

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

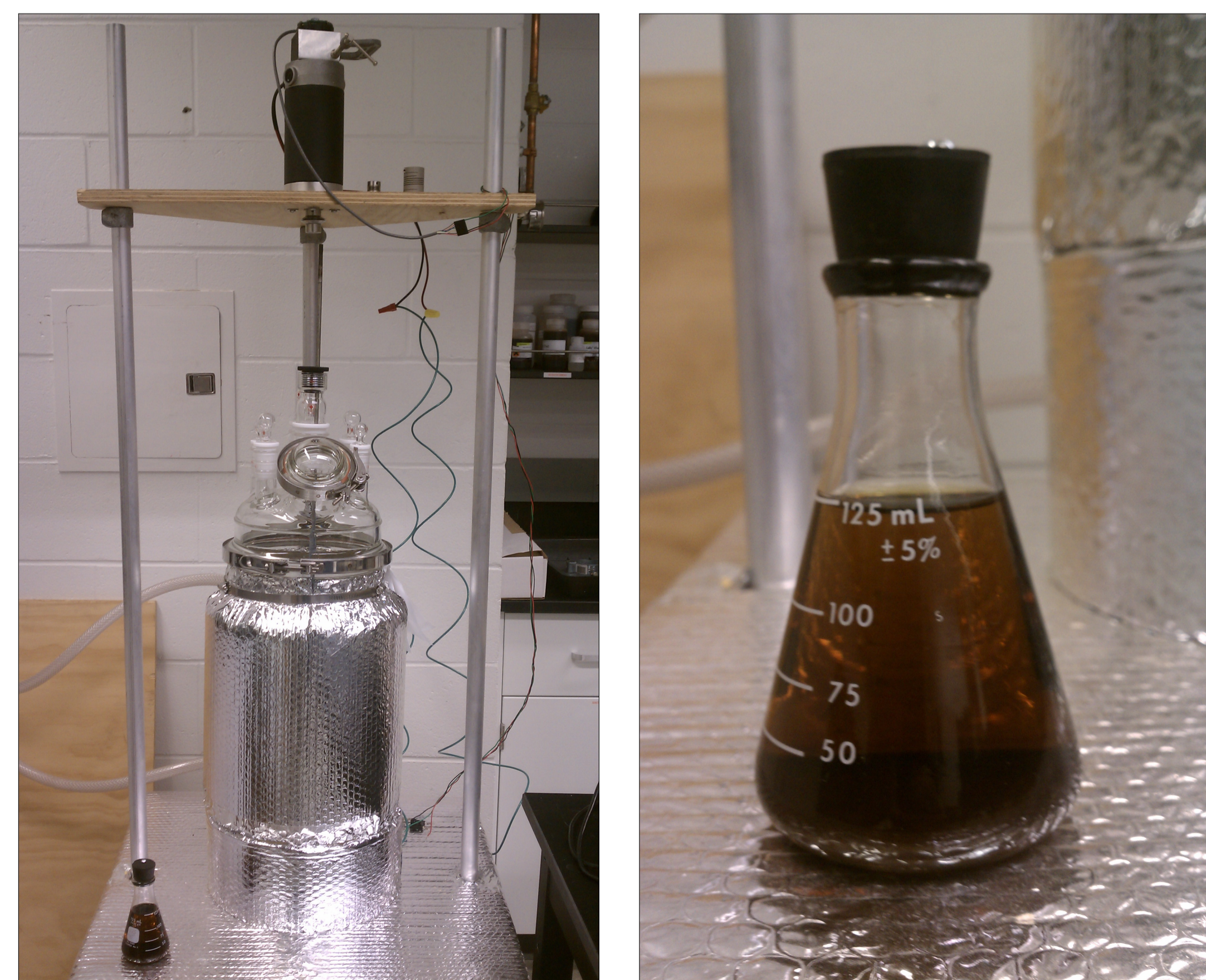
## Motivation and Background

- U.S. Biorefinery Initiative (30 by 30), where 30% of all petroleum derived products be 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 a 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 fluid flows using ultrasound.
- Understanding the behaviour of this complex and particle laden fluid will help in the overall infrastructure design and pumping requirements, which in turn will increase the efficiency at which liquefied biomass is transported.

## What is Liquefied Biomass?

In short it is the hydrolysis 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.

April 14, 2015

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.

