EFFECT OF ENTRAINED AIR ON THE PERFORMANCE OF A PRESSURE SCREEN

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ABSTRACT

The aim of this work was to study the effect of entrained air on the screening efficiency of a pressure screen. The experiments were performed with groundwood, using a pilot-scale screening system with pressure and flow measurements together with sampling facilities in the feed, accept and reject lines. The effects of operating parameters such as rotor frequency, volumetric reject rate, accept flow and feed pressure on the performance of the screen were tested with three amounts of air in the feed pulp. These effects were examined by means of freeness and consistency measurements performed on the feed, accept and reject samples. The results showed that increases in rotor frequency, volumetric reject rate and especially accept flow cause a decline in screening efficiency, but that this decline is independent of the volume of air in the feed pulp under typical screening conditions. However, if the feed pressure or accept flow is low, air can cause a considerable decline in screening efficiency.

INTRODUCTION

Pressure screens are in widespread use in the pulp and paper industry, as a last guard in paper machines, for debris removal in both chemical and mechanical pulping, for the cleaning of secondary fibers and more commonly for the separation of short fibers from the long fibers to be used in the different layers of composite board. Pressure screening is nowadays the major method for fractionating pulp and removing debris from the flow in pulp mills and paper machines, and centrifugal cleaners are often required only for sand removal as a pre-treatment to pressure screening [1]. Fibers are generally screened at least two to four times by this method between pulping and the paper machine headbox.

The effect of most stock parameters, such as pH [2], temperature [2,3], consistency [4,5] or fiber type, on screening efficiency are qualitatively well known and also their effects on the quality of the accepted pulp. There is no published material, however, on the effect of air bubbles in feed pulp on screening efficiency or accept quality, even though the pulp to be screened often contains gaseous components. Gases pass into the process with the raw material, and also through many process units such as mixing tanks and pumps.

Some of the entrained air dissolves in the process liquid and the rest stays in gaseous form. Dissolved air in itself does not for the most part disturb mechanical processes such as pressure screening, but problems are encountered in chemical processes, where it can lead to increased agent consumption in dithionite bleaching of mechanical pulps [6], for instance. Dissolved air readily changes back to gaseous form, however, and may therefore disturb mechanical processes as well. This phase transition takes place particularly under shear forces, as the shear velocity produces locations where local pressure is markedly lower than the pressure of the process. As the precipitation of air is a faster phenomenon than dissolving, the precipitated bubbles tend to stay in gaseous form for a relatively long time even if the surrounding pressure would be capable of dissolving them.

Since the rotor of a pressure screen produces high shear forces in the screen cylinder, there is good reason to assume that screened pulp almost always contains air bubbles. Accordingly, we found it useful to study how these changes in the amount of entrained air affect screening efficiency, and correspondingly the quality of the accepted pulp. A practical stimulus for the initiation of this work was the number of inexplicable cases of blinding encountered in many industrial screen rooms.

We aimed to investigate the effect of entrained air on screening efficiency, and to ascertain whether it could, at least partially, explain the mysterious operation problems occurring in pressure screens. The experiments were performed in two parts, first preliminary experiments with a low feed pressure (140 kPa) and then primary experiments with higher feed pressures (150, 200 and 300 kPa). Air seemed not to affect screening efficiency under the screening conditions normally used in industry, but it decreased significantly when a low feed pressure or low accept flow was used.

MATERIALS AND METHODS

The pulp used in the preliminary and primary experiments was pre-screened Norway spruce (*Picea abies*) groundwood (GW) with an average length-weighted fiber length of 0.69 mm. The original mill pulp was tapped at a consistency of 10% and then diluted in a stock chest before the pilot screening to a consistency of 1.2% for the preliminary experiments and 1.3% for the primary experiments. The freeness of the diluted pulp was 50 mL in the preliminary experiments and 47 mL in the primary experiments. The stock temperature during the experiments was 30°C.

The experimental work was performed using an axially fed, foil-type pressure screen (Valmet TAP 25) equipped with a wedge wire screen basket having a slot width of 0.15 mm and a contour height of 0.82 mm. The pressure screen was connected to a pulp screening pilot system (**Fig. 1**) provided with the valves and instrumentation required for controlling pressure, flows, reject rate, rotor frequency and air feed rate. The pulp was stored in a stock chest (6 m^3) located approximately 6 m from the pressure screen and fed to the screen using a 110 mm pipeline. The diameter of the accept line was also 110 mm and that of the reject line 56 mm. Both the accepted and rejected pulps were circulated back into the mixed stock chest during screening, and the same pulp was used again as feed. The pulp was circulated in the pilot system about one hour prior to the screening experiments to avoid changes in its properties due to shear forces in the feed pump and screen. The change gradient at the end of this recirculation period was small and the pulp properties could be considered to be constant during the screening experiments. Samples were collected from the accept, reject and feed flows with pneumatic ball valves and analyzed for freeness and consistency in the laboratory according to TAPPI standards, T 227 om-94 and T 240 om-93.

