter is the result of the air content changing more quickly than either

instrument's ability to sample the system. This is shown in Fig. 3, where the PAM data for air content fluctuated by ± 0.5 volume percent, and in Fig. 5, where fluctuations in stock density were of the same order. Therefore, it was impossible to acquire PAM and densitometer measurements on pulp samples with the same air contents.

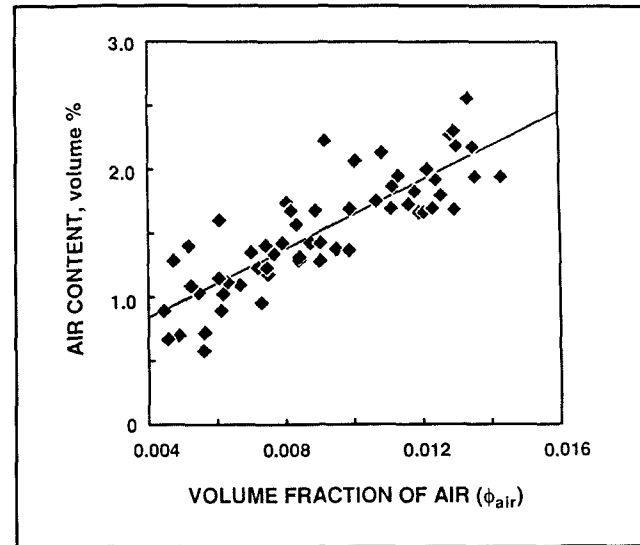
Calculation of ϕ_{air} requires two measurements of stock density at different pressures. Pressure jumps in the densitometer were induced by closing the downstream valve, B, followed by the upstream valve, A (Fig. 1). This isolated the densitometer contents, which were recirculated by the peristaltic pump, P. Results for a typical pressure jump are shown in Fig. 5. Before the pressure jump, the pressure was constant, whereas the density showed the usual fluctuations we attributed to erratic bubble generation in our loop. After the pressure jump, the range of density fluctuations was lower because the measurements were made on an isolated sample. On the other hand, without the continuous flow of hot pulp through the densitometer, there was an upward drift in the calculated density of water because of a slight cooling of the densitometer. From 50–70 s, the pulp density drifted upward while the pressure drifted downward. We attribute this behavior to mass transport from the dispersed gas phase to the dissolved gas phase at constant volume. The results in Fig. 5 are typical of the numerous sets of data collected in the course of this work.

Pressure-jump experiments such as that shown in Fig. 5 were analyzed by applying Eq. 4 to obtain the volume fraction of dispersed air. These values, together with the PAM data, were converted to corresponding volume fractions at 1 atm assuming that the dispersed air obeys the ideal gas law and that there is no gas transport between the liquid and vapor phases. This conversion was done because the absolute pressure values at the PAM sensor were different from either of the pressures measured during the density measurements. Figure 6 compares air contents determined by the two instruments, and the results show good agreement.

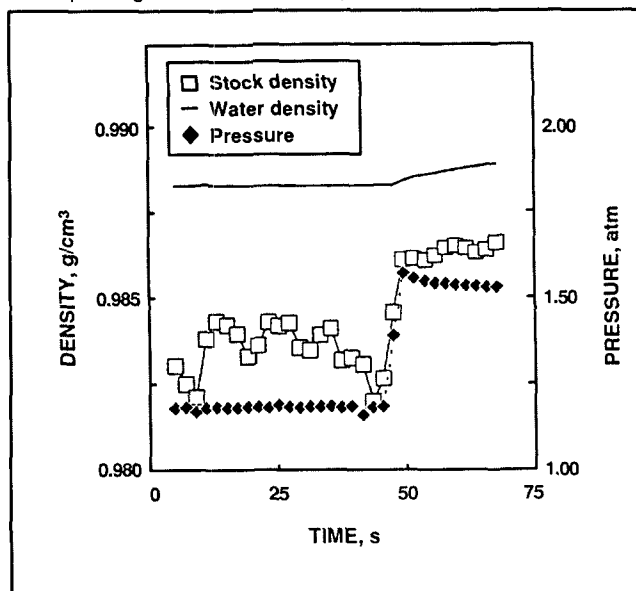
3. Raw data from pilot-plant flow loop showing stock density and air content (measured by PAM sensor) as functions of time. The line representing water density is the computed density of pure water corresponding to the measured temperature.



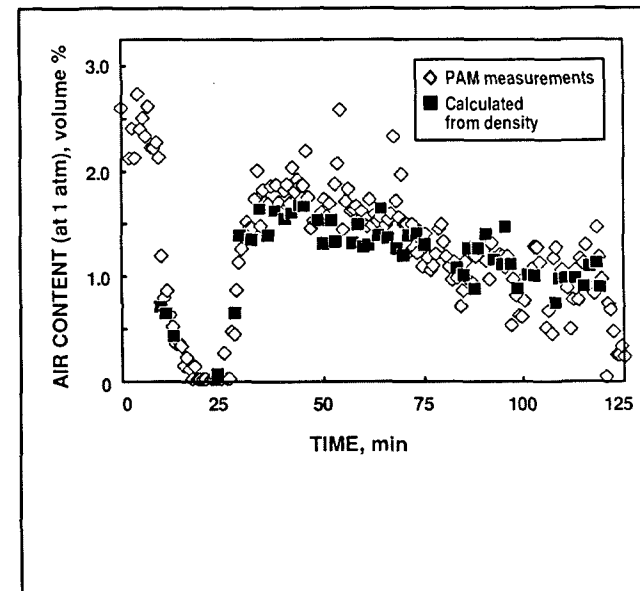
4. Comparison of air content as measured by PAM sensor at 1.75 atm and volume fraction of air (ϕ_{air}) as determined by measuring density and assuming the density of deaerated pulp equals that of pure water (see Eq. 5)



5. Stock density and pressure as functions of time before and after the pulp was isolated (at 46 s) under increased pressure. The line representing water density is the computed density of pure water corresponding to the measured temperature.



