NEW INSIGHTS INTO DISPERSED AIR EFFECTS IN BROWNSTOCK WASHING

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ABSTRACT

A laboratory washing cell was used to visualize pad formation on the surface of a simulated brownstock washer drum submerged in a washer vat. Large dispersed air bubbles (diameter > 10 mm), obtained in the presence of defoamer or the absence of black liquor, passed through the fiber pad having little influence on the water flux. By contrast, small bubbles (< 2 mm) were trapped in the pad lowering filtration fluxes by as much as a factor of 100. The detrimental effects of small bubbles on drainage were diminished by defoamer addition which caused the little bubbles to coalesce and to escape through the pad.

The passage of large bubbles through the growing pulp pad appeared to produce channels. It is possible that the channels may explain poor displacement washing efficiencies reported for some washers.

KEYWORDS: brownstock washing, dispersed air, defoamers, channeling, pad permeability, entrained air.

INTRODUCTION

Brownstock washing is a key unit operation in the production of kraft pulp, affecting the efficiencies of both bleaching and the recovery cycles. Our interest in washing is focused on the effects of dispersed air which is known to interfere with washing [1, 2]. Excessive air can influence washing efficiency in at least two ways. First, foam buildup in the drop leg decreases the drum vacuum which is the driving force for water flow through the pulp pad [3]. Second, air bubbles present in the vat lower water drainage rates through pulp pads [4]. The paper technology literature provides no information about the relative importance of these mechanisms. This work focuses on the effects of dispersed air in the washer vat on the formation and drainage properties of the pulp pad, which in turn influence washer productivity [5].

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Air bubbles thrive in wood pulp suspensions. The fibers play two important roles. First they isolate dispersed bubbles from each other giving a reduced opportunity for bubble-bubble collisions that can cause the bubbles to coalesce. The fibers also inhibit bubble rise and escape to the headspace. Piette and Pelton showed that in quiescent pulp suspensions, small bubbles could not break through the network of fiber flocs to reach the surface [6]. In flowing pulp, where fiber network structures are more transient, bubble rise is somewhat easier [7]. The overall effect is that it is relatively easy to sustain a dispersed air content of four volume percent in a 1% consistency pulp whereas in water this air would rise to the surface either to give foam or to dissipate into the headspace.

Brecht and Kirchner [8] reported in 1961 that drainage rates in a handsheet machine were significantly lower when dispersed air was present. This observation has been verified in more recent work [9], however, we still have no quantitative information about the effects of air bubble size or concentration on pad permeability. From a practical perspective, the solution to air-related problems is to use defoamers.

Brownstock defoamers are continuously added to alleviate the adverse effects of dispersed air. This is critical for most washer operations – without defoamer addition washer throughput is too low. The mechanisms by which defoamers improve pulp pad drainage are not that obvious. By contrast, the scientific literature contains many papers (see references in [10]) and a textbook [11]) describing how defoamers prevent foam formation. The details are beyond the present scope – the key conclusion is that defoamers accelerate the rate of coalescence of neighboring bubbles in foam. In a pulp this means that when two air bubbles collide in flow they have a much higher probability of coalescing to form a single, larger bubble in the presence of defoamer. Why should this give better washer operation? An obvious explanation is that if defoamer is added upstream, the dispersed air bubbles in the pulp will coalesce to give larger bubbles, within the forming pulp pad, that can more easily escape to the headspace. In support of this explanation Dougherty has shown that defoamer addition dramatically lowers the dispersed air content in the vat [1] and many mills now use dispersed air sensors to control defoamer addition rates. An interesting point however is that under normal operating conditions the amount of added defoamer is too low to remove all the dispersed air and yet washer throughput is high – could another mechanism be operative?

Herein we report the results of direct observations of the behavior of air during pulp fiber pad formation on the surface of a washer screen. We will show that air can influence both pulp pad structure and permeability. Furthermore, we will show that defoamers prevent small air bubbles from being trapped in the compacted pulp pad adjacent to the screen to interfere with drainage.

EXPERIMENTAL

Figure 1 shows a schematic diagram of the McMaster laboratory pulp washer which simulates pulp pad growth on a washer drum screen while submerged in a washer vat. The transparent, poly(methyl methacrylate), filtration cell 20 x 15.5 x 2 cm (H x W x T) is the heart of the apparatus. A washer screen forms the top of the cell. A vacuum is applied above the screen causing pulp to enter from below and form a pad by filtration on the underside of the screen. The thin cell is illuminated by transmitted light (Visual Plus, Model VP-4050v) and pad formation is recorded with a digital video camera (Canon ZR 30 frames per second and 720x480 pixels) located about 2 m from the cell. The range of bubble diameters were estimated from the video images taken at a higher magnification.

