Turbulence Measurements within Fibre Suspensions

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Abstract

Velocity measurements were performed within a 0.1 % fibre suspension and compared with a 0% fibre suspension. Measurements within a mixing jar are presented here demonstrating the ability to collect data within the fibre suspension. Initial results demonstrate the effect of the suspension on a number of turbulence quantities. For the conference, data will be presented from a flow channel to model the effect of the fibre suspension on a duct flow.

1 Introduction

Measurement of the velocity field within pulp slurries is difficult because the presence of wood fibres makes the slurries opaque to light transmission. Therefore, it is impossible for light to penetrate the slurry for LDV (Laser Doppler Velocimetry) or PIV measurements. Kerekes and Garner (1988) performed LDV measurements downstream of a grid in a narrow channel with a 0.5% suspension of softwood kraft pulp. They concluded that the presence of the fibres resulted in a decrease in the turbulence intensities compared with a zero fibre concentration water flow. The measurements were limited to the near wall of the channel (with respect to the laser position) because the data rates dropped significantly as the measurement point was moved into the fluid. Kerekes and Garner noted an additional difficulty in differentiating between the fibre and fluid velocity.

Steen (1989b, 1989a) used refractive index matching to perform LDV measurements within a pipe flow, thereby providing a method to measure a two phase fibre–fluid mixture. Steen matched the index of refraction of Pyrex fibres by mixing benzyl and ethyl alcohol. Because LDV only provides point measurements of the turbulent velocity he could not investigate spatial correlations within the flow. His results showed that there can be either an increase or decrease in the turbulence intensities depending on the mass concentration and fibre length. Li et al. (1995) performed NMRI measurements within a pulp suspension. The measurements were made through a pulp suspension, at extremely large scale resolution (0.2 mm) compared to other measurement methods. Substantial differences were found between Steen's work and the NMRI measurements.

This suggests that turbulence is probably a very important mechanism of floc destruction and creation. Lee and Brodkey (1987) suggested that the mechanism of floc dispersion was a combination of small scale motions and global disruptions. However, there should be a limited range of scales that actually played a role in floc destruction and creation via turbulence. Global motions act to transport the flocs, and small scale motions act to disrupt or create flocs. The limiting scales would be the floc scales and the individual fibre scales both of which act as spatial filters on the flow.

The focus of this work is to use PIV to investigate the effect of fibres on the turbulence within a duct flow. Instead of using a combination of ethyl and benzyl alcohol and Pyrex fibres as Steen did, the matching of the index of refraction of Sterling acrylic fibres (Engineered Fibers Technology, LLC, 3 mm lengths and 10 μm) used in the manufacture of transparent paper with Duoprime Oil (Lyondell oils)). The flow is seeded with a combination of $15-20\mu m$ diameter silver-coated hollow glass spheres and the acrylic fibres. The glass spheres are highly reflective and will follow the fluid flow enabling us to make accurate measurements of the fluid turbulent velocities using PIV.

2 Index Matching

Measurements were initially made to determine the sensitivity of the PIV system to differences in the index of refraction. Four mixtures (b=0;60;80;100 [%]) of Anisole and Benzyl Alcohol were prepared and 1.25% by mass S_2 fibres were added to each mixture. The Anisole - Benzyl Alcohol suspension were poured into cubical beakers (a=4cm) and stirred. A laser sheet was pulsed parallel to the wall of the beaker and 150 image pairs were obtained. A comparison of the index of refraction for various mass percentages of Benzyl Alcohol and Anisole is shown in figure 1(a).

The refractive index changes from 1.536 at 100% Benzyl Alcohol to 1.513 at 100% Anisole. The mean gray level was found to vary little for the various mass percentages of Anisole (figure 1(b)).

The minimum gray level ($\approx$ 43.25), and consequently the optimum for the experimental conditions at 589 nm and 20^oC, occurred at a mass percentage of 70% Anisole - 30% Benzyl Alcohol. It must be noted that a perfect match, an averaged gray value of 0, is impossible. Various sources of error include: (a) Micro-particles in the liquid; (b) nonhomogeneous structure at the fibre surface layer; (c) the interface between the liquid and fibres; (d) camera noise; and (e) hardware offset. The mixture that best matched the S_2 glass fibres had a refractive index of 1.52. However, the gray level variation was very small over the entire range shown in figure 1(b).