6. Air content as a function of time as measured by PAM sensor and as calculated by measuring density at two pressures. To facilitate comparison, results for both sensors were normalized to correspond to a pressure of 1 atm.



Discussion

Relationship between pressure and the state of air in stock

Many terms have been used in the literature to describe the location and the form of air in pulp: "loose," "entrained," "combined," "adsorbed," "free gas," and "residual gas." We use the terms "dispersed air" and "dissolved air," which are standard designations in physical chemistry.

Dispersed air can exist as discrete bubbles, as bubbles attached to fiber surfaces, or as bubbles trapped inside the fiber lumen. It is also possible that a small fraction of the dissolved air could physically adsorb onto fiber surfaces or diffuse into amorphous parts of the fiber. We do not believe that either possibility is significant.

According to Henry's law, the solubility of air in water is proportional to the applied pressure. The

results in Fig. 5 show that the time scale for complete dissolution of air bubbles is minutes. There are many operations in the approach system of a paper machine where the stock experiences pressure changes. Therefore, the presence of air bubbles in approach flows does not necessarily mean that the water is saturated with air. Instead, it is possible that the dispersed bubbles have not had time to dissolve. (There is no information

on the dissolution times of air bubbles in pulp in the literature.)

In summary, pressure affects not only the pressure-volume behavior of the dispersed phase but also the partition between the dispersed and dissolved phases. Ideally, pressure and degree of saturation should be reported with dispersed-air contents, as should the percent saturation for the air components in the liquid phase. None of the published techniques for characterizing air in pulp measure the concentration of dissolved air or, equivalently, the degree of saturation.

Measuring dispersed air

Dispersed air in pulp is thermodynamically unstable and, given the opportunity, all the air bubbles will dissipate to the head space. Unlike formulated foams such as aerosol shaving foams, which contain high-efficiency bubble stabilizers, bubbles in newsprint pulp are large and poorly stabilized. This situation makes air in pulp particularly intractable for scientific investigations. At best, a steady state can be achieved where bubble generation balances bubble dissipation. However, the results presented in this report show that air content fluctuates rapidly even in a simple flow loop.

The two techniques for measuring dispersed-air contents with a densitometer have distinctive advantages and drawbacks. The single-pressure/continuous-density technique provides relative air contents and has the advantage of being rapid (about 2 s per measurement) and easy. Calibrated densitometers and associated electronics can be purchased, directly installed, and interfaced with paper-machine computers with little anticipated maintenance. The disadvantage is that many assumptions or ancillary data are required for the computation of absolute air contents.

The dual-pressure technique shown here gives dispersed-air contents with no restrictive assumptions. Furthermore, data such as those shown in Fig. 5 contain mass-transport information from which we are attempting to estimate average bubble size. However, there are two significant disadvantages to our dual-pressure measurement technique.

1. Valves must be opened and closed, making the technique cumbersome.
2. The technique is slow, typically requiring 100 s per set of measurements.

We were able to collect good data with the PAM sensor. However, we feel the densitometer offers several advantages. Densitometers are fast, rarely in need of calibration, and require only a simple, small pipe connection to collect a small stream of pulp. By contrast, the PAM sensor either must be plumbed in and thus protrude into the stock line, or a significant quantity of pulp must be circulated through a PAM sample cell. Further disadvantages of the PAM sensor include the use of mechanical seals, valves, and moving parts, any of which can fail. The PAM sensor is also slow, requiring about 30 s per measurement.

The techniques studied in this work were targeted at the analysis of newsprint headbox pulps. Obviously, the instruments have application in other pulp-processing operations, including the characterization of dispersed air in flotation cells and in brownstock washing systems.

Conclusion

The amount of dispersed air in newsprint pulp suspensions can be measured using off-the-shelf densitometers. The densitometer must be run with flowing pulp to prevent artifacts caused by bubble coalescence or migration to or from the measuring tube. Two measurement techniques were demonstrated. In the first, density was measured continuously to obtain relative air contents. The second technique involves measuring the density of an isolated sample at two pressures, thus permitting direct calculation of dispersed air content.

The densitometer shows that a change in pressure induces mass transport between dispersed and dissolved gas states. This behavior is expected to be operative in the approach system of a paper machine. □

Literature cited

1. May, O. W., and Buckman, S. J., *Tappi* 58(2): 90(1975).
2. Woodworth, M. D., *Tappi* 73(11): 135(1990).
3. Karras, M., Pietikainen, T., Kortelainen, H., and Tornberg, J., *Tappi* 71(1): 65(1988).
4. Karras, M., and Springer, A., *Tappi* 72(2): 155(1989).
5. Dougherty, S. J., *Tappi* 72(1): 50(1989).
6. Karnis, A., and Shallhorn, P. M., On-line monitoring of fiber length of mechanical pulps, Canadian pat. 1,138,224 (1982).
7. Karnis, A., and Shallhorn, P. M., Method and apparatus for on-line monitoring of specific surface area of mechanical pulps, U.S. pat. 4,441,960 (1984).
8. Janssen, W., Method and apparatus for the determination of nondissolved gas in liquids, U.S. pat. 4,584,866 (1986).
9. Kell, G. S., *J. Chem. Eng. Data* 20(1): 97(1975).

The authors acknowledge Abitibi-Price Inc. and the Canadian Natural Science and Engineering Research Council for financial support.

Received for review Nov. 30, 1990.

Accepted Aug. 20, 1991.