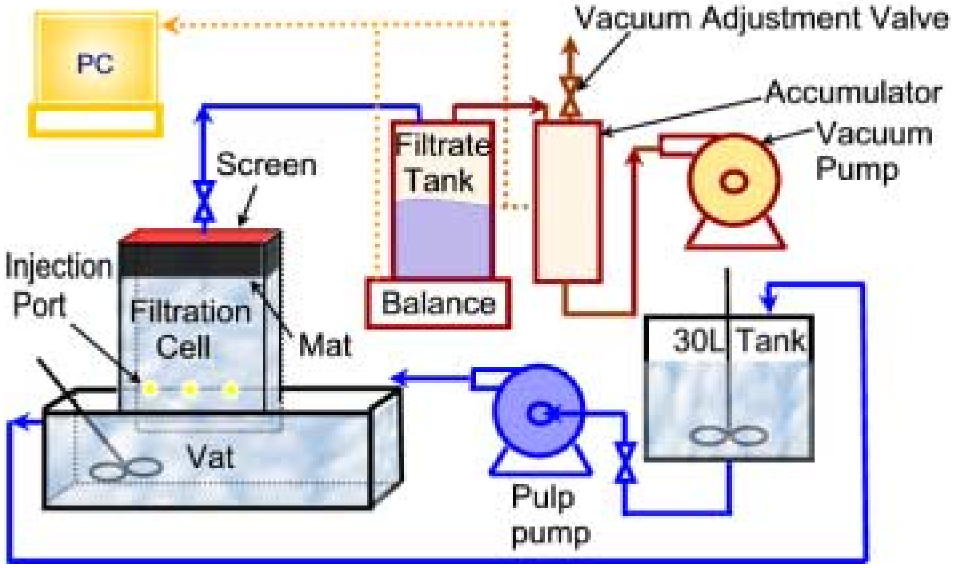

Figure 1. Schematic diagram of laboratory pulp filtration apparatus.

A Welch duo-seal vacuum pump (Sargent-Welch Scientific Co. model: 1400) coupled to a 9.6 L accumulator was used to generate the vacuum. The accumulator vacuum was measured with a Celesco DP30-0001-111 pressure transducer whose readings were logged on a PC using TESTPOINT™ (Capital Equipment Corporation, version 2.0a 1995) software coupled to a DAS-802 A/D board (Keithley Metrabyte Co.). The accumulator pressure was adjusted manually by an air-bleed valve. The filtrate mass was measured with a digital balance (Mettler PM16) and logged by the PC at a frequency of 1hz.

A Moyno Progressing Cavity Pump model A1B SS03 AAA was used to circulate pulp between a 30L tank and the 4 L vat. A weir was employed to maintain a constant vat level.

In a typical experiment the tank (see Figure 1) is filled with 30 liters of water and 300 gram of air-dry softwood bleached kraft pulp (Avenor, Thunderbay), to give a final consistency of 0.93%. After turning on the pulp slurry pump and the two mixers, the vacuum pump is turned on and the pressure adjusted manually to the desired value (usually 150 or 500 torr). The valve between the filtration cell and the filtrate tank is opened slowly to fill the filtration cell and then fully opened to commence flow through the screen.

In some cases air was injected at a controlled volumetric flow rate through ports on the side of the filtration cell. The flow rate was controlled with a Harvard Apparatus Model: 2400-004 syringe pump. The orifice was a plastic tubing with an inner diameter of about 1.5 mm. For other experiments Palmolive dishwashing liquid was employed to obtain small stable bubbles. For these experiments the pulp recirculation loop was not used because the weir entrained too much air. Instead, the vat was filled with 4L of pulp and up to 0.5 g of Palmolive dish washing detergent was added and the vat mixing propeller was used to entrain air.

RESULTS

A 1% consistency bleached kraft pulp suspension was used in the laboratory filtration apparatus (Figure 1) to visualize pad formation. Upon applying a vacuum, pulp suspension rises from the vat to fill the filtration cell. A pad accumulates below the screen as water passes up through it. Thus, the apparatus mimics pulp pad formation on the submerged sector of a pulp washer drum.

Four video frames showing the filtration cell (20 cm x 15 cm) during a typical experiment are shown in **Figure 2**. The dark regions correspond to high local fiber concentration whereas the white regions are pure water. At 10 s most of the cell contains flocculated pulp suspension which is characterized by a mixture of fiber rich and fiber lean (white) domains. Only the top two centimeters are uniformly dark – this is the fiber pad. At longer times the pad continues to grow down towards the vat. Note that in a real washer, fiber pad formation stops after approximately 5-10 seconds when the drum rotates out of the vat.

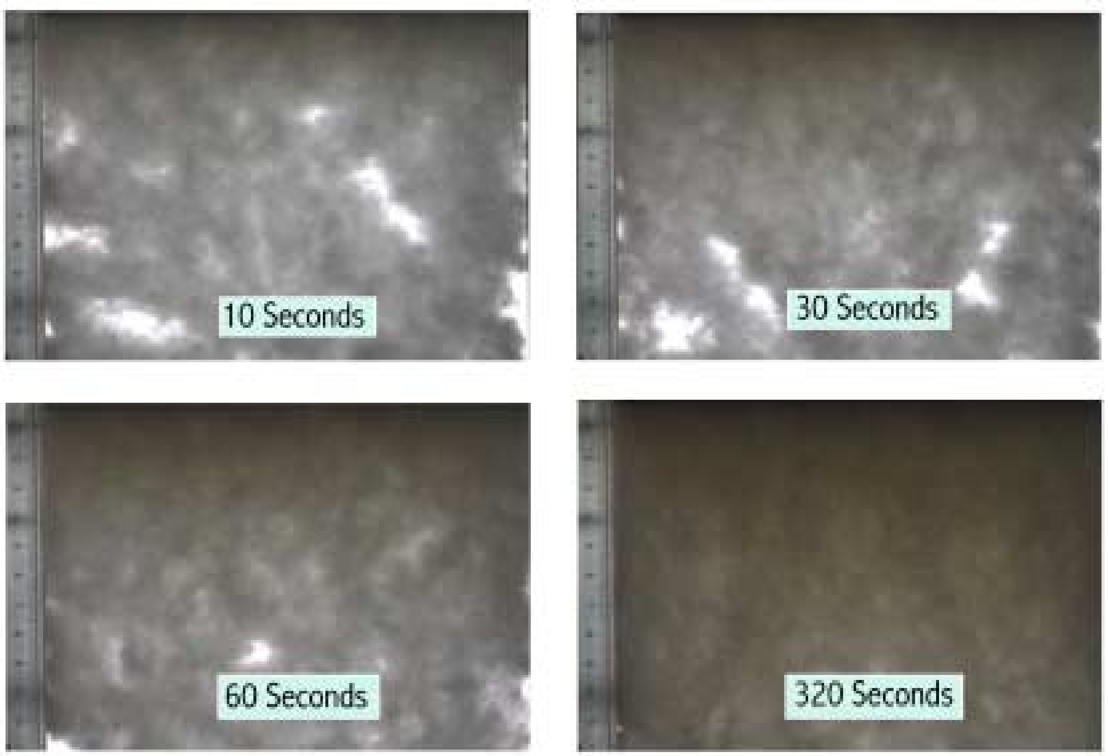

Figure 2.** **Four frames from a pad formation experiment in which the system vacuum was 150 torr and the suspension contained no added air or surfactant. The white areas are water and the fibers are gray. The scale at the left shows centimeters.

In an attempt to simulate air effects in washing, pad formation experiments were conducted with air injections into one or more ports at the bottom of the filtration cell (see Figure 1). **Figure 3** shows nine frames from a pad formation experiment with air. The paths of the air bubbles are clear when watching the video but are somewhat obscure in single frames. The white solid lines were hand-drawn to highlight the position of the bubble paths, and ellipses, also hand-drawn, indicate the location of trapped bubbles.

Air bubbles rise towards the screen much more rapidly than do the pulp flocs. An initial bubble, like an icebreaker, creates a channel by weaving between the flocs. Subsequent bubbles follow the same path. An example of channel formation is shown in the top center of the 8 and 10 sec frames in Figure 3. The tendency for rising bubbles in pulp columns to form channels has been reported by others [12, 13, 14].