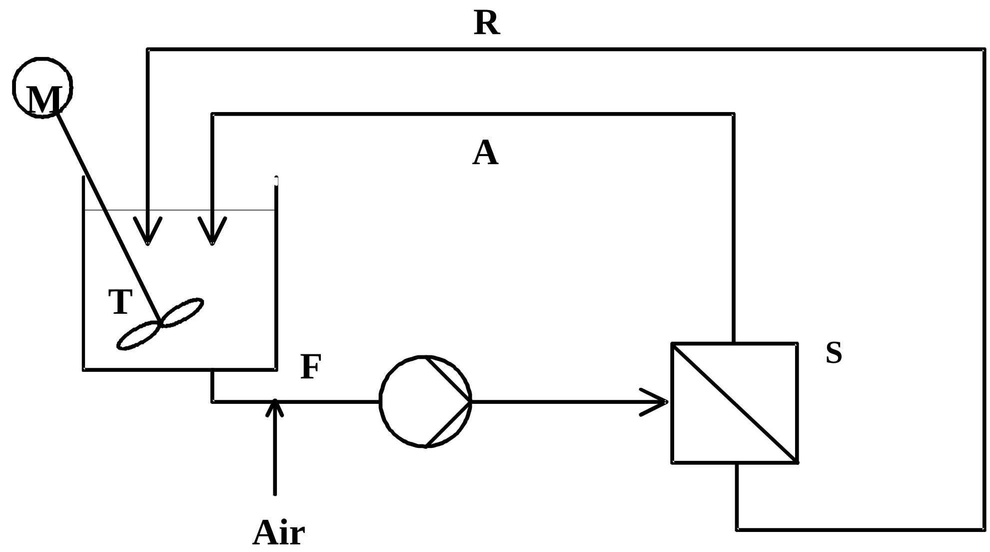

Figure 1. The pulp screening pilot system. F = Feed line, A = Accept line, R = Reject line, Air = Air feed, S = Screen, T = Mixing tank and M = Motor.

EXPERIMENTAL

The experiments were carried out to find out how different volumetric amounts of air in the feed pulp affect screening efficiency, which was examined in terms of consistency and freeness changes in the accepted and rejected pulp. All air volumes quoted here apply to conditions of normal atmospheric pressure (101 kPa) and room temperature (20 °C). Corresponding volumes at the process pressures and temperature (30 °C) can be calculated according to the combined gas law [7],

$$\frac{p_1\, V_1}{T_1} = \frac{p_2\, V_2}{T_2}\,, \qquad (1)$$

where V_1 is the volume of air at atmospheric pressure,
V_2 is the volume of air at the process pressure,
p_1 is atmospheric pressure,
p_2 is process pressure,
T_1 is room temperature and
T_2 is process temperature.

The preliminary experiments (series 0) were carried out with air amounts of 0, 1.5 and 3 vol-% at low feed volumetric flow rate and low feed pressure. The primary experiments (series A, B, C, D) were carried out with air amounts of 0, 1 and 2 vol-% under conditions that corresponded closely to those employed in industry. The screening system operating parameters examined were rotor frequency (f_r), volumetric reject rate (RR_V), accept flow (V_A) and feed pressure (p_F). Feed consistency (C_F) was not used as a variable in these experiments. Details of the test conditions are presented in **Table 1**.

Table 1. Screen operating parameters and air feed used in the preliminary and primary experiments.

Experiment	*Series*	C_F	f_r	v_{foil}	RR_V	V_A	v_{slot}	p_F	*Air*
		%	*1/min*	*m/s*	*%*	*L/s*	*m/s*	*kPa*	*vol-%*
Preliminary	0	1.2	600	9.0	40	9	0.6	140	0, 1.5 and 3
Primary	A	1.3	600	9.0	20	20	1.4	200	0, 1 and 2
		1.3	750	11.3	20	20	1.4	200	0, 1 and 2
		1.3	900	13.5	20	20	1.4	200	0, 1 and 2
		1.3	1050	15.8	20	20	1.4	200	0, 1 and 2
		1.3	1200	18.0	20	20	1.4	200	0, 1 and 2
	B	1.3	900	13.5	10	20	1.4	200	0, 1 and 2
		1.3	900	13.5	20	20	1.4	200	0, 1 and 2
		1.3	900	13.5	30	20	1.4	200	0, 1 and 2
	C	1.3	900	13.5	20	10	0.7	200	0, 1 and 2
		1.3	900	13.5	20	15	1.1	200	0, 1 and 2
		1.3	900	13.5	20	20	1.4	200	0, 1 and 2
		1.3	900	13.5	20	25	1.8	200	0, 1 and 2
		1.3	900	13.5	20	30	2.1	200	0, 1 and 2
	D	1.3	900	13.5	20	20	1.4	150	0, 1 and 2
		1.3	900	13.5	20	20	1.4	200	0, 1 and 2
		1.3	900	13.5	20	20	1.4	300	0, 1 and 2

Series A was carried out to clarify the effect of three amounts of air on screening while the rotor frequency was changed gradually from 600 to 1200 min^{-1}, corresponding to foil tip speeds from 9 to 18 m/s, respectively, and the other operating parameters were kept constant. The rotor frequency was first set to the desired value and then the air feed to the feed line was set at 0%. After the system had reached a steady state, samples from the feed, accept and reject lines were collected. The air feed was then raised to 1%, and after the system had again reached a steady state further sampling was carried out. Finally, the air feed was set at 2%, and after sampling the rotor frequency was changed to a new value and the air feed and sampling procedure started again.

In the experiments of series B the volumetric reject rate was changed gradually from 10 to 30% and the other operating parameters kept constant. The air feeds were again 0, 1 and 2%. The sampling procedure was the same as in series A. The experiments in series C and D were carried out in same way, the operating parameters that were changed being accept flow (10 to 30 L/s, corresponding to slot velocities from 0.7 to 2.1 m/s) and feed pressure (150 to 300 kPa), respectively.

RESULTS

Results of the preliminary experiments

The preliminary experiments were performed to see whether any further research was necessary. The screening conditions were chosen to be such that if entrained air had any effect, this would certainly occur, which meant using a low screening pressure and accept flow and inserting a substantial amount of air into the system. The results were surprisingly clear, as we can see in **Figures 2** and **3**, where the freeness and consistency of the feed, accept and reject pulps are presented as functions of the volume of air added (calculated at normal pressure and room temperature). The differences in freeness and consistency between the accepted and rejected pulps decreased as the amount of air increased. In other words, added air in the feed pulp causes a decline in screening efficiency. At an air content of 3% the screen practically ceased to fractionate the pulp. In order to describe the phenomena comprehensively, supplementary tests were carried out under conditions typical of industrial screens.

Results of the primary experiments

Estimation of error limits

As the feed properties are known explicitly, the standard deviations in feed freeness and consistency analyses indicate stochastic errors due to sampling and the laboratory analyses. Assuming that the standard deviations of the analyses of the accepted and rejected pulp samples were equal to those of the feed and that they were independent of each other, we can estimate the standard deviations of the freeness and consistency differences between the accepted and rejected pulps with the following equations [8]:

$$S_F = S_A = S_R , \qquad (2)$$

$$S_\Delta = \sqrt{S_A^2 + S_R^2} = \sqrt{2S_F^2} , \qquad (3)$$

where S_F is the standard deviation in feed pulp freeness (or consistency),
S_Δ is the standard deviation in accept pulp freeness (or consistency),
S_R is the standard deviation in reject pulp freeness (or consistency) and
S_Δ is the standard deviation in the difference in freeness (or consistency) between the accepted and rejected pulp samples.

If we assume that the errors are normally distributed, the confidence interval *a* at a confidence level of 95% can then be calculated as [8]:

$$a = \pm 1.96\, S_\Delta , \tag{4}$$

According to the calculations the confidence interval for the freeness difference was ±4 mL and that for the consistency difference ±0.02 %-points. Due to the relative narrow freeness and consistency ranges, the confidence interval can be considered constant in these experiments.

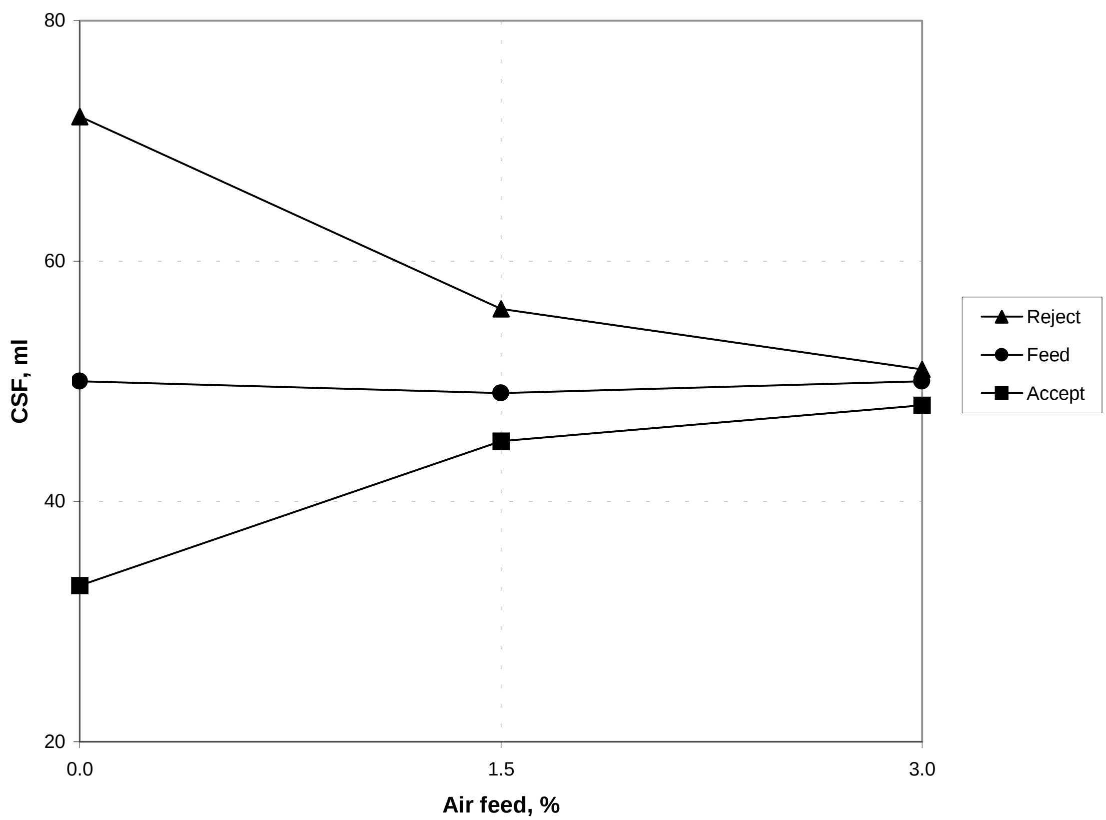

Figure 2. Freeness of feed, accept and reject pulp as a function of added air (vol-%).

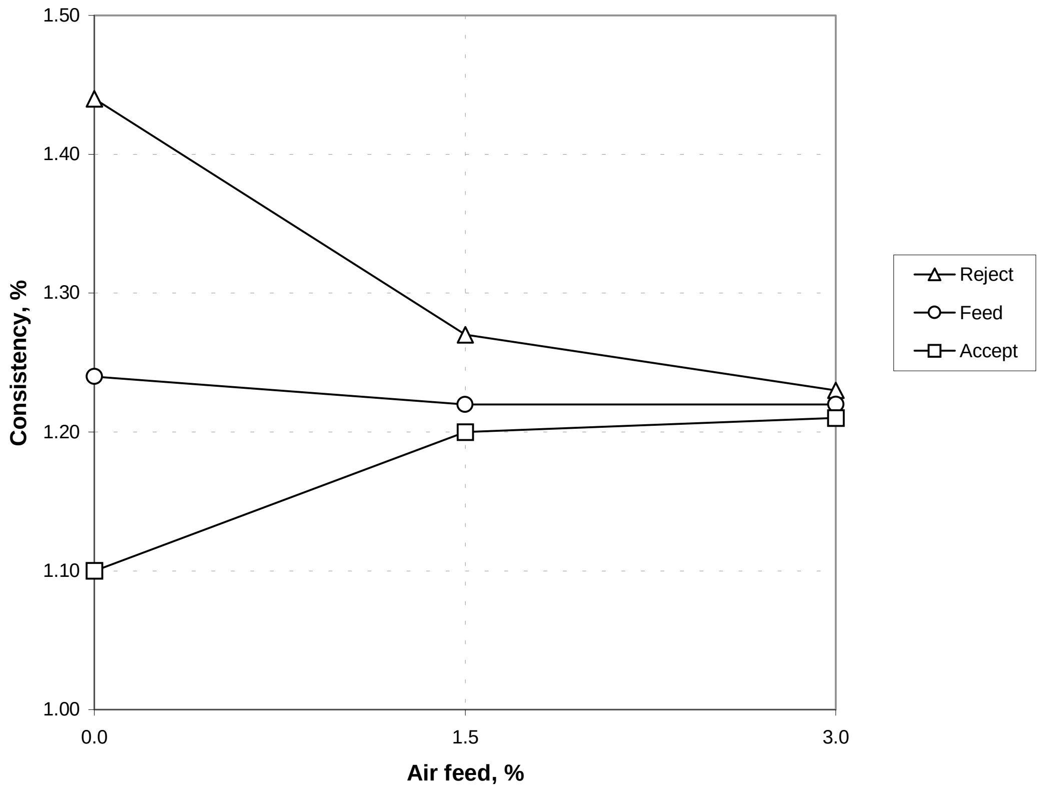

Figure 3. Consistency of feed, accept and reject pulp as a function of added air (vol-%).

General results

The results of the primary experiments are illustrated in **Figures 4 – 11**, where the freeness and consistency differences between the reject and accept pulp are presented as functions of the given operating parameters. The curves for the amounts of air are fitted to the same figures. The lower and upper confidence limits illustrated with dotted lines in Figures 4 – 11 were calculated using Equation 4 for smoothed and averaged lines of air 0%. The results show clear and predictable effects of the screening operating parameters on the performance of the screen. An increase in rotor frequency, in volumetric reject rate and in accept flow rate all reduced screening efficiency. The effect of the accept flow rate was clearly the highest, whereas the rotor frequency showed only a moderate effect and the reject rate a minimal one. Comparing the freeness and consistency figures, it can be seen that they were quite clearly correlated. Thus one confirms the conclusion obtained from the other.

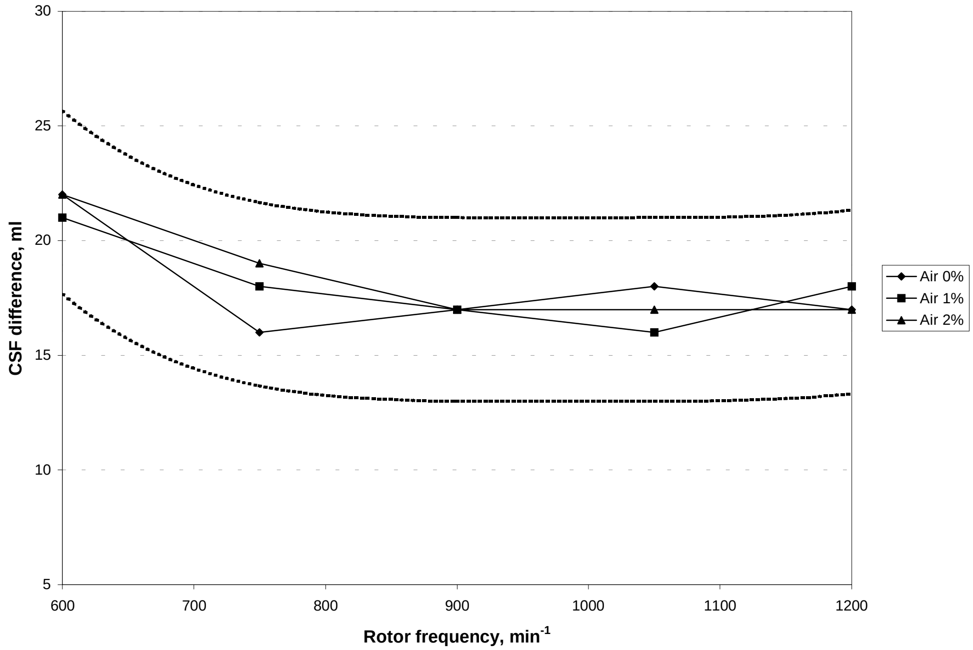

Figure 4. Freeness differential between reject and accept pulp as a function of rotor frequency with three amounts of air.

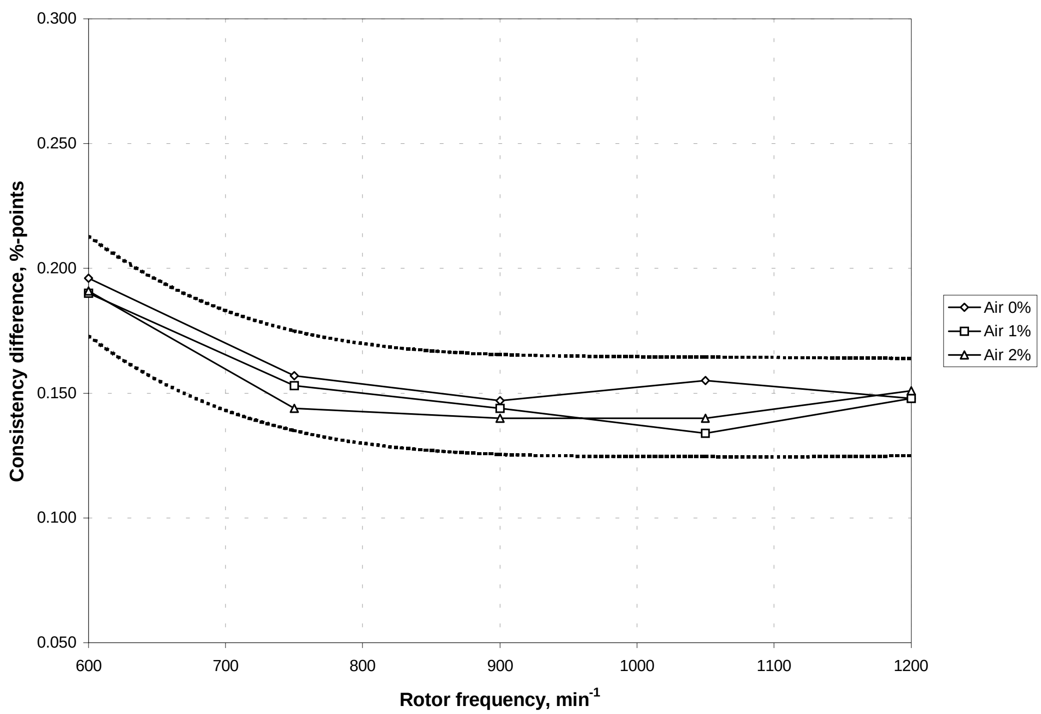

Figure 5. Consistency differential between the reject and accept pulp as a function of rotor frequency with three amounts of air.

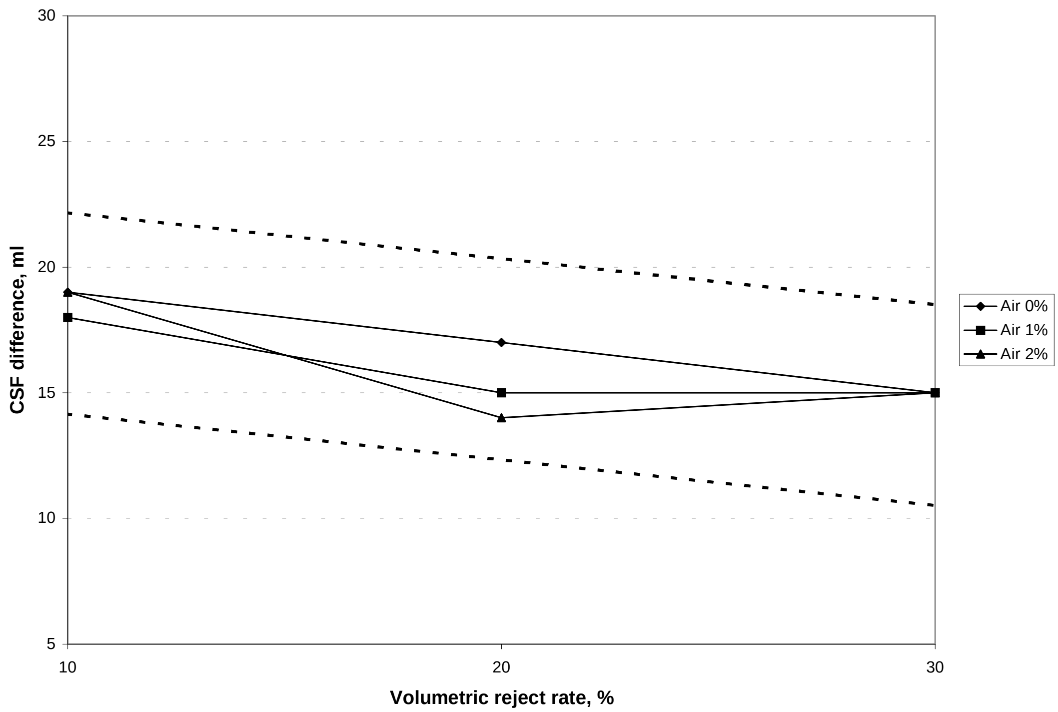

Figure 6. Freeness differential between reject and accept pulp as a function of volumetric reject rate with three amounts of air.

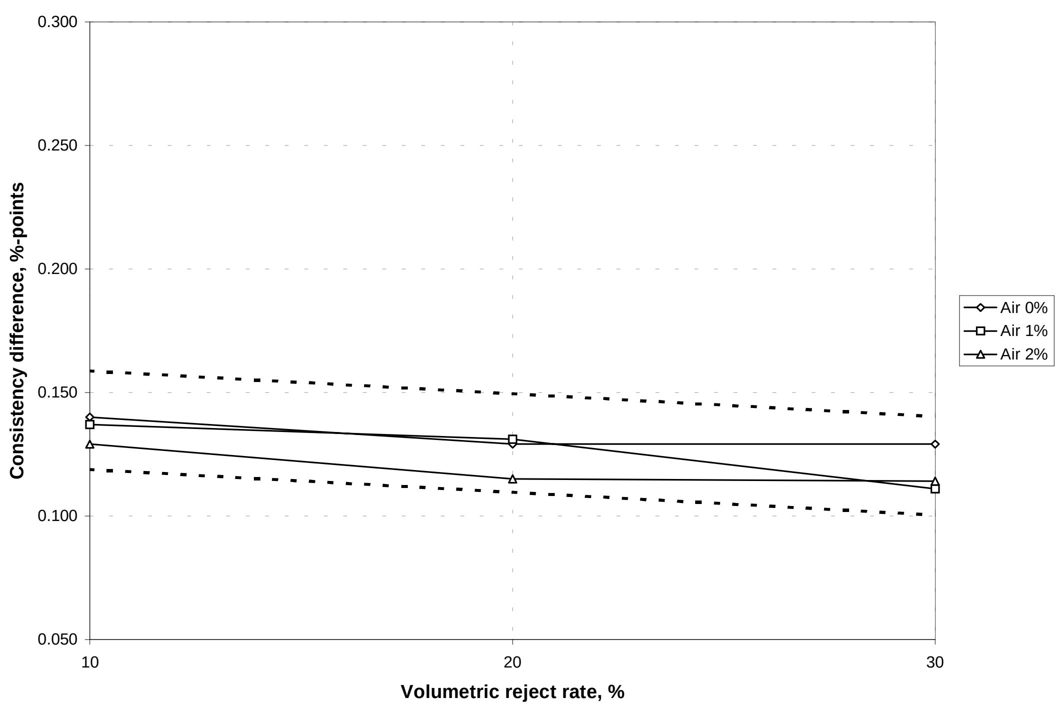

Figure 7. Consistency differential between reject and accept pulp as a function of volumetric reject rate with three amounts of air.

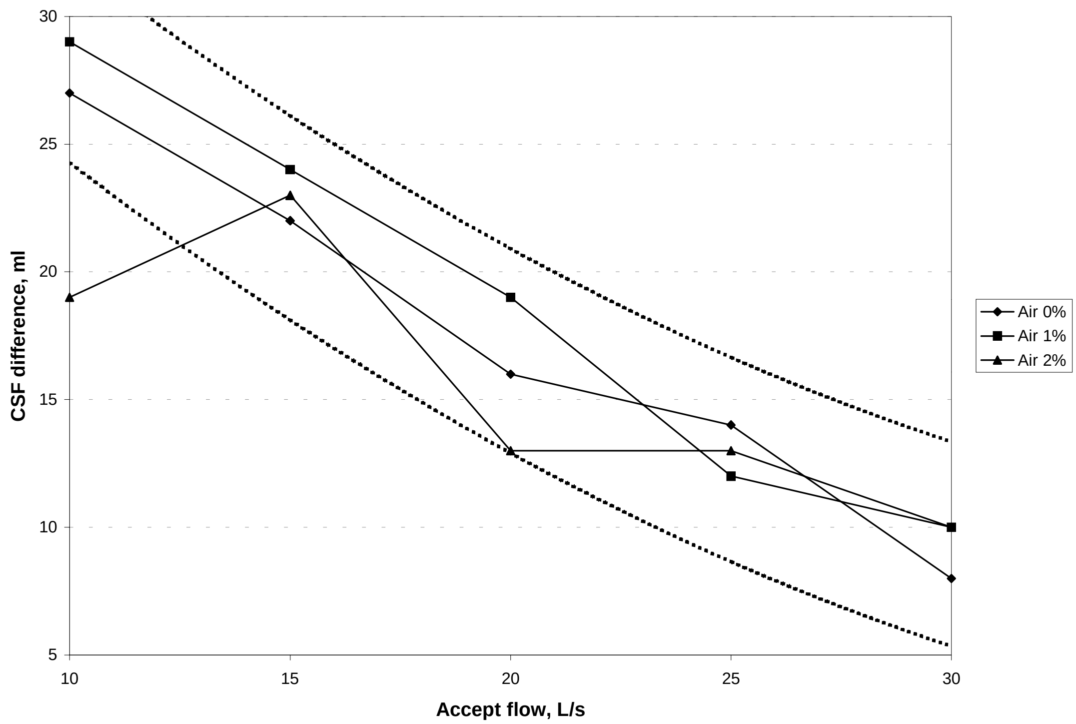

Figure 8. Freeness differential between reject and accept pulp as a function of accept flow with three amounts of air.

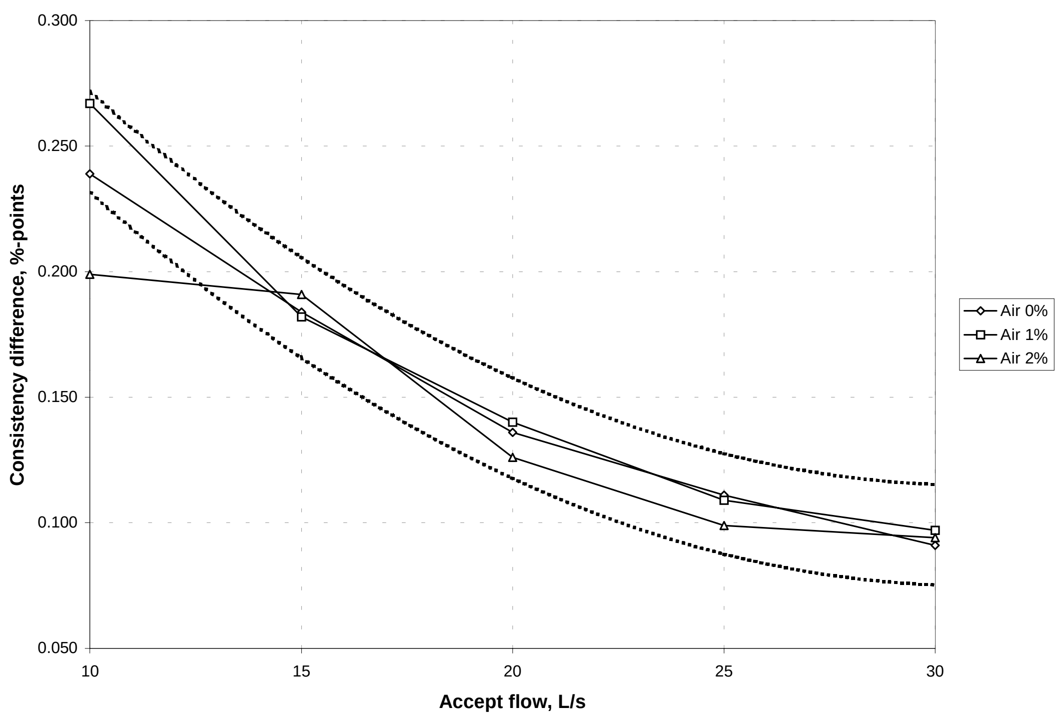

Figure 9. Consistency differential between reject and accept pulp as a function of accept flow with three amounts of air.

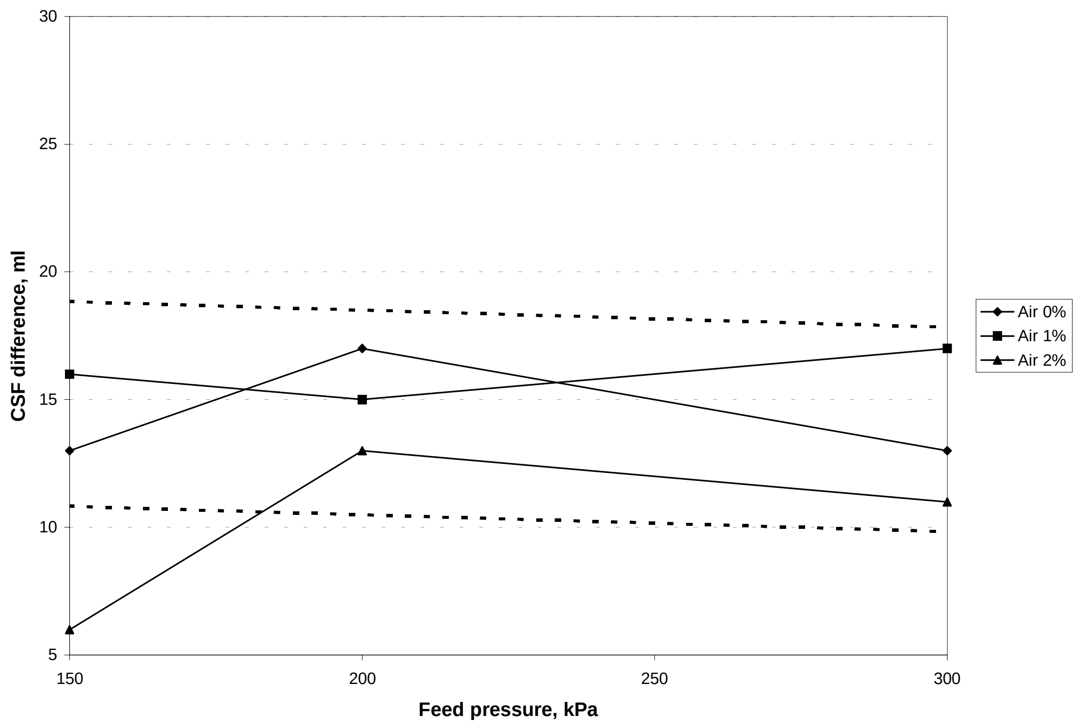

Figure 10. Freeness differential between reject and accept pulp as a function of feed pressure with three amounts of air.

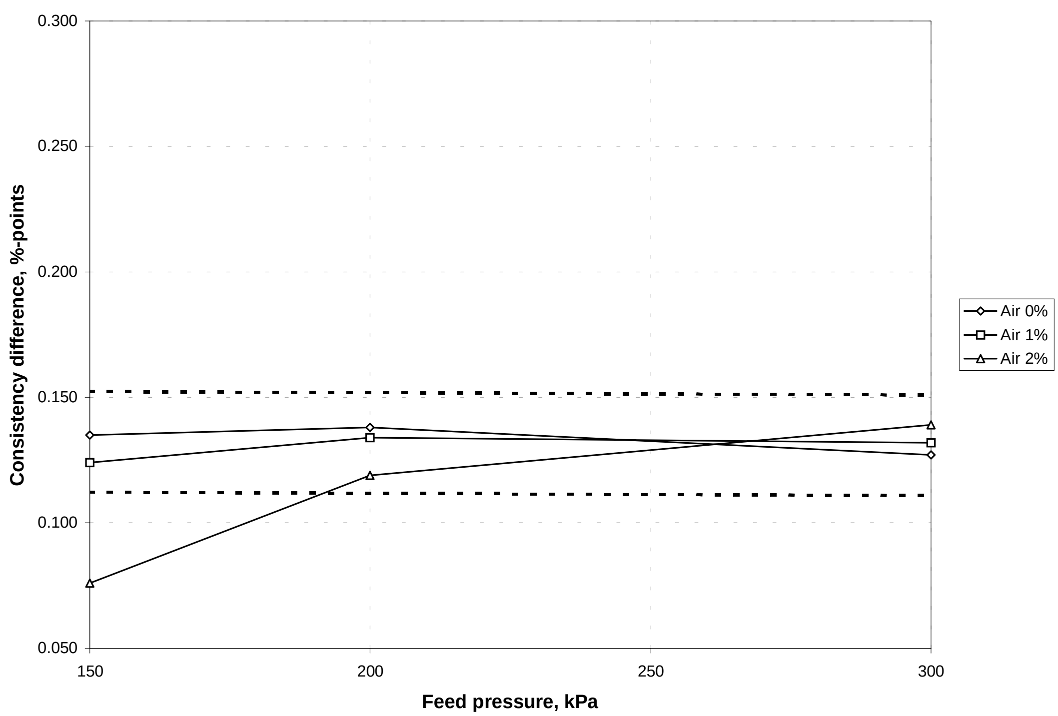

Figure 11. Consistency differential between reject and accept pulp as a function of feed pressure with three amounts of air.

Effects of entrained air

Up to 2% entrained air seemed not to affect screening performance under typical industrial conditions, but there were a few test points where the results differed significantly from the prevailing trends, i.e. they lay outside the confidence limits. At quite a low feed pressure, 150 kPa (see Figures 10 and 11), the fractionation tendency decreased considerably with increasing air content. In addition, a low volumetric flow in the accept line of 10 L/s seemed to reduce the consistency and freeness differences between the accept and reject lines if the air content was high (see Figures 8 and 9). These results were corroborated by the preliminary experiments.

DISCUSSION

Screening mechanisms

Pressure screening is based on two mechanisms of separation: probability and barrier screening. Probability screening [9] is based on the probability of particles having at least one dimension smaller than the screen aperture passing through the screen, while barrier screening separates out oversize particles. Pre-screened pulp was used here to eliminate the barrier effect of debris and thus to ensure that the screening was based on passing probability. In probability screening, the consistency and freeness in the accept and reject lines go in opposite directions as fractionation tendency, i.e. screening efficiency, increases. This together with the constant feed properties of the pulp makes it possible to examine the effects of air in terms of the fractionation tendency of the pulp in screening, which means monitoring the consistency and freeness differences between the accept and reject pulp lines.

Physical form of air in the pulp suspension

Air is always present in a pulp suspension in two physical forms, dissolved and gaseous, the equilibrium between these phases being dependent on the process conditions. Dissolved air as such does not induce disturbances, but it easily precipitates in gaseous form due to the shear forces and pressure drop in the agitating vane. The precipitated air bubbles are of small diameter, about 40 – 100 μm [10], but with time they tend to combine to larger bubbles. If bubbles have been formed due to mechanical dispersion, they are typically of the order of 1 mm in size [10,11]. Bubble diameter and its deviation is mainly a function of pressure, surface tension of the liquid and the dispersing shear forces [11].

Explanations for the effects of air

Pressure and drag force

Our findings in both the preliminary and primary experiments may be explained by the change in bubble diameter together with the drag force affecting the bubbles due to the accept flow. Equation 1 shows that the change in volume is proportional to the change in pressure. Thus doubling of the pressure halves the volume of gas. The change in diameter is not so large, however, because the volume of a sphere is proportional to the diameter to the power of three. Thus doubling of the pressure reduces the bubble diameter only by about 20%. With an air content of 2% at normal air pressure in the feed, the actual volumes of air in the screen at pressures of 150, 200, and 300 kPa were 1.4%, 1.0% and 0.7%, respectively, and the corresponding relative diameters of the bubbles, if one assumes the distribution of bubble size to be similar in each test, were 0.89, 0.81 and 0.70 (the relative diameter in the feed being 1.00).

Both mechanically dispersed larger bubbles and smaller precipitated bubbles were present in the screen in our experiments. Precipitated bubbles produced by the foil of the rotor can be considered to have only a minor effect on screening efficiency, as they are smaller in diameter than the slot width, and they readily pass through the apertures. By combining they could form larger bubbles, but the time in the screen basket was presumably too short for that. The bubbles dispersed mechanically by the feed pump were obviously larger than the slot width under all the conditions used in our experiments, but bubbles are so elastic that they can go through an aperture smaller than their diameter if the driving force, which in this case was the pressure difference over the screen plate, is great enough. Thus no effects on screening efficiency occur.

A decrease in feed pressure will nevertheless increase the diameter of the air bubbles. At a certain point, with a constant pressure difference, the driving force will be too low to impel the bubbles through the slots, and correspondingly, at constant feed pressure and with decreasing accept flow, there is a point where bubbles of a constant diameter cannot pass through the screen aperture. As a consequence, air bubbles accumulate on the screen surface, which reduces the effective open area of the screen plate. This introduces an increasing slot velocity and leads to lower fractionation of the pulp. These phenomena can be seen clearly in the results of the preliminary experiments (Figures 2 and 3) and those primary experiments in which the accept flow (Figures 8 and 9) and feed pressure (Figures 10 and 11) were varied, being marked by the test points that lie outside the confidence limits. The decrease in the effective open area of the screen plate due to entrained air may lead to a blinding of the screen plate, especially if the screen is working close to its maximum capacity.

Shear forces

The impeller of the feed pump and the rotor of the screen produce a great shear force, so that they may disperse air bubbles to smaller sizes. Changes in the frequency of the screen rotor (Figures 4 and 5) showed no effect on screening at air content values tested here, however, perhaps because the bubbles were already small enough after the feed pump. We have no clear evidence regarding the effect of the impeller of the feed pump on the size distribution of the bubbles, but changes in fractionation did occur at low feed pressure and at low volumetric accept flow capacity with high air content. This was probably mostly due to the effect of pressure on the air volume in the former case and to the small pressure difference over the screen surface in the latter. In both cases, however, the frequency of the feed pump was at a low level and the bubbles remained larger due to lesser shear force, which emphasized the effect of the air. The differences in relative bubble diameter between the air content values were probably more pronounced in these experiments.

CONCLUSIONS

Small or moderate air content usually has no effect on the fractionation of pulp in pressure screening under typical industrial conditions, i.e. at least relative high feed pressure and slot velocity. If the volumetric air content is high, however, and the feed pressure and slot velocity are low, fractionation of the pulp may decrease considerably. This may also lead to blinding of the screen plate, if a screen is working close to its maximum capacity.

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