Echo Particle Image Velocimetry (EPIV) in Pipeflow of Liquefied Lignocellulosic Biomass

Motivation and Background

- U.S. Biorefinery Initiative (30 by 30), where 30% of all petroleum derived products be derived from renewable biomass by 2030.
- Current techniques involve shipping dry biomass to refineries via trucking, extremely inefficient could be circumvented using a pipe based infrastructure.
- After liquefaction, biomass presents itself as a complex slurry of both liquid and solid phases, which increases the complexity and cost of pumping.
- EPIV provides a much needed diagnostic technique that is non-invasive and can measure through both opaque geometries and opaque fluid flows using ultrasound.
- Understanding the behaviour of this complex and particle laden fluid will help in the overall infrastructure design and pumping requirements for the U.S., which in turn will increase the efficiency at which liquefied biomass is transported and converted to biofuel.

What is Liquefied Biomass?

In short it is the hydrolysis (saccharification) of biomass:

- Biomass - In this case the biomass being used is corn stover (i.e. the husk, stem, and roots of the corn plant). Unlike ethanol produced from the foodstock of corn, the corn stover is lignocellulosic which is more difficult to break down and requires more aggressive enzymes.
- Hydrolysis - Hydrolysis is the bio-chemical technique in which sugars (glucose) are broken out from the cellulose and hemi-cellulose present within the biomass. Once the sugars are released, the result is a liquefied biomass which can be fermented into ethanol and used as a petroleum product.

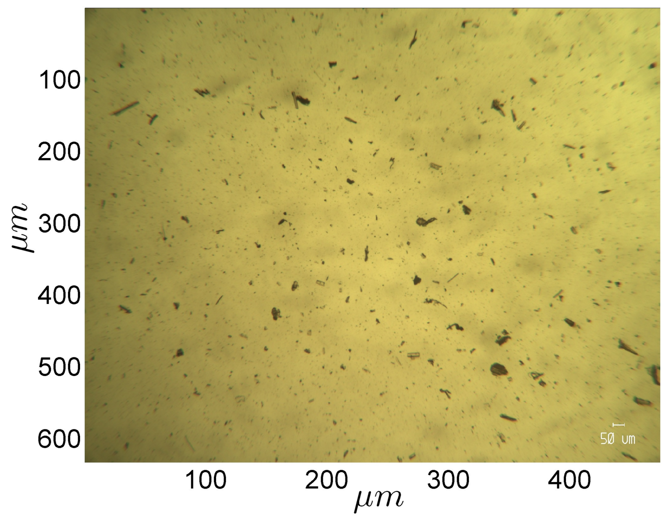
(a) 10L glass sleeved reactor.

(b) Resulting liquefied biomass.

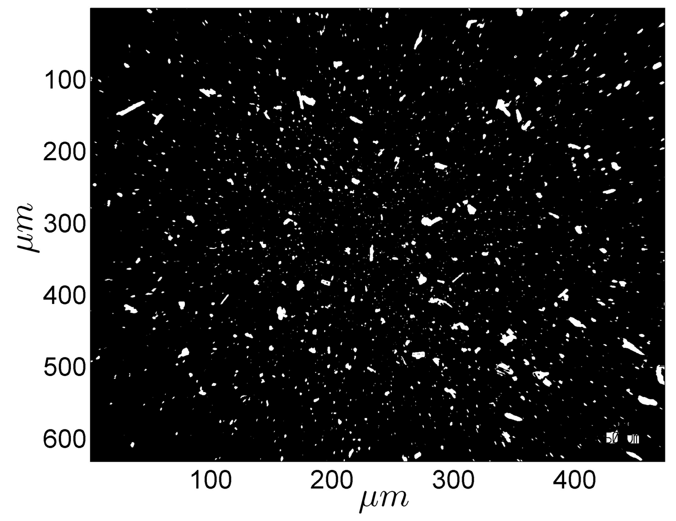
Figure 1: Producing Liquefied Biomass.