3 Effect of Anisole on the PIV measurements

To investigate the effect of the various mixtures on the recognition algorithm, image pairs were computed at the different concentrations for mixtures without any seeding particles. For a flow with seeding particles, it is expected that the algorithms compute 1000–1200 vectors per field with Particle Tracking Velocimetry (see Marxen et al. (1999)), Figure 1(c). shows a graph of the number of found particle pairs (vectors) versus anisole's concentration. From these results, it is expected that up to 3% of the computed vectors will be spurious. Thus, it is justifiable to use Anisole instead of the Anisole - Benzyl Alcohol in index matching. There are two main consequences from this experiment: (a) a change of temperature of a few degrees will not effect the results, (b) there is no need to use Benzyl Alcohol. Anisole matches the refractive index of the glass fibres well enough to allow accurate measurements.

A constant thickness of the laser sheet is important for the precision of the algorithm and the velocity output. In poorly matched mixtures, the thickness of the laser sheet grows rapidly (for example water - glass fibre mixtures). Pictures were taken in the same conditions as described above but with the camera parallel to the plane of the light sheet. As the four mixtures are all relatively close optically, the change in the laser sheet increase over the beaker cross section was negligible. An interesting conclusion is that PIV/PTV measurements are much less sensitive to refractive index changes than LDV measurements. In his experiments, Steen (1989b) had to ensure the temperature remained in a 1^oC range.

Due to chemical handling difficulties, measurements in the large scale flow cells are performed with Tufflo 6016 and Duoprime 90 oil. Both fluids has an index of refraction of 1.48 while the acrylic fibres have an index of refraction of 1.48-1.5. This is within the range of index of refraction differences found to be acceptable. The viscosity of the fluids (Duoprime 90 $(15.6 \times 10^{-6} \frac{m^2}{sec})$, Tufflo 6016 $(15.6 \times 10^{-6} \frac{m^2}{sec})$).

4 PIV measurements

Results of measurements within a mixing jar are presented one position, at 0% and 0.1% fibre consistency. A comparison of the influence of the fibres on the mean vorticity and dissipation rate are presented. The dimensions of the jar was $5cm \times 5cm \times 7cm$. A magnetic stirrer was used to do the mixing (set at maximum). Due to the high viscosity of the Tufflo 6016, it is not expected that there would be significant differences in rotational speed of the rotor for the two consistencies investigated. The rotor remained in the centre of the mixing jar. All measurements are presented at a location located 3 cm above the bottom of the jar and 1 cm for the vertical centreline of the jar, data are collected over a $0.8 \times 1cm$ area. All statistics are based on 500 samples.

4.1 Mean vorticity

Figure 2(a) and 2(b) shows the comparison of the mean vorticity levels in the mixing jar for 0% and 0.1% fibre suspension. The vorticity was calculated as (Cheng et al., 1997),

$$\begin{aligned}\omega_z(i,j) = \frac{\Delta r}{4\Delta r^2}(u_{i,j-1} + \frac{1}{2}(u_{i+1,j-1} + v_{i+1,j-1}) \\ + v_{i+1,j} - \frac{1}{2}(u_{i+1,j+1} - v_{i+1,j+1}) \\ -u_{i,j+1} - \frac{1}{2}(u_{i-1,j+1} + v_{i-1,j+1}) - v_{i-1,j} + \\ \frac{1}{2}(u_{i-1,j-1} + v_{i-1,j-1})) \quad (1)\end{aligned}$$

where Δr is the distance between points, $u_{i,j}$ and $v_{i,j}$ are the velocity components in the x and y directions.

The vorticity is found to be significantly effected by the addition of fibre. For the position shown, it is found to have an average value of $101 \frac{1}{sec}$ for 0% concentration and $254 \frac{1}{sec}$ for 0.1% fibre concentration. At another measurement position, similar behavior is found ($41 \frac{1}{sec}$ for 0% concentration and $184 \frac{1}{sec}$ for 0.1% fibre concentration).

4.2 Dissipation rate

The dissipation rate was calculated following Cheng et al. (1997). The results again show a significant influence of the fibres. The dissipation rate at this position increased by nearly a factor of 2 (3.6 $\frac{m^2}{s^3}$ for 0% fibre and 7.2 $\frac{m^2}{s^3}$).