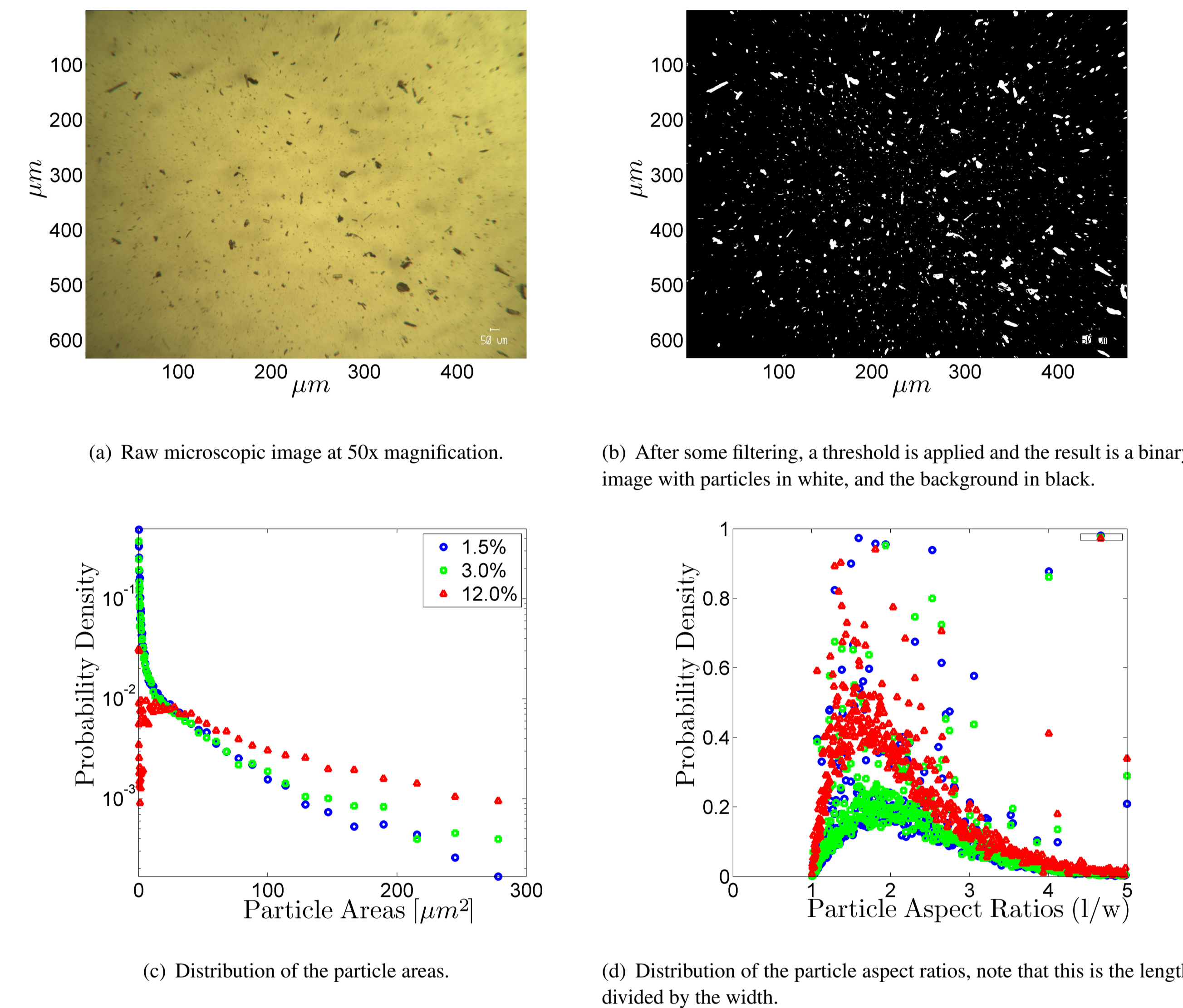