Studying Liquefied Biomass

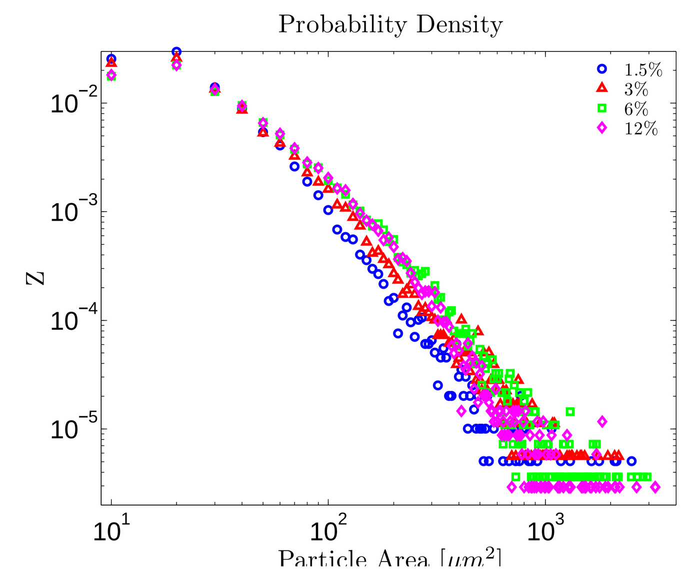
To study how liquefied biomass will behave in pipeflow conditions there is a need to investigate: Microstructure of particles in the fluid, Rheology of the fluid, Settling Rates of the particles, and how the discrete phase of particles move within the flow.



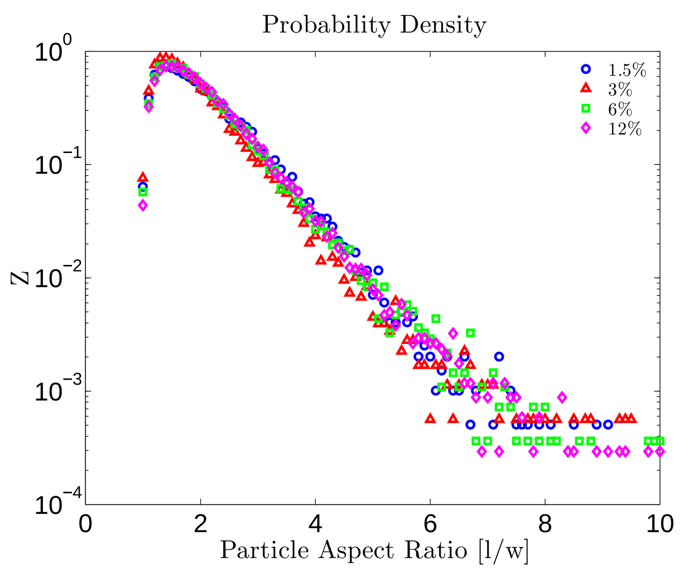
(a) Raw microscopic image at 50x magnification.



(b) After some filtering, a threshold is applied and the result is a binary image with particles in white, and the background in black.



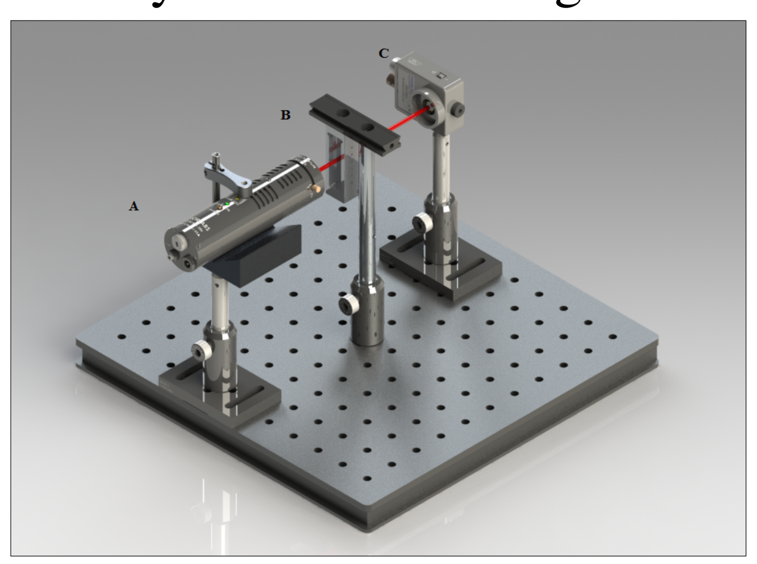
(c) Distribution of the particle areas.



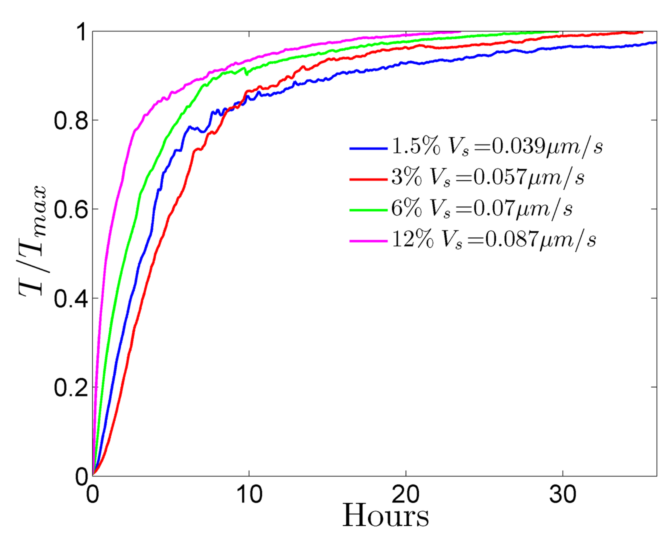
(d) Distribution of the particle aspect ratios, note that this is the length divided by the width.

Figure 2: Image analysis of liquefied biomass created with a 1.5% solid mass fraction.

The first step in quantifying the complexity of liquefied biomass is by characterizing the solid particles (see Figures 2(c) & 2(d)) that are present within the fluid. Here this is done using the image processing toolbox supplied via MATLAB. Multiple sets of data have been taken for liquefied biomass having solid mass fractions of 1.5%, 3%, 6% and 12%. The knowledge of how particle sizes are dispersed through the fluid are combined with particle settling rates which are experimentally determined using the setup below:



(a) Settling rate experimental setup consists of: (A) Photodiode 670nm Laser (B) Glass cuvette containing mixed liquefied biomass (C) Photodiode receiver measures intensity of laser light over time.

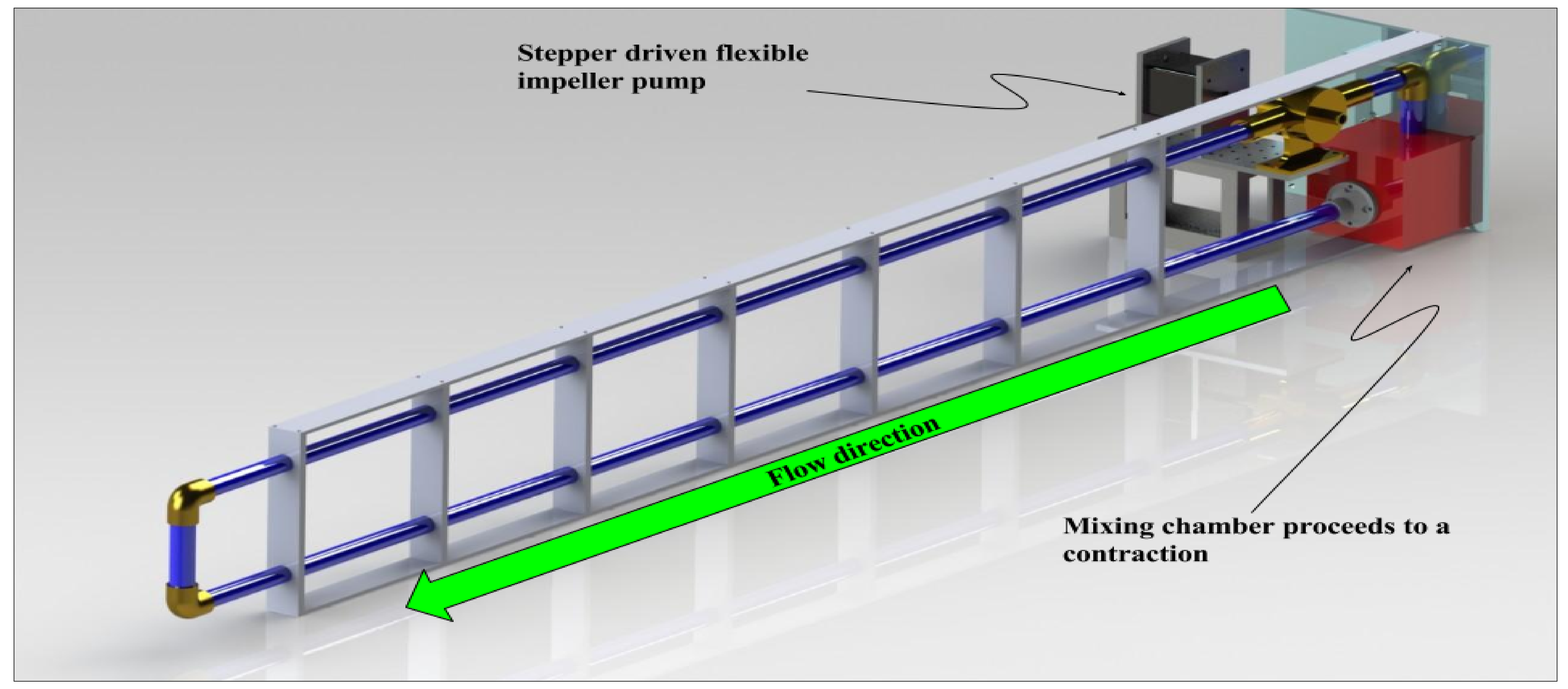


(b) Experimental results using a monodisperse solution and a simple simulation assuming particles are Poisson distribution.

Figure 3: Experimental setup for settling rates and a results for each solid mass fraction of liquefied biomass.

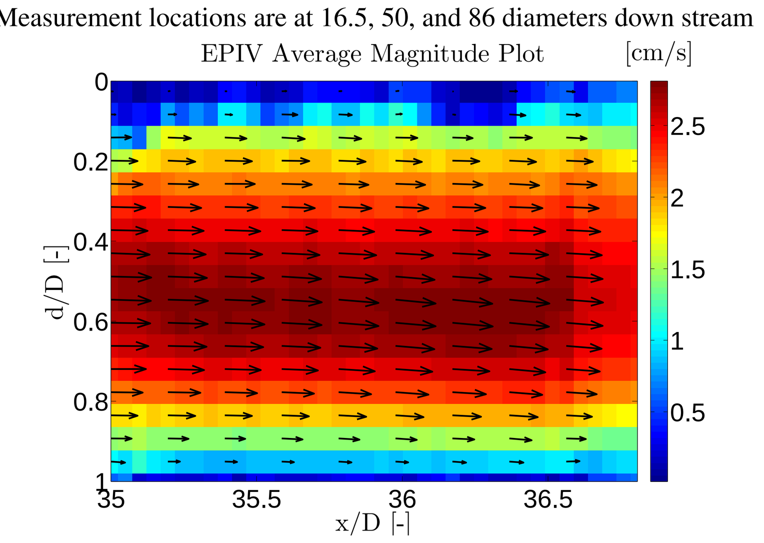
Coupling the knowledge of the distribution of particles, how they settle, and the rheology/viscosity will allow us to increase our ability to model these flows a priori, and validate our experimental results.