5 Conclusions

Results have shown that there is a significant effect from the addition of fibres to a flow. The current measurements have shown that it is not appropriate to model a fibre suspension as a fluid with the addition of a neutral particle. For the conference, measurements will be performed in a duct flow at high Reynolds number using Duoprime oil.

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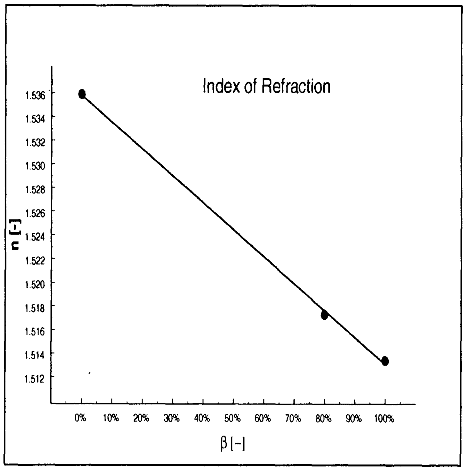
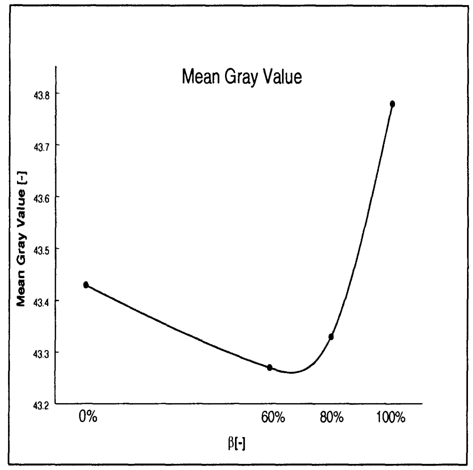
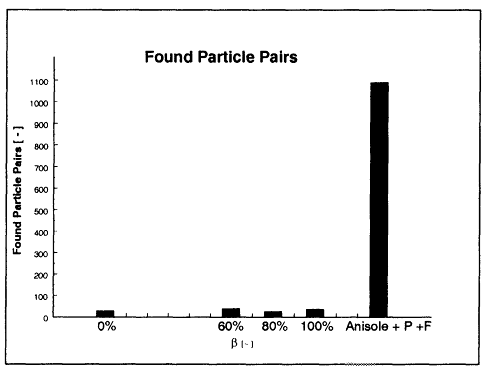


(a) Index of refraction

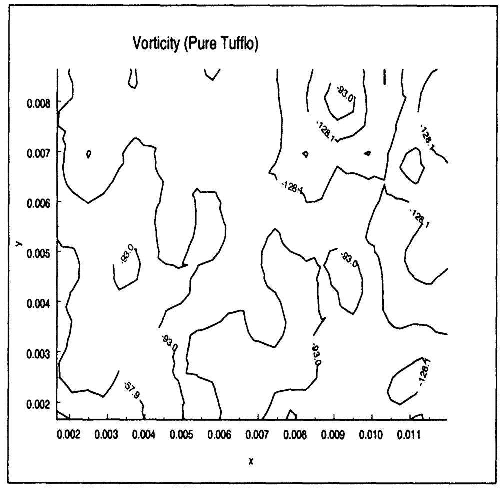


(b) Mean gray level

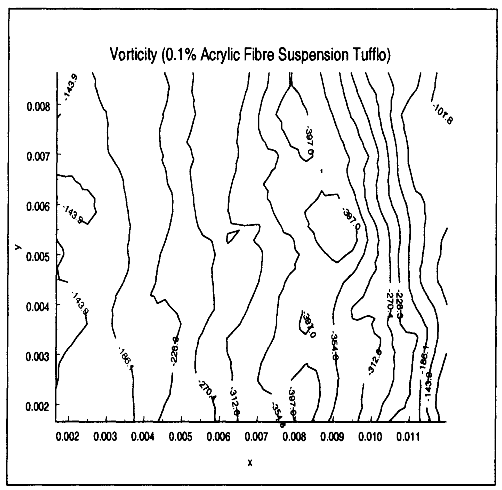


(c) Comparison of vector counts

Figure 1: Effect on measurements of various percentages of Benzyl Alcohol and Anisole.



(a) Mean vorticity, 0 percent



(b) Mean vorticity, 0.1 percent

Figure 2: Mean vorticity in 0 and 0.1 percent fibre suspension (by mass) in Tufflo 6016, N = 500 samples. x and y are in meters.