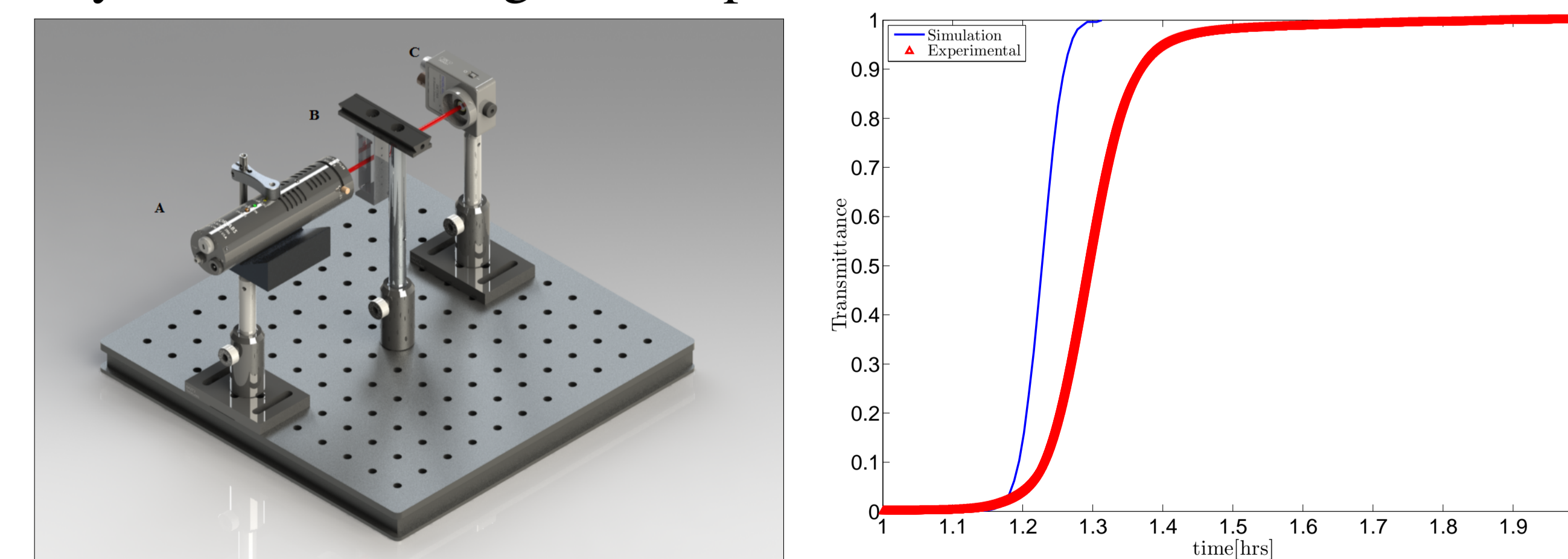


