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Effect of precipitated gas bubbles in papermaking

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SUMMARY

The gas in papermaking is divided into dissolved and entrained gas, which is further divided into free and bound gas bubbles. Dissolved gas is not believed to affect papermaking, as long as it remains dissolved. However, it can precipitate into free and bound gas if the temperature and pressure changes. In most studies concerning the effect of entrained gas on papermaking the gas has been formed from dispersed gas bubbles. In laboratory conditions, dispersed gas is rarely transformed into bound gas, unlike the precipitated gas that is formed on fibres and fillers. Recent research has been designed to determine if precipitated gas bubbles affect papermaking in a different way compared with dispersed gas bubbles. A furnish with different precipitated air contents was studied in a Moving Belt Drainage Tester (MBDT). The results showed differences between dispersed and precipitated gas bubbles in their effects on tear and wet tensile strength.

Keywords
Gas, air, MBDT, entrained gas, dissolved gas, dispersed and precipitated gas

The gas present in the papermaking process consists of normal air, water vapour and various gases produced by microbiological and chemical reactions in the paper machine's water circulation, such as decomposition of calcium carbonate pigments into carbon dioxide at acid pH (*1*). Different gases are dissolved into the fibre suspension at concentrations related to their solubility. The most common effect of entrained gas in a paper mill is surface foam, which may cause spots in the sheet. In addition, entrained gas causes pinholes, pressure pulsations in the paper machine's approach flow system and also impairs formation and drainage. (*2,3*).

Deaeration is used as a means to eliminate the adverse effects of air and other gases on the paper machine (*3,4*). Entrained gas can be removed either chemically with defoamers or mechanically (*5,6*). Competent process design, including good pipeline design, and using the correct stock composition, the right temperature and the right pressure conditions will prevent formation of gas bubbles in the fibre suspension. Although these measures reduce the need for deaeration, some mechanical deaeration is still required. A large part of the entrained gas can be removed in the wire pit. For complete gas removal, a vacuum deaerator is commonly used, or for removal of all the entrained gas a centrifugal pump (known as a "pomp") (*4,6,7,8*).

The gas present in the papermaking fibre suspension is divided into dissolved and entrained gas. Entrained gas is further divided into free and bound gas bubbles (*3,6*). Bound gas bubbles are attached to the fibres, fines or pigments. Dissolved gas has no effect on the fibre suspension's physical characteristics and is not believed to affect the papermaking process, as long as the gas remains dissolved in the fibre suspension (*9*). Dissolved gas can be precipitated into entrained gas because of pressure or temperature variations, which may occur in normal papermaking conditions, for example as a result of pressure changes before and after pumps (*10,11,12*). Precipitated gas bubbles are usually formed on the surfaces of fibres and pigments, being therefore bound gas bubbles (*12*). The dispersed gas bubbles are free bubbles, as they are formed in the fibre suspension. Some of the dispersed free bubbles can be mechanically attached to the fibres and fibre network, thus becoming bound gas bubbles (*12,13*).

Most of the studies made so far concerning the effect of entrained gas on the papermaking process deal with free gas bubbles. In almost all studies the gas has been formed from dispersed air bubbles (*2,3*). According to the studies made by Pelton et al., dispersed air bubbles are not adsorbed on the fibre surfaces (*13*). In the latest studies it has been found that the precipitated gas bubbles are very likely to be bound to fibres and fillers (*12*).

Recent research has been designed to determine if precipitated gas bubbles affect papermaking in a different way compared with dispersed gas which mostly consists of free gas bubbles (*12*).

MATERIALS AND METHODS

The present study was carried out using a Moving Belt Drainage Tester (MBDT). The sample was a headbox furnish from a commercial paper machine producing machine finished coated (MFC) paper, Table 1. A commercial paper machine furnish was used in order to cover all the compounds present in normal papermaking. No hydrophobic sizing was used on the MFC paper machine.

The MBDT is different from a traditional sheet mould; the drainage is pulsed as on a commercial paper machine. On a paper machine, the pulses are caused by foils under the moving wire. In a MBDT, the pulses are caused by a toothed belt, which moves against a stationary suction box and a stationary wire. In other words, its design is inverted compared with a normal paper machine (Fig. 1). Previous MBDT trial results have correlated very well with those of Fourdriner paper machines, even at full production speeds (*14,15,16*).

The Moving Belt Drainage Tester settings used in the trial are shown in Table 2. The target settings for the trials were 60 g/m^2 grammage and a stock with two different entrained air contents, 0 and 0.5 to 1.0%, and a temperature of 50°C.

