

On-line air entrainment tests on paper machines

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ABSTRACT: *An on-line ultrasonic air content meter was used to measure entrained air in the short, white water circulation of some North American newsprint, fine paper, paperboard, and corrugated medium paper machines. The results indicate that such a meter is an effective diagnostic tool for paper machines in which air-related problems are suspected.*

KEYWORDS: *Air content, air entrainment, costs, metering equipment, on-line measurement, paper machines.*

The amount of entrained air in a papermaking furnish depends on the process conditions and the properties of the furnish. There are several sources of air entrainment, which refers to gas bubbles that are stabilized or attached to the furnish or to large unbound bubbles (free air). Air also can be dissolved in the bulk liquid and released later as bubbles; otherwise dissolved air is not a problem in papermaking (1, 2).

Turbulent flows in open channels, leaking pumps, and free-fall of stock or additives into a chest can entrain air in papermaking slurries. Intensive agitation in the process will generate shear forces which may subdivide the incoming air bubbles and attach them to the furnish components. The large amount of entrained air in white water evidently comes from the free-fall of draining water into the wire pit.

Pressure and temperature changes can cause gas bubbles to dissolve in

water or be released from it. As pressure increases, the bubbles decrease in size and part of the gas dissolves. If the fresh water for diluting high-consistency stock contains dissolved air, this will be a continuous source of adsorbed air bubbles. The bubbles generated readily attach themselves to water-repellent surfaces covered by wax or other pitchy material (2).

The bubbles are anchored to the furnish mainly by soap stabilization, the substances involved being mostly resin and fatty acids and their derivatives, although organic compounds such as lignin and proteins will similarly stabilize bubbles (3-5).

The furnish also contains unstabilized gas bubbles, which are free to escape unless the fibers prevent them from rising. These bubbles are relatively harmless, but they are a potential source of adsorbed bubbles due to the shear forces present in process flows.

Gaseous air also can be utilized in papermaking. For example, in the Radfoam process an aqueous foam is used as a fiber suspending medium to ensure good fiber dispersion in the finished paper—even with long fibers (6).

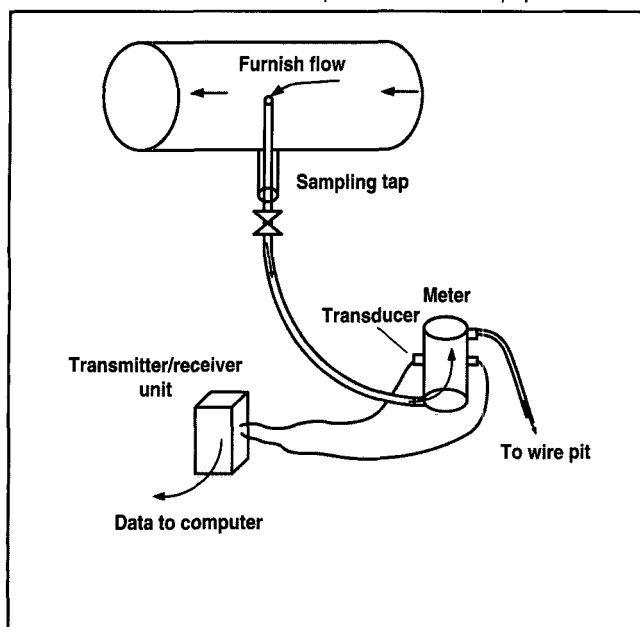
Problems due to entrained air

Some reports on the adverse effects of entrained air on papermaking are based on experiences reported by the control staff in mills. The foam problems encountered in papermaking are clearer and better understood than those due to entrained air; they involve stock flotation, clumping, sheet breaks, slime, and an increased need for machine cleanups. The foam content is usually estimated visually, with or without a TV camera, from the trays or from the Deculator. Various surface-level meters also have been used to measure the foam level. The relationship between foam and stabilized air is not a straightforward one, since the entrained air content can be high without visible foam and vice versa.

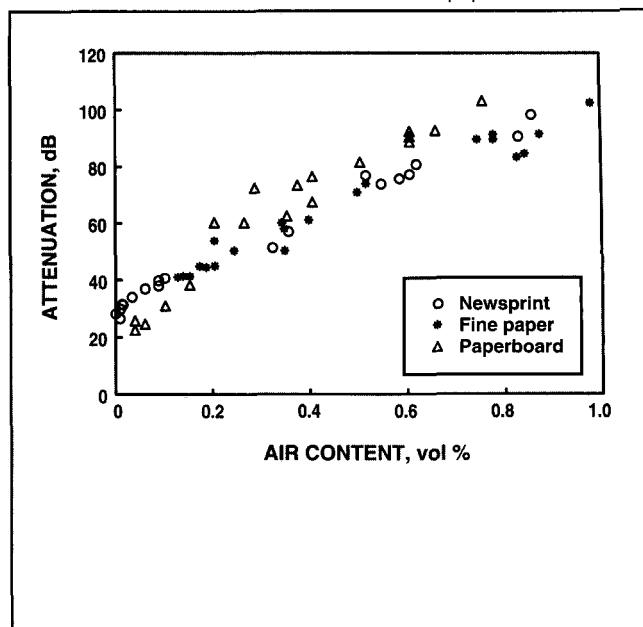
Air content is normally measured by batch sampling methods based on pressure changes (compression or expansion) or density changes (7). A vibrating U-tube densitometer has recently been proposed for the measurement of entrained-air bubbles (8). The rotation rate of the mixing pump has been used to estimate changes in air content, as these measures correlate well (9).

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1. Installation of the meter on the process line of the paper machine



2. Attenuation efficiencies of ultrasound on the paper machines



General experience regarding the adverse effects of entrained air on papermaking stock and final sheet properties include foam and spots on sheet, pin holes, retarded drainage, energy losses in pumps, and sheet breaks (1-3, 8). Stabilized (or adsorbed) air bubbles also are generally known to impair paper formation, drainage, and tensile strength.

Air bubbles promote fiber and fines flocculation by attaching to nonwetable parts of the fibers. Where a bubble makes contact with two or more fibers, it will hold them together to form a floc (2, 3).

The relationship between air content and drainage is not a simple one. The gas bubbles in the furnish are assumed to block the pores in the fiber mat upon reaching the wire of the paper machine and thereby retard drainage (2, 3). However, according to Karras and Springer, rising free-air bubbles (or nonadsorbed entrained foam) may assist drainage. In some tests, a certain dose of retention polymer in the aerated furnish enhanced the drainage rate and did less harm to mat formation than the same polymer dose in an air-free slurry (10).

The film of an air bubble may collect hydrophobic fines on its surface, pre-

venting the fines from strengthening the fiber bonding (3).

The critical amount of air leading to noticeable problems depends on the type of paper machine, the grade of paper, and the kind of furnish being used.

The objectives of this work were to determine by means of on-line measurements the amount of entrained air in the short, white water circulation of different paper machines, the sources of entrained air where it was identified as a problem, and the effects of entrained air on the papermaking process.

Experimental

Paper machines

The research was carried out at various North American paper mills employing newsprint, fine paper, paperboard, and corrugated medium machines. The sample flows were taken from the short circulation of the machines. Sampling taps were installed before and after the cleaners, before and after the Deculator, and near the headbox. The sampling tubes illustrated in Fig. 1 were used to obtain a representative flow of furnish from the process line to the meter. The sampling

taps were installed downward, if possible, to prevent rising air bubbles from collecting in the sample flow. The material flowing from the meter was sent to the wire pit.

Data collection

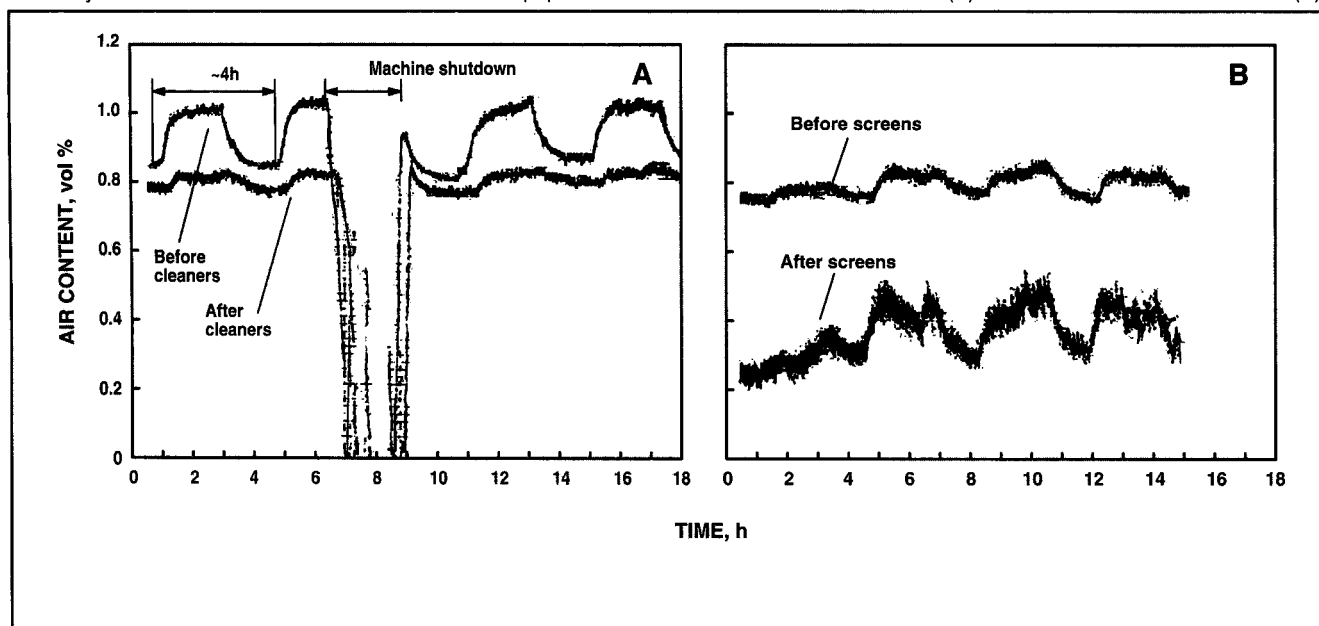
The measurement principle employed in the meter is based on the attenuation of ultrasound due to air bubbles (9), the output signal of the device corresponding to an attenuation range of 0 dB to 127.5 dB. The meter transmitted a new signal (mean of 250 measurements) once every 10 seconds. The data from the meters were displayed on a chart recorder (SOLTEC VP-6232S). A connection to the process-control computer system of the mill also was established whenever possible.

Process parameters and trends were collected from the process-control computer system and from stock preparation log sheets.

Calibration of the meter for different machines

The attenuation of ultrasound is very sensitive to the quantities of stabilized air bubbles present but insensitive to free bubbles. Also, the attenuation efficiency of the air bubbles is somewhat

3. The cyclic air content variation observed on the fine-paper machine before and after the cleaners (A) and before and after the screens (B)



I. Linear regression of plots of air content vs. attenuation for the machines studied

Paper machine	Slope, dB/vol%	R^2	Std. error of air, vol%
Newsprint	79.5	0.989	0.033
Fine paper	71.1	0.970	0.055
Paperboard	112.2	0.925	0.059

different in different furnishes because it depends on the bubble size distribution and on the mechanism of the air bubble stabilization (11). The sensitivity of the meter to stabilized bubbles is advantageous because these are far more harmful than loose bubbles in the papermaking process (1-3, 8). The dependence of ultrasonic attenuation on the consistency of the airless furnish is low, approximately 2-6.4 dB/% consistency, according to the type of furnish (11). High fines and filler content and a high-viscosity bulk liquid slightly increase the attenuation of ultrasound in the airless furnish.

The quantity of gaseous air is linearly correlated with the attenuation of ultrasound when the air content is below about 0.9 vol%. If the air content is large, the number of large, free bubbles increases and the dependence of at-

tenuation on air content will no longer be valid (11).

The total volume of air in the furnish was measured intermittently by the compression method (7-9). Plots of the attenuation efficiency of the air bubbles in newsprint, fine paper, and paperboard machines are shown in Fig. 2. The correlation between air content and attenuation was fairly linear for each machine. It was not possible to make a valid correlation in the corrugated medium furnish because the variations in stabilized air content were too small. A linear regression equation was calculated for each curve plotted. The slopes of the curves (attenuation efficiencies), squares of correlation coefficients, and standard errors of the estimates of air volume are listed in Table I.

The higher the attenuation efficiency, the smaller the bubbles and the more firmly they are anchored to the furnish components (11). The attenuation efficiency of the bubbles was largest in the paperboard machine furnish, suggesting that it was here that the smallest bubbles were formed.

Results and discussion

Air content measurements and possible sources of air

Entrained-air levels (vol%) at various locations in the process during normal machine operation which were considered "safe foam levels" by the control staff are displayed in Table II. No problems in machine operation due to air were identified at these levels.

The consistency range was from 0.4% to 1%, temperature range from 40°C to 52°C, and machine speed range from 256 m/min to 1280 m/min on the different machines.

Newsprint machine. Simultaneous measurements indicated that the cleaners with a mechanical deaerator reduced gaseous air in the furnish, but heavy use of a defoamer was necessary to keep the air content at an acceptably low level of 0.0-0.1 vol% after the

II. Typical air content values for the machines studied

Machine	Before cleaners, vol%	After cleaners, vol%	Headbox, vol%
Newsprint	0.06–0.6	0.0–0.1	0.0–0.1
Fine paper	0.80–1.1	0.3–0.9	0.1–0.4
Paperboard			
Top ply	1.3–1.5	1.20–1.50	0.60–0.8
Middle ply	0.3–0.6	0.04–0.15	0.04–0.1
Bottom ply	Consistency too high for the meter		
Corrugated	No cleaner nor Deculator		1.2

III. Average air content levels, vol% on paperboard machine

	Top-ply furnish,	Bottom-ply furnish,
Before the cleaners	1.5	0.40
After the cleaners	1.3	0.10
Near the headbox	0.7	0.07

headbox fan pump. Generation of foam in the trays was observed at higher air contents. The air content was lower at startup (just after the machine had been washed clean of organic dirt, fillers, and chemical residuals) than after a prolonged run and increased during changes in the process conditions.

The white water in the wire pit contained about 1 vol% air. It is possible that the circulating white water may have gradually contaminated the whole process flow with interfering substances capable of stabilizing air bubbles.

About 90% of the newsprint stock was thermomechanical pulp (TMP), which had a high fines content; the other 10% was semibleached kraft. The freeness level in the headbox furnish was around 50 mL. TMP stock contains a high proportion of fines with lignin, which tend to promote the binding of air bubbles (4, 11).

Fine-paper machine. The cleaners and screens removed the entrained air so that the signals followed each other consistently. Typical air content levels were: 1 vol% before the cleaners, 0.8 vol% after the cleaners, and 0.2–0.3 vol% in the headbox.

A cyclic air-content variation of about four hours, with good repeatability, was found in both fine-paper machines (Fig. 3), and the magnitude of this variation remained almost the same throughout the measurements. In Fig. 3A, the average air content in the cleaners was reduced from 1.00 vol% to 0.80 vol%. A typical value for

the amplitude in air-content variation before the cleaners was about 0.17 vol%, while the cleaners reduced this to about 0.04 vol%. As Fig. 3B indicates, the screens also removed air from the furnish, from an average level of 0.8 vol% to about 0.4 vol%. In contrast to the cleaners, the relative variation in air content was higher after the screens than before, increasing from 0.04 vol% to 0.15 vol%.

The cleaners cause the furnish to spin, and the low pressure inside the resulting vortex sucks some of the air bubbles and dissolved air out. The screens may reduce the remaining larger bubbles to smaller ones, thus increasing their surface area and the attenuation of ultrasound.

The reason for the observed air-content cycle is not clear. Almost every process parameter studied in the fine-paper machine had a cycle, many of them almost four hours in length. For example, the starch tank for the sizing emulsion, the carbonate feed tank, and various chests all had a capacity of about four hours. It is possible that when there was air coming into the process from the stock chests, the sizing starch stabilized it and the bubbles became attached to the fibers, fines, and fillers.

The properties of fine-paper stock should not promote efficient air uptake. Most of the stock was well-bleached kraft with a low lignin content. The freeness level was around 400 mL, so the fines content was also low. No fillers were used.

The process-control computer system was used to determine correlations between air content and various machine variables. Only the most clearly indicated trends are presented.

Changes in calcium carbonate flow seemed to have no effect on air content. Carbon dioxide is not formed in the furnish under the prevailing alkaline conditions, but it may be liberated in reactions with acidic additives (3).

Grade changes had an effect on air content. When the caliper was increased from lower (0.14 mm) to higher (0.18 mm) and chemithermomechanical pulp (CTMP) was added to the stock, the air binding capacity increased, as did the air content, from 0.1 vol% to 0.8 vol%. Upon reverting to a lower caliper after about 12 hours and reducing the use of CTMP, the air content decreased to its normal level of 0.1 vol%.

The decrease in the total head inside the furnish may have contributed to slightly greater volumes of air in the furnishes meant for high caliper and basis weight. When the pressure decreased, the total volume of gas bubbles increased. The air was less harmful to runnability when the paper caliper was large and the machine speed slow.

Previous measurements performed on various paper machines have shown a clear correlation between air content and mixing-pump speed at a constant production rate (9). This correlation was weak for the fine-paper machines studied here.

The addition of internal starch and alum similarly are reported to have

had a strong effect on air content in other tests (12) but not in the case of the fine-paper machines studied here. It is probable that the addition systems used for chemicals and fillers are the active factors leading to high air content in some machines. It is also possible that pumps mix air with the additives and thereby aerate the furnish.

Paperboard machine. Measurements were made only on the top- and bottom-ply furnishes because the air content meter used could operate only at stock consistencies below 1.5% and not at the filler-ply consistency of about 2.5%.

The average air-content levels by volume are shown in **Table III**.

The freeness of the pulps was around 460 mL. The top- and bottom-ply furnishes were both made from a mixture of hardwood (20–30%) and hemlock (70–80%) fibers combined with the same additives. Yet, the top-ply furnish had a higher air content than the bottom, especially when measured after the headbox fan pump. The most obvious reason for this was an improper stock feed to the top-ply Jordan chest.

The stock levels in the two Jordan chests were practically equal, but the stock came into the bottom-ply chest horizontally from the chest wall and dropped down gently about 1.5 m away from the suction of the Jordan pump, whereas in the top-ply line it spurted directly down from the ceiling of the chest through the stock surface near the suction of the Jordan pump, pushing air into the process line.

Corrugated medium paper machine. The ultrasonic measurements showed the amount of stabilized air to be constant at the level of about 1.2 vol% in the headbox and about 0.9 vol% before the screens during measurements taken over 10 days. Changes in machine speed and basis weight did not have an effect on the air content. The consistency of the furnish was high for the meter, from 1.2% to 1.5%. Because the sampling valve into and the drain valve out of the meter were only 0.5 in. (12.7 mm) in diameter, the high consistency caused some plug-

ging and interruption of the flow through the meter chamber.

The main reason for the high air content (1–3.2 vol%) in the corrugated medium furnish was its large air binding capacity associated with high lignin and fines content and coarse fibers. The freeness of the furnish was around 180 mL. We believe that the free-fall of stock into various chests promoted air entrainment.

Defoamer trials

The objectives of the newsprint defoamer trials were to study the effect of defoamer dosage level on entrained-air content, to determine the optimal dosage level, and to investigate the effects of air on the process.

Excessive defoamer dosage is reported to increase deposit formation and reduce drainage, retention, and tensile strength (2, 13, 14). Certain defoamers can even generate foam as surface-active chemicals at high dosage levels.

The defoamer was introduced at four places on machine No. 1. The maximum pumping capacities are as follows:

- Pump 1: 3.03 L/h to trays
- Pump 2: 1.89 L/h to trays
- Former seal pit: 11.73 L/h
- Wire pit: 3.03 L/h
- Saveall: 1.89 L/h
- Total: 21.6 L/h.

The trial was carried out just after a machine shutdown for cleaning. The effect of a stepwise change in total defoamer feed on air content after the Deculator and headbox fan pump is shown in **Fig. 4**. The total defoamer dose was decreased stepwise from 100% (maximum level, 21.6 L/h) to 38.4% (8.14 L/h). Each step lasted at least one hour to assess changes in the air and foam levels. The measurements showed that the air content started to increase slowly as the defoamer dosage was gradually reduced, but an increase in tray foam levels was noticed only after a 38.4% of maximum de-

foamer feed had been maintained for five hours (hours 10–15 of the trial). During this time, the meter also showed a marked increase in the stabilized air content from 0.04 vol% to 0.08 vol%.

When the amount of foam in the trays rose to the critical level (at hour 20 of the trial) and the air content had increased to 0.13 vol%, the defoamer feed was increased to 41.2% of the maximum. This reduced the foam to tolerable levels for about three hours and simultaneously reduced the air content to 0.11 vol%. When the air content started to rise again five hours later, the defoamer dosage was increased to 47.4% (at hour 25 of the trial), which kept foam and air levels under control for the rest of the trial.

The defoamer requirement increased to 70–80% of the maximum dosage during a 10-day period after the trial, possibly due to the buildup of inorganic and organic deposits (fines, fillers, size, pitch, microbiological deposits, lignin) in the machine and in the circulating white water during that period.

The savings in defoamer consumption in machine No. 1 ranged from 14% to 62% (100%–21.6 L/h) during the test period for which the air-content meter was connected to the process.

Tests made on another newsprint machine, No. 2 at the same mill, gave similar results, but there was a great increase in air content during the measurements, from an airless level to over 0.9 vol%, due to a defoamer pumping problem. The latter air content was so large that the machine suffered losses in production because of a sheet break and bad paper quality. The foam levels in the trays increased so much that they overflowed.

The savings in defoamer use on machine No. 2 during the measurement period was 20–30% of the normal average dosage (85% of maximum = 46.7 L/h). The total average savings in defoamer expenses alone on the two newsprint machines corresponded to about US\$ 250,000 annually.

Earlier I pointed out that foam level is not necessarily related to entrained-air content. During the measurements

on both newsprint machines, the amount of entrained air could be high without any visible foam, but when the foam level was high, the furnish always contained more entrained air than at a foamless level.

Effects of entrained air

Newsprint machine. The critical air content for the machines studied here ranged from 0.12 vol% to 0.2 vol% after the headbox fan pump. Larger air contents had noticeable effects on the process. According to the measurements, the increase in entrained-air content caused reductions in the surface level of the Deculator, the Deculator overflow tank level, and the Deculator vacuum. High air content also caused increased foam generation in the trays, reductions in paper quality, and sheet breaks. There were marked fluctuations and reductions in first-pass retention when the air content was high and the defoamer level low.

The control staff of the mill reported that the following effects are also observed due to high foam and air levels:

- Increased standard deviation in the machine direction (MD) basis weight
- Increased standard deviation in MD reel moisture
- Fluctuations in suction box No. 1 and retention shoe vacuum
- Reductions in drainage rate (former seal-pit control valve).

These effects could not be verified during this study, however.

The parallel trends in air content and the surface level of the furnish in the Deculator, the Deculator vacuum level, and wire retention are shown in Fig. 5.

When the air content increased from 0 to over 0.9 vol% between hours 7 and 18, the surface level decreased by about 20 cm, and when it was reduced to normal by a heavy dose of defoamer during hours 18–20, the surface level of the furnish rose by about 30 cm. Smaller changes in air content from 0 to about 0.08 vol% and back to 0 occurred be-

tween hours 27 and 43 and between hours 44 and 66, which also caused noticeable changes of about 12.5 cm in the surface level of the furnish inside the Deculator.

When the air content increased, there was a simultaneous decrease in the Deculator vacuum level because expanding air reduced vacuum and bound-air bubbles decreased the density of the furnish. Simultaneous changes took place during hours 7–10, 27–43, and 44–66. The vacuum drop (or pressure increase) was about 1.3 kPa per 0.1-vol% increase and 5 kPa per 0.9-vol% increase in air content.

Simultaneous trends of the air content and (first-pass) wire retention (measured with the Kajaani LC-100 meter) show that when the air content increased there was a coincident decrease in retention and vice versa (between hours 7 and 20, 27 and 43, and 44 and 66). The reason for the decreased retention could lie in the lower defoamer dosage. Defoamers, being highly surface-active chemicals, have an effect on retention (14).

Fine-paper machine. The simultaneous trends in the most susceptible parameters and in air content did not show any clear correlations concerning the source of the air or its effect in the case of the fine-paper machine.

The air content of 0.1 vol% to 0.4 vol% in the headbox was so small that it had no major effect on the runnability of the machine, but it is possible that the highest air content of 0.6 vol% could cause problems with lower-caliper paper, for which the speed of the machine is also higher.

Paperboard machine. The measurements did not reveal any clear sources of or effects of the air. The air content in the top-ply furnish was high, from 0.6 vol% to 0.8 vol% near the headbox. The high level of entrained air may have reduced the formation of the top-ply sheet.

The air content of 0.04 vol% to 0.1 vol% in the bottom-ply furnish is so small that it probably would not have any effect on runnability or sheet quality.

Corrugated medium paper machine. Although the content of stabilized air in the headbox was at saturation level all the time, it did not have any noticeable effect on the quality of the paper produced or on the runnability of the paper machine. Air content was not a critical factor in the production of corrugated medium. The machine speed was quite slow and the paper caliper high.

Conclusions

The ultrasonic air-content meter proved to be a good indicator of changes in entrained-air content and could be used for continuous measurement. Visual observation of tray foam levels, Deculator surface levels, and other air-related parameters were inadequate to permit the control of defoamer use.

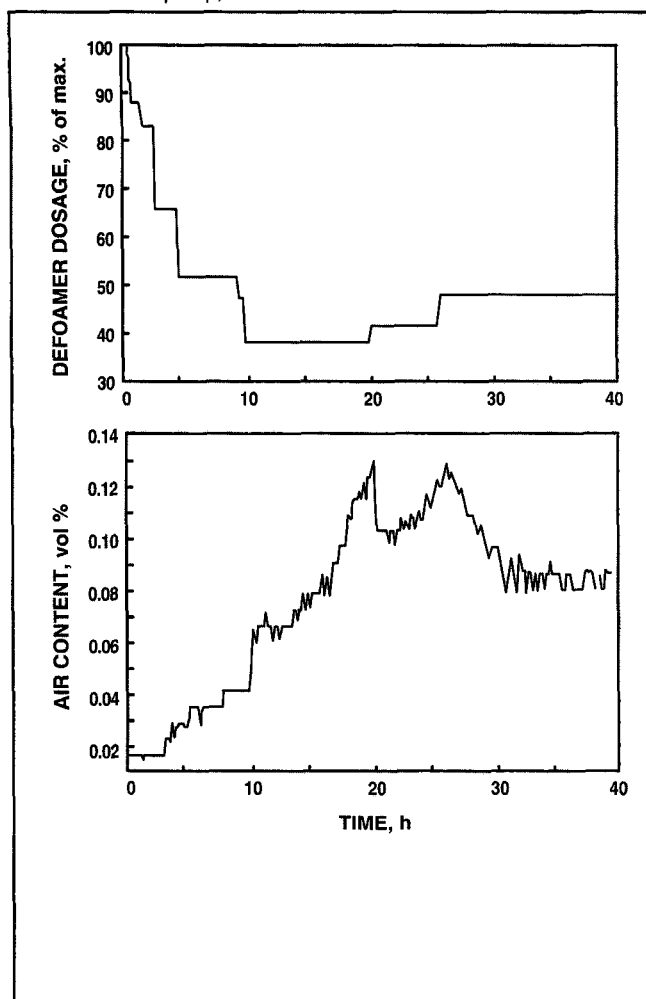
We were able to show that on-line knowledge of air content could be utilized to control defoamer feed rates on newsprint machines, resulting in average savings of 30% in defoamer consumption. This corresponded to an annual savings of more than US\$ 100,000 per machine.

On-line monitoring of the sources of entrained air was possible with the meter. The measured air content in different machines varied from 0 to 1.2 vol% depending on the measurement point. The highest amounts of air were measured in the white water in the wire pit, and the air content decreased toward the headbox. The cleaners and the mechanical deaerator (when installed) reduced gaseous air in the furnish as expected; the screens also removed air from the furnish but seemed to reduce large bubbles to smaller ones at the same time.

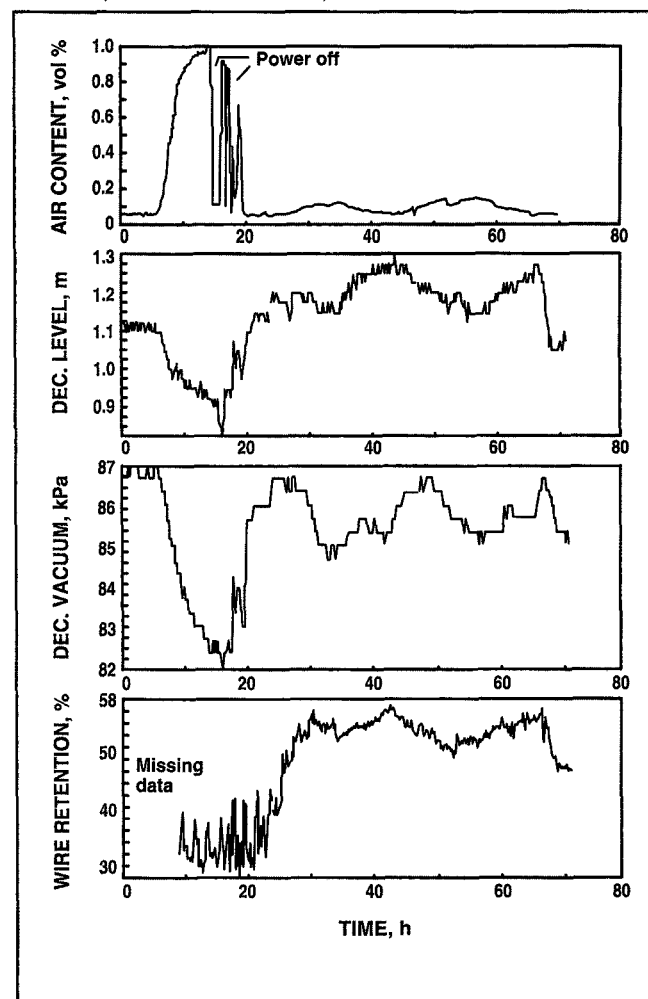
Evident sources of air included the makeup and feed systems for the various additives and leaking pumps. Free-fall of stock or additive into a chest entrained air and increased both the air content of the furnish and foam levels in the trays in the case of newsprint machines.

Entrained air caused reductions in the Deculator surface level, the Deculator overflow tank level, and the

4. Effect of a stepwise change in defoamer dosage on air content after the headbox fan pump, measured with an ultrasonic air content meter



5. Effect of air content on the surface level of the furnish inside the Deculator, the Deculator vacuum, and wire retention



Deculator vacuum in newsprint machines, and a high air content also caused increased foam generation in the trays, reductions in paper quality, and sheet breaks at very high air contents (>0.8 vol%).

When the air content was high and the defoamer level was low, there were marked fluctuations and reductions in first-pass retention.

The most sensitive parameters did not show clear correlations with air content in the case of fine paper, paperboard, and corrugated medium machines. **■**

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