Figure 2: Image analysis of liquefied biomass created with a 1.5% solid mass fraction.

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, 3.0, and 12.0%. 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:

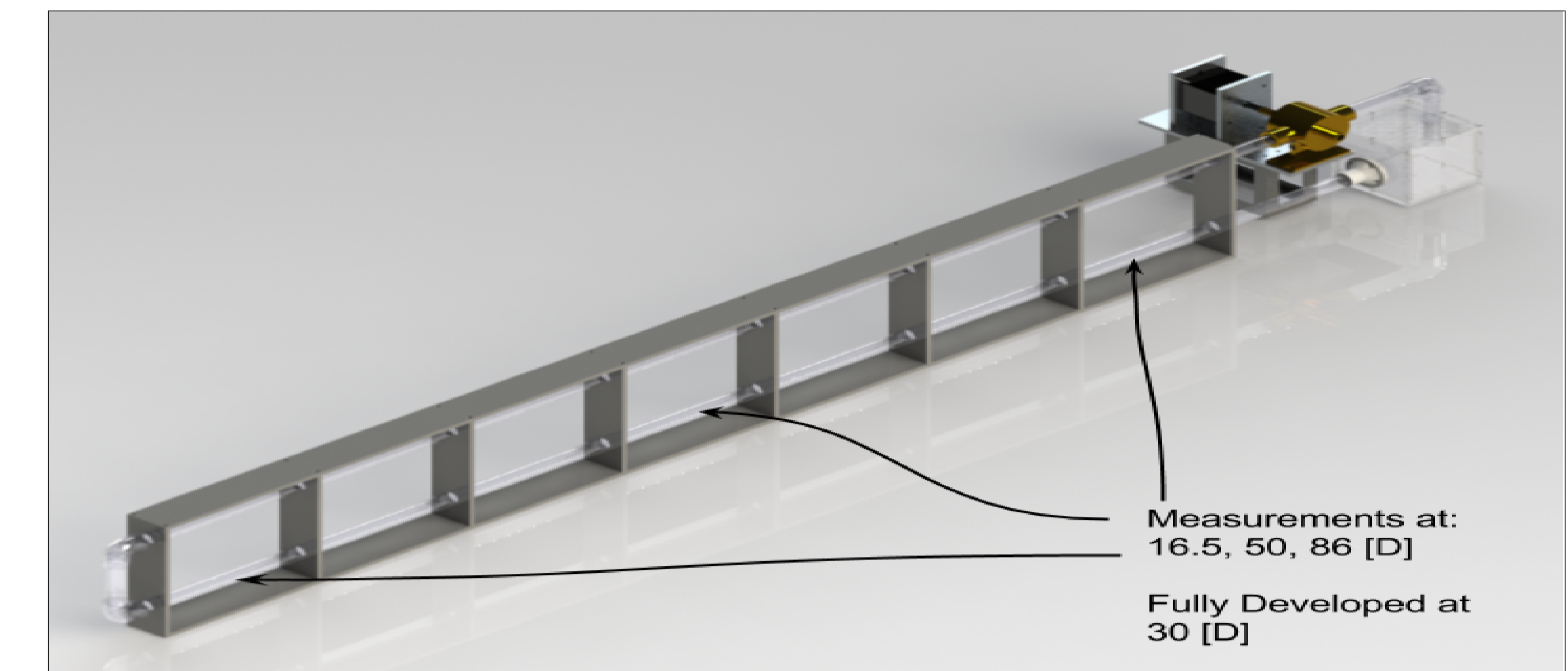


(a) Settling rate experimental setup consists of: (A) Photodiode 670nm (b) Experimental results using a monodisperse solution and a simple Laser (B) Glass cuvette containing mixed liquefied biomass (C) Photodiode receiver measures intensity of laser light over time. simulation assuming particles are Poisson distribution.

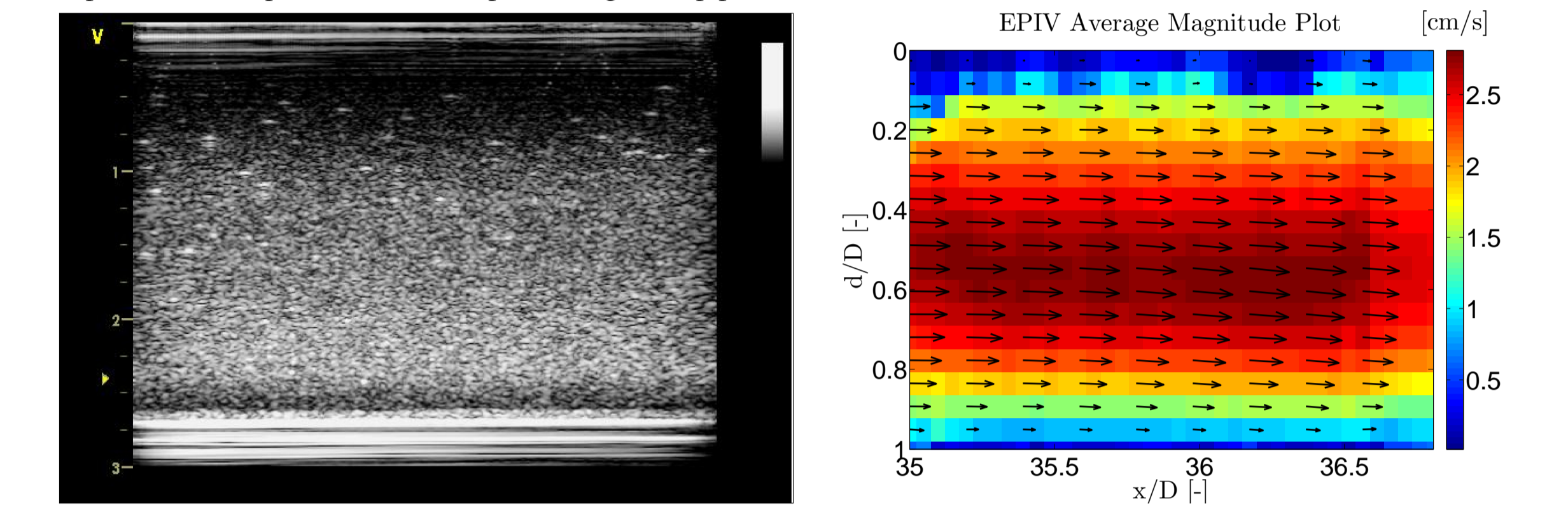
Figure 3: Experimental setup for settling rates and a result of some preliminary measurements.

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 downstream



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

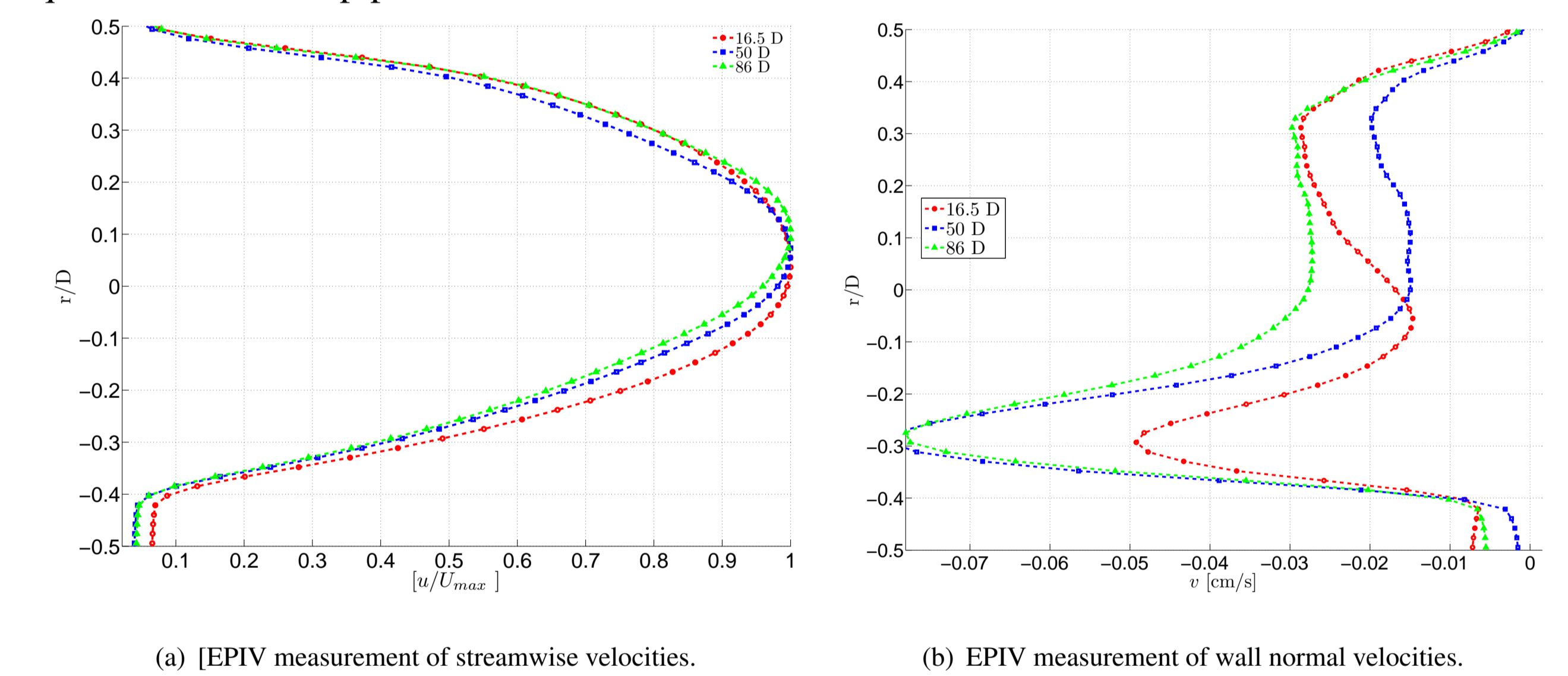


Figure 5: Streamwise and wall normal velocity profiles at different diameters downstream of the inlet.

Experimental results so far have been promising, the particle laden flow exhibits behaviour expected such as the upward shift of the centerline 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 will be on rheology and particle settling measurements, pushing towards a model of how this complex fluid will behave under these type of flow conditions.

## References and Acknowledgments

- The author gratefully acknowledges support by the National Science Foundation, CBET0846359
1. White, F.M. Fluid Mechanics. McGraw Hill, New York, New York, (1994).
  2. Zheng H., Liu L., W. L. and J., H. Appl Phys. Lett. 88, 261915 (2006).
  3. Poelma, C., Mari, J.M., Foin, N., Tang, M. X., Krams, R., Caro, C. G., Weinberg, P. D., and Westerweel, J. Exp. Fluids 50(4.S1), 777-785 (2011).
  4. Luk, J., Mohamadabadi, H.S., Kumar, A. Biosystems Eng. Elsevier 15375110 (2012)
  5. Vaezi, M., Pandey, V., Kumar, A., Bhattacharyya, S. Biosystems Eng. Elsevier 15375110 (2012)
  6. GE VINGMED ULTRASOUND A/A. Horten, Norway. Vivid 7/Vivid 7 PRO Users Manual, GEVU #FC092326 edition, (2003).
  7. DaVis Imaging Software by LAