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Visualization of the Flow of a Papermaking Suspension in an Axisymmetric Sudden Expansion Using Positron Emission Tomography

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ABSTRACT

Positron Emission Tomography (PET) was used to investigate the dynamics of a 0.4% (wt) fibre suspension flowing through an axisymmetric 1:5 sudden expansion. Six scans were conducted in which both the upstream velocity and the size of tracer particles labelled were varied. Images were taken upstream and downstream of the expansion plane with the upstream velocity being varied from 0.5 to 0.9 m/s. The expansion plane imparts shear that disrupt the fibre network causing measurable changes in the local fibre concentration. Both an asymmetry in the flow and a water annulus surrounding the core plug are clearly visible downstream of the expansion. We consider these to be the most significant findings in this work and are currently trying to develop a mechanistic understanding of these phenomena.

INTRODUCTION

It is widely known that pulp suspensions do not flow until a certain critical shear stress (or yield stress) is exceeded. With traditional papermaking, the papermaking suspension is initially fluidized by turbulence created locally from a sudden change in flow area in a device called a “headbox”. In this case, the fibre network is broken down into smaller flocs and single fibres with weakly correlated velocities. Suspension fluidization is attained by inducing turbulence and is aided by the addition of chemical deflocculants. Characterizing this event is difficult as these suspensions are opaque.

There are a number of experimental techniques currently available to visualize the opaque suspensions: light transmission, X- or γ-ray, acoustics, or nuclear magnetic resonance. For papermaking suspensions, it is important to measure the motion of the various fibre fractions within a suspension, from low to high concentrations, in order to gain insight into the macroscopic properties of the suspension. The experimental measurements mentioned above are “global” in nature in that the motion of individual particles cannot be detected. Salmela et al[1] have recently visualized the motion of marked glass fibres, in a suspension of unmarked fibres made optically transparent by matching the index of refraction. Although this technique worked well with glass fibres, where all particles have similar physical properties, this technique would be difficult to use with papermaking suspensions. As a result, one objective of this work is to further extend a method to visualize the motion of the fibres in papermaking suspensions. We do so using positron emission tomography (PET).

Positron emission tomography (PET) is an imaging technique widely developed for diagnostic medicine but has recently been applied to papermaking fibre suspensions[2,3]. Each emitted positron annihilates with a nearby electron producing two co-linear 511-keV γ-rays travelling in opposite directions. Simultaneous detection by γ-ray sensitive detectors located on either side of the system defines a line close to which the radioactive decay must have occurred. By detecting many of these decays, the distribution of activity can be determined. In this study, we measure the activity profile of a flowing fibre suspension after a sudden expansion in order to gain insight into the mechanism of floc rupture. Fully three-dimensional images will be acquired in both in the region near the expansion plane.

EXPERIMENTAL DETAILS

The visualization experiments were conducted by first radioactively labelling a selected Bauer-McNett fraction of fibres with ^{18}F. Three fractions were retained, namely the R14, R48, and R100. Briefly, these fractionated fibres were suspended in a solution of acetic acid while ^{18}F-F_2 was bubbled through the suspension at 10 ml/min with constant stirring. After the addition of the fluorine, the fibres were filtered and washed with distilled water. At this point the fibres were labelled with ^{18}F with a 10% yield based upon the total radioactivity introduced.

A 0.4% (wt) suspension of non-radioactive SBK pulp in water was then recirculated through a 1:5 sudden expansion in closed flow loop as shown in Figure 1. Prior to the commencement of imaging, the radioactive tracer fibres were introduced into

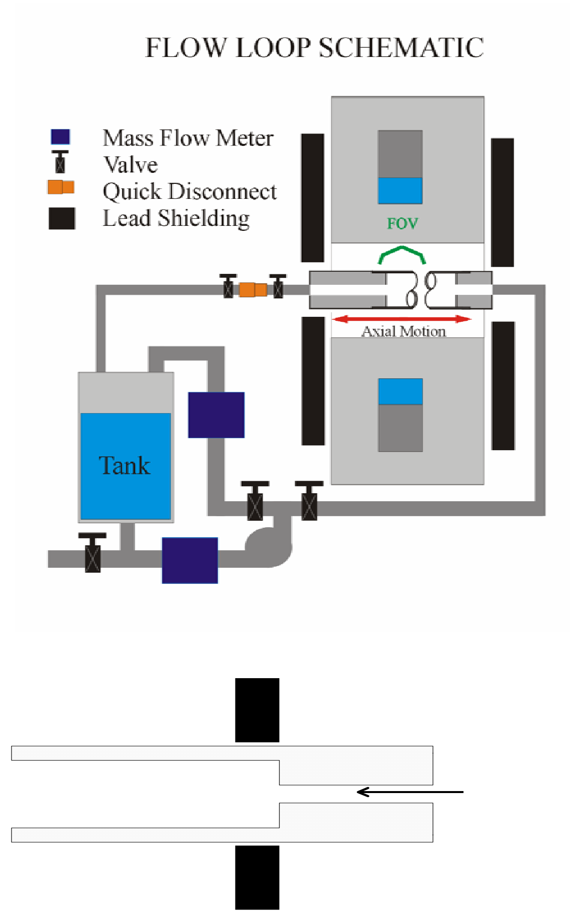

Figure 1. A schematic of the flow loop and the sudden expansion

the system by addition to the tank. Less than 1% of the total fibres in the system were radioactive. The radioactive fibres were then allowe to distribute through the system evenly for approximately 5 minutes. At this point imaging commenced. Six scans were conducted in which the upstream velocity and the selection of the tracer particles were varied. The details of each experiment are given in Table 1.

The following imaging protocol was employed for all tests. A maximum of three images were captured over approximately 2 hours of imaging. Typically the exposure time was approximately 45 minutes. Prior to each experiment a transmission scan was made in order to calculate the correction for photon attenuation from the non-radioactive materials in the suspension and the chamber walls.

Table 1. A summary of the scans conducted

Scan	Tracer (Fraction)	U (m/s)	Act. (Mbq)	Image Dur (s)
1	R14	0.5	1050	2573
2	R14	0.9	1300	1220
3	R48	0.5	635	3599
4	R48	0.7	500	2212
5	R48	0.8	1180	2708
6	R100	0.9	490	2772

RESULTS

We begin the presentation of the results by examining the effect of velocity on the suspensions behaviour. We do so by comparing scans 2 and 3 (Figure 2). As shown in the upper panel in this figure, at the higher velocity the suspension is “fluidized”, i.e. well-mixed, and the tracer fibres are dispersed throughout the entire area of this cross-sectional image. At the lower velocity, the stress imparted on the network is insufficient to cause rupture and the tracer fibres travel through as a plug through the device.

A comparison of the behaviours of different fractions at the same flowrate is given in Figure 3. Scans 2 and 4 are shown in this figure. As shown, in both cases the suspension was fluidized and no apparent difference could be observed between these two cases. We conclude from this that under fluidized conditions, the different fibre fractions are well mixed.

In what we consider the most significant finding of this work, we find that under

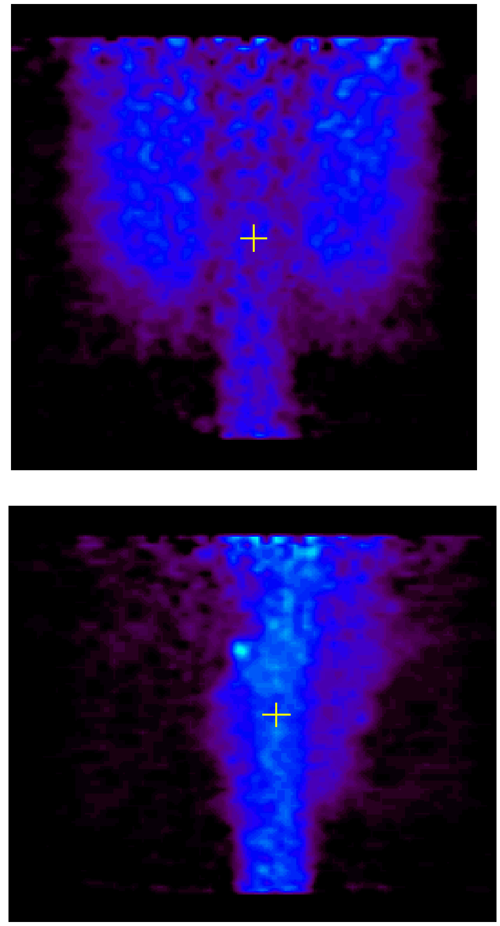

Figure 2. The effect of velocity on the activity profile. The upper image represents the case with an upstream velocity of 0.9 m/s. The lower image represents the case with an upstreamvelocity of 0.5 m/s. In this case the suspension is not fluidized and a central plug progressed through the device.

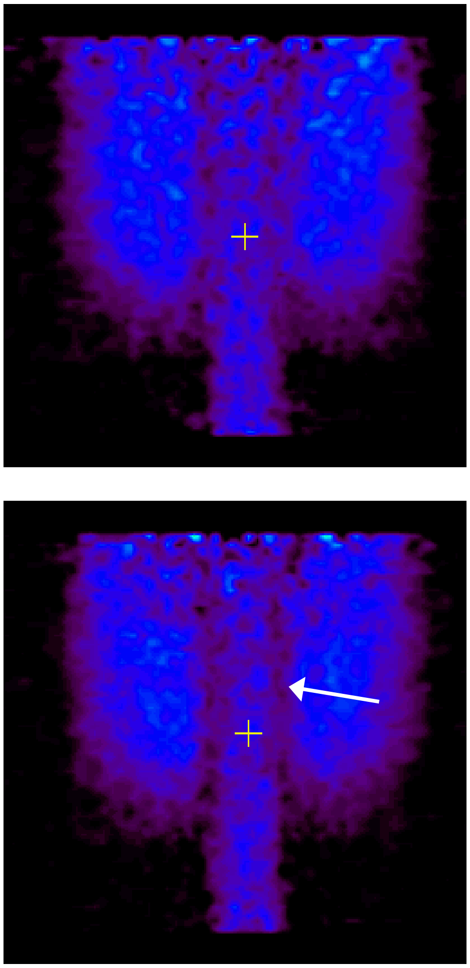

Figure 3. The effect of fraction size on the activity profile. Both images were captured with an upstream velocity of 0.9 m/s fibres acting as the tracers. The upper image represents the case with the R14 fraction as the tracer fibres. The lower image represents the case with the R100 fraction as the tracer fibres.

fluidized conditions a water annulus exists in the centre of the channel. This feature of the flow is highlighted in Figure 3 by the arrow. To our knowledge, this feature has not been reported previously in the literature. We are currently trying to develop a mechanistic explanation of this phenomenon.

SUMMARY

PET has been used to measure the activity profile after a sudden expansion. Images were acquired over a 45 minute period of ^{18}F labelled tracer fibres flowing with a 0.4% SBK pulp suspensions. Our results highlight cases in which fluidization was achieved and when the suspension behaved as a plug. No discernable difference was found on the behaviour of the different fraction under fluidized conditions. Finally, we report that under the fluidized conditions tested, a persistent water annulus was observed downstream of the expansion plane.

ACKNOWLEDGMENTS

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