EPIV Results



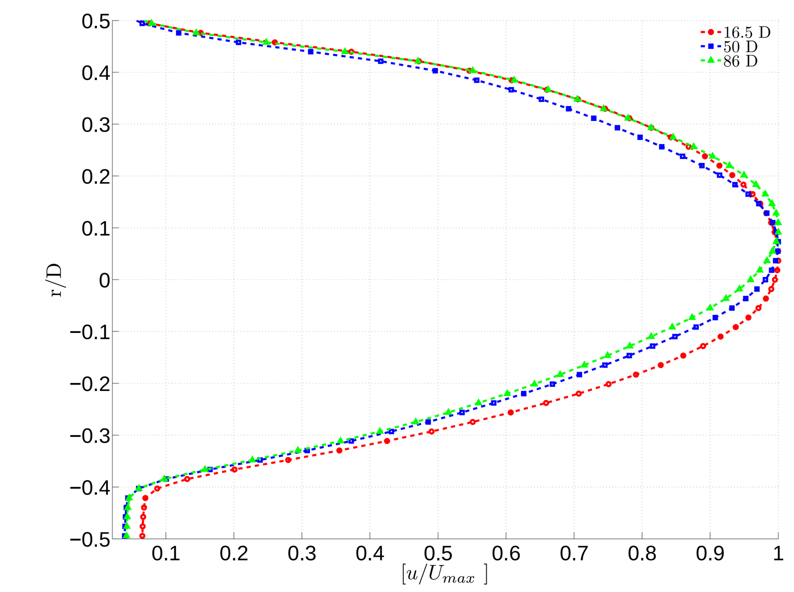
(a) Experimental setup for biomass transport through a 1" pipe. Measurement locations are at 16.5, 50, and 86 diameters down stream

(b) Raw image taken via ultrasound of liquefied biomass in transpor.t

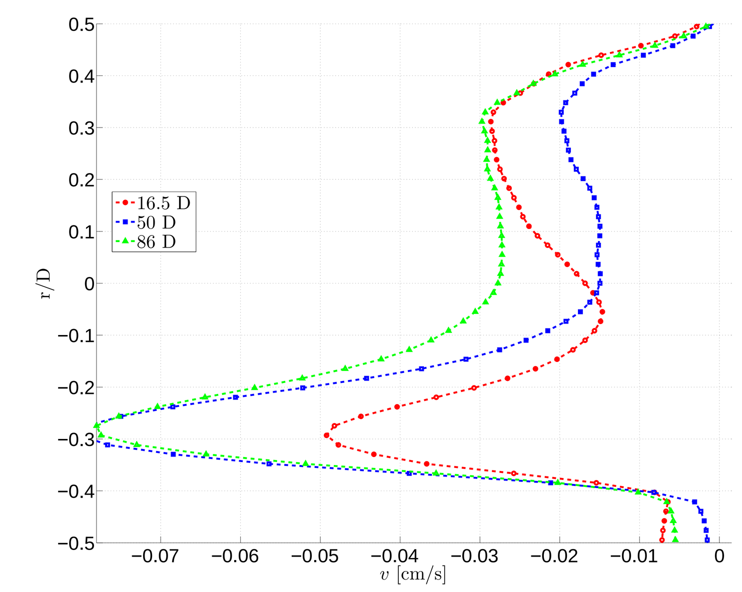


(c) EPIV analysis provides a discretized view of the ensemble averaged velocity field within the pipe.

Figure 4: Experimental setup, raw ultrasound image, and an EPIV ensemble averaged result for liquefied biomass in pipeflow.



(a) [EPIV measurement of streamwise velocities.



(b) EPIV measurement of wall normal velocities.

Figure 5: Streamwise and wall normal velocity profiles at different diameters downstream of the inlet.

Experimental results so far have been promising, the particle laden flow exhibits behaviour expected such as the vertical shift from the centerline of the maximum velocity with increasing diameter downstream as seen in Figure 5(a); and the non-zero wall normal velocities seen in Figure 5(b). Future work continues to experimentally determine the viscosity of the liquefied biomass, as well as its transport behaviour.

References and Acknowledgments

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