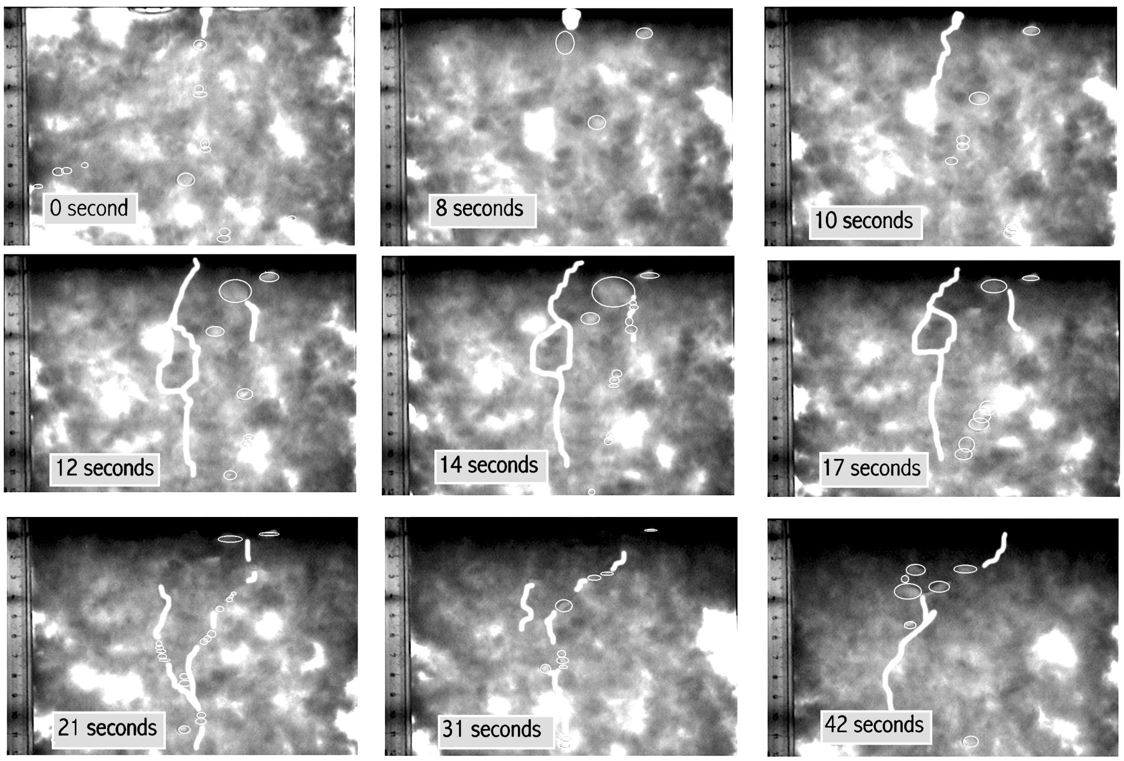

Figure 3. Pad formation with injected air. White solid lines were hand drawn and indicate the position of channels formed by rising bubbles.

The air that escapes through the pad and wire was visible (but not shown here) in the transparent section above the cell. The rising bubbles are very small as if the pad/screen were acting like a fine frit.

Air bubbles in defoamer-free water tended to coalesce upon contact. For example, at 12 seconds the largest ellipse shows the position of a cluster of large bubbles at the end of a channel. Two seconds later the large bubble cluster has grown, having been fed by the stream of small bubbles rising through the channel. However, by 17 seconds, part of the coarse bubble cluster has broken though the pad and screen.

A continuous source of air bubbles seems to be required to maintain a channel. Two channels are highlighted at 21 s, whereas by 42 s the left hand channel has disappeared. Apparently many of the rising bubbles followed the right hand branch after 21s allowing the left hand channel branch to be eroded by flowing pulp.

Finally, visible channels seemed to end in the concentrated region of the pad without reaching the screen. On the other hand, our qualitative impression is that many of the air bubbles introduced in this experiment do pass through the pad and the screen. Thus it is possible that a relatively high permeability path continues to the screen and we simply cannot see into the concentrated mat. Pad compression near the screen may remove channels.

Black liquor is very surface active, thus any air bubble present will not tend to coalesce upon contact. In an effort to make our experiments more representative of real washer operation, pad formation experiments were run with added dish washing detergent which is a mixture of surfactants with good bubble stabilizing properties. With detergent, small bubbles (approximately 2 mm diameter) can collide without coalescing into larger bubbles. By contrast, without detergent, the bubbles are much larger and they readily coalesce when pushed together.

In the pad formation experiments with detergent, many small bubbles were trapped in the pulp and they tended not to escape through the pad and the screen. No picture is shown because the bubbles were too small to be seen with our optics . The presence of small, trapped air bubbles had a dramatic effect on the pad permeability. **Figure 4** shows the mass of filtrate versus time for a number of experiments. Hundreds of data points were collected for each experiment and the scatter was small ($\pm$ 0.1%) so only lines are shown. The curves labeled *water* were for essentially air-free pulp suspension. The initial drainage rates (the slope of the curves) were high but decreased as the pulp pad grew. This was classical behavior and as expected the higher vacuum gave higher initial drainage rates. The curves labeled *detergent* were runs with air and added detergent. The drainage rates were about two orders of magnitude lower with detergent than without indicating that the accumulation of small air bubbles in the pad interfered with water flow.

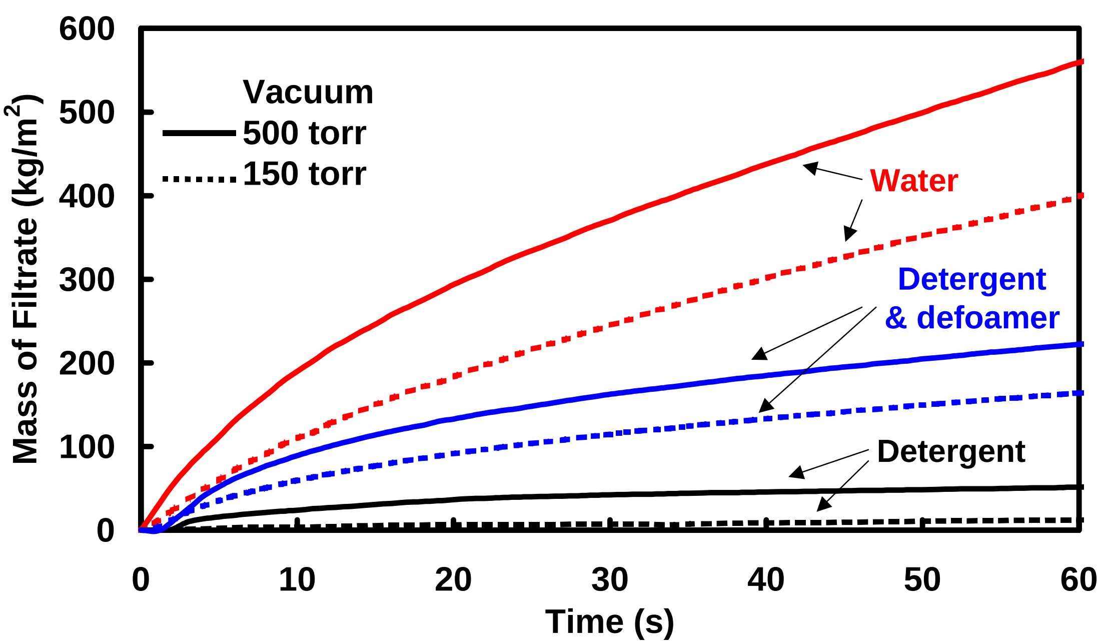

Figure 4. The total mass of water drained though the forming pad as a function of drainage time.

Experiments were also conducted with water, air, fibers and a commercial brownstock washer defoamer. The defoamer was added just before pad formation so that the entrained air could not escape. The resulting curves are labeled *detergent & defoamer* in Figure 4. The drainage behavior lay between the other two cases. In other words, air in the presence of defoamer has a reduced detrimental effect compared with the defoamer-free case.

DISCUSSION

Every conventional brownstock washer operator knows that defoamer addition is crucial – without it washer operation in highly surface-active brownstock is impossible. This work shows for the first time that small air bubbles trapped in the pad dramatically reduce flow whereas large bubbles are able to "leak" through the pad and screen and thus have a less serious influence on washing. Thus, the role of defoamers is not only to remove air from stock but more importantly to induce small bubbles to coalesce into large ones which are much more likely to pass through the pad.

In a fundamental study of displacement washing of pulp pads, Crotogino et al. [5] concluded that compared with pulp pads carefully formed in a laboratory, pads formed on commercial washers are not uniform. They speculated that pad non-uniformity is a consequence of forming pads with flocculated fiber suspensions. In this work we observed channel formation caused by streams of rising air bubbles – perhaps this is another mechanism for broadening the permeability distribution in pulp pads.

Most of the results described in this work are qualitative. We do not know the quantitative effect of air content in the vat or the minimum size required for an air bubble to be to pass through the pad. Ongoing work should clarify these issues.

The main conclusions from this work are:

1. Large bubbles (> 10 mm) pass through the forming pad and the washer screen whereas small bubbles (< 2 mm) remain trapped in the pad on the washer drum.
2. Rising air bubbles form channels through the pulp pad during pad formation in the washer vat.
3. Channels appear to end as they approach the high consistency region near the screen.
4. Channels formed at early stages disperse without a steady stream of air to keep them open.
5. Large bubbles near the screen "leak" through the pad and screen to give a stream of very small bubbles downstream of the screen.
6. Trapped air bubbles dramatically reduce mat permeability.
7. A role of defoamers is to aid the coalescence of small bubbles into larger bubbles, which can escape through the fiber pad, reducing the interference with washing.

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