The sample furnish was aerated in a pressurised tank to increase the entrained air content. The temperature in the vessel was adjusted to the desired level with a temperature sensor and a heating element. Compressed air was led into a 50-litre tank through a hose fitted with a pressure controller (Fig. 2). The stock sample was aerated according to the following procedure: a) The tank was filled with the sample and the temperature was adjusted to 50°C. b) The excess pressure in the vessel was adjusted to 150 kPa. A small flow of air was led through the pressure valve to cause turbulence, which stirred the sample well. The sample was aerated for a minimum of ten minutes to saturate it

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Table 1
Composition of commercial paper machine headbox furnish used in the study.

Paper grade	MFC paper
Stock materials	Bleached pine sulfate chemical pulp Bleached spruce TMP Calcium carbonate filler Coated broke (calcium carbonate, clay, SB latex and CMC) Furnish freeness 70 to 90 CSF
Process chemicals	Polydadmac fixative, PAM retention aid, bentonite, defoamer, alum
Headbox stock properties	Suspended solids 5 g/L Ash content 5 % pH 7.5 Temperature 50°C Conductivity 0.4 mS/cm

Table 2
Moving Belt Drainage Tester settings in air trials.

Properties	MBDT trial
Paper grade	MFC paper
Grammage (g/m^2)	60
Corresponding production speed (m/min)	1000*
Wire	Tamfelt 2868
Vacuum levels (kPa)	0, 18, 34
Vacuum time (ms)	0, 25, 62, 249
Pulse frequency (Hz)	75
Temperature (°C)	50
pH	>7
Target entrained air content (%)	0 and 0.5 to 1.0

*The corresponding production paper machine speed depends on the foil distances used in the wire section.

Table 3
Measurement methods used with the 60 g/m^2 MBDT laboratory sheets.

Measurement	Method
Solids content	SCAN-W6:71
Grammage	SCAN-P6:75
Ash	SCAN-P5:63
Density	SCAN-P7:75
Tensile strength	SCAN-P38:80
Wet tensile strength	Modified SCAN-P38:80*
Tear strength	SCAN-P11:73
Porosity, Bendtsen	SCAN-P60:87
Roughness, Bendtsen	SCAN-P21:67

* Paper strip samples were 50 mm in width, 23 mm in tension distance and dry solids was 20%.

with dissolved air. c) The aerated sample was led from the pressurised tank to the MBDT sample chamber for the trials. At atmospheric pressure, the dissolved air in the sample fibre suspension was precipitated into entrained air.

The gas content of the sample stock in the MBDT trials was measured before and after aeration with a gas meter working according to the compression method. The measurement is based on Boyle's ideal gas law, Equation 1.

$$p_0 \cdot V_0 = p_1 \cdot V_1 \qquad [1]$$

where V_0 is the initial volume, V_1 is the final volume, p_0 is the initial pressure and p_1 is the final pressure.

When the sample is subjected to increased pressure, the relative change in the volume is equal to the relative change in the amount of gas, because the volume of the liquid is almost independent of the pressure, Equation 2.

$$i = \frac{\Delta V}{V} \cdot 100\% \qquad [2]$$

where i is the percentage of air by volume, ΔV is the decrease in volume and V is the volume of the sample chamber. (*17*).

The following properties were measured from the MBDT trial sheets: solids content, tensile and tear strength, porosity, roughness, wet tensile strength, density, grammage and ash content, Table 3. From each trial point over ten sheets were made.

RESULTS AND DISCUSSION

In some cases it is difficult to get enough entrained air into the fibre suspension, but in this case it was easier, since the stock contained mechanical pulp. Surface active dissolved and colloidal substances in the mechanical pulp stabilise the air bubbles and thus retard the removal of entrained air from the stock (*18*). For practical reasons, complete deaeration was not done for the reference point without entrained air. The reference point contained a small amount of entrained air, below 0.1%, in the fibre suspension. The upper entrained air content reached in the MBDT trials was 0.8%.

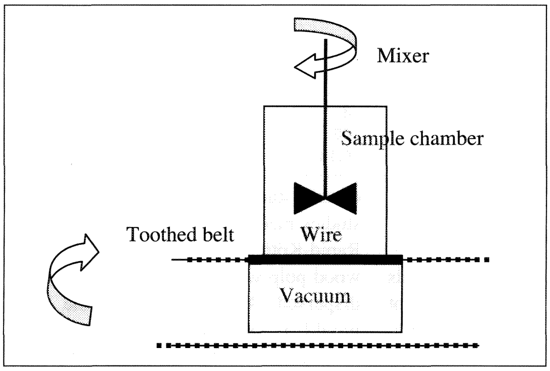
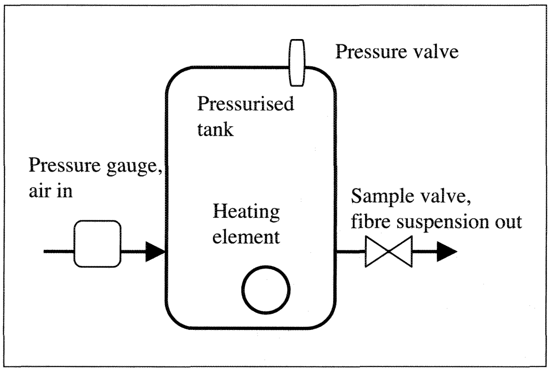


Fig. 1 Moving Belt Drainage Tester. The sheet is formed



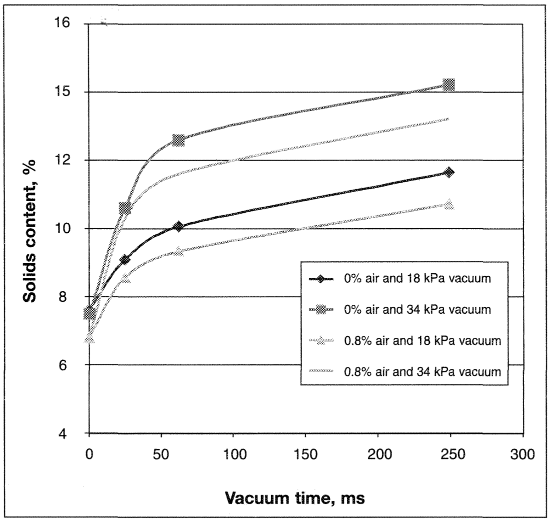


Fig. 3 Solids content (%) achieved in the Moving Belt Drainage Tester air trials.

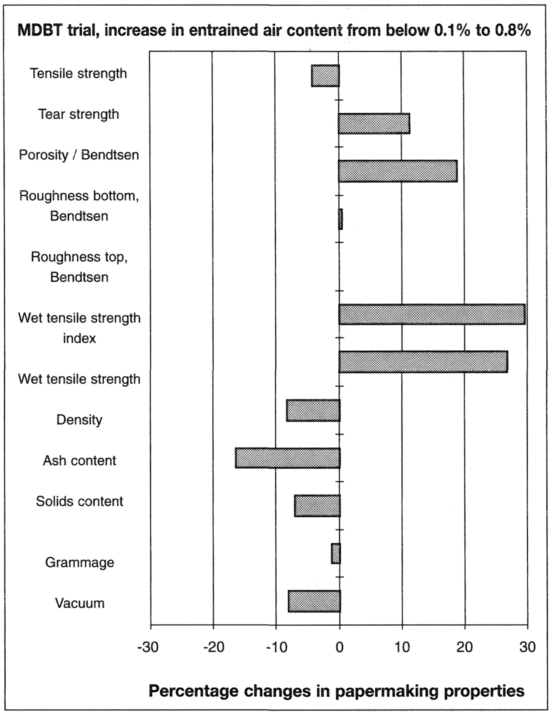


Fig. 4 Effect of raising entrained air content from below 0.1% to 0.8% on different properties in a Moving Belt Drainage Tester trial. (Percentage changes from average values of papermaking properties measured from paper sheet samples.)

Table 4
Properties of the Moving Belt Drainage Tester trial paper sheets (60 g/m^2).

Property	0% entrained air, Average value	95% conf. limits	0.8% entrained air, Average value	95% conf. limits
Grammage (g/m^2)	61.3	0.4	60.5	0.4
Wet tensile strength (N/mm)	0.056	0.004	0.071	0.008
Wet tensile strength index (N/g)	0.91	0.06	1.18	0.14
Density (kg/m^3)	325	8	295	7
Ash content (%)	4.5	-	3.7	-
Roughness top, Bendtsen (ml/min)	2020	122	2020	140
Roughness bottom, Bendtsen (ml/min)	2060	120	2070	161
Porosity, Bendtsen (ml/min)	196	8	233	12
Tear strength (mN)	568	33	632	37
Tensile strength (kN/m)	2.58	0.14	2.47	0.14

The maximum vacuum in the MBDT device decreased from 37 kPa to 34 kPa, i.e. by 8%, as the entrained air content increased from 0% to 0.8%. Therefore, the comparison of dry solids values at higher vacuum was made at 34 kPa vacuum (Table 2). The maximum dry solids content achieved in the MBDT trial sheets decreased from 14.2% to 13.2%, i.e. by 7%, as the air content increased (Fig. 3). This indicates that the entrained air content has a strong effect on drainage on the paper machine.

The measurements made from the dried MBDT trial sheets are summarised in Table 4. The ash content fell, and also density, as the entrained air content increased. Presumably, the large surface area of the air bubbles adsorbed some of the retention aid polymer and thus reduced its effectiveness. Porosity increased with an increase in the air content. It can be assumed that the bound air bubbles left a porous structure on the surface of the fibre network. The reduction in density could be explained by the decreased ash content and enhanced porosity.

The wet tensile strength and tear strength increased unexpectedly. The increase in wet tensile strength could be explained by the surface tension of the air bubbles in the wet fibre network (19.8% solids content). The tear strength could have been enhanced by the increase in the amount of fines and number of bonds (*19,20*). There is an optimum amount of fines for tear strength when using mechanical pulps. Flotation caused by precipitated air may have increased the amount of fines and the number of bonds in the paper sheet. The air content did not significantly affect tensile strength, roughness or grammage.

Percentage changes in different properties are shown in Figure 4. The results of this study agree quite well with the studies made by Kirchner (*2*). He used a Rapid-Köthen sheet mould with groundwood pulp without filler, and the air was dispersed. The drainage in the sheet mould is not pulsed as on a paper machine. The effect of entrained gas on sheet porosity and drainage in MBDT trials was similar to that found in the trials by Kirchner, but not so strong. According to Kirchner's studies, the porosity should have increased by 50% and drainage time by 100% with the 0.8% air content. In the MBDT trials, the porosity was enhanced by 19% and the vacuum, which indicates drainage, by 8%. It is possible that the pulses removed some of the entrained air from the fibre suspension. The wet strength decreased in Kirchner's studies, in the MBDT trials it increased.

When the MBDT results are compared to the findings of the pilot plant trial made by Helle at KCL with the same furnish as in the MBDT trials, the results are also quite similar (*3*). The main target of this MBDT trial was to find out if the aeration method makes a difference to the effect of gas in papermaking. In the MBDT trial, the aeration was made with precipitation, and with dispersed air in the pilot paper machine trial. Another target of the MBDT trial was to determine the effect of the faster drainage compared with the slower drainage on the pilot paper machine. In the MBDT trial, the drainage was similar to that on a Fourdriner production machine running at a speed of about 1000 m/min. (*3*)

The pilot machine trial produced similar results for tensile strength and drainage. On the pilot paper machine, the effect of entrained air on porosity was stronger. The faster pulsed drainage of the MBDT may have reduced the amount of entrained gas. Ash retention was also reduced to some extent on the pilot paper machine. Tear strength and wet tensile strength decreased in the pilot plant trial, in contrast to the MBDT trial. The surface tension of the bound air bubbles may have increased the wet tensile strength, thus the ash content was reduced in both the pilot plant and the MBDT trials, and therefore it could not have explained the difference in tear and wet tensile strength. Furthermore, the dry tensile strength did not increase in the MBDT trials, which would be expected if the wet tensile strength had increased due to lower ash content.

CONCLUSIONS

The following conclusions can be drawn from the results obtained in the Moving Belt Drainage Tester (MBDT) trials in which the entrained air content was increased with the aid of precipitated air.

The drainage was significantly reduced by entrained air, so the vacuum decreased in the MBDT.

Porosity, tear strength and wet tensile strength increased in these trials. The bound air bubbles in the fibre network probably enhanced porosity and wet tensile strength. The wet tensile strength could have been somewhat increased by the surface tension of the bound gas bubbles. The increase in tear strength could be explained by the increase in the amount of fines and the number of bonds caused by flotation. There is an optimum amount of fines for tear strength, so the flotation could in some cases also reduce the tear strength.

Ash, total retention and density all decreased. The large surface area of the air bubbles presumably adsorbed some of the retention aid, reducing the retention values. The density was reduced by the lower ash content and increased porosity.

No definite conclusions regarding the effect of entrained air on roughness and tensile strength can be drawn based on the MBDT trial.

Precipitated gas bubbles appeared to have largely the same effect on papermaking as dispersed gas bubbles. However, some differences were found compared to the findings of previous studies made with dispersed gas. Tear strength and wet tensile strength have not been found to increase in the presence of dispersed gas bubbles, but they were improved by precipitated gas in these MBDT trials. This could be caused by the large amount of bound gas bubbles in precipitated gas.

According to these results, both dispersed and precipitated gas bubbles have mostly negative effects on papermaking. Only a few positive effects were found, so in general, the gas content in the fibre suspension should be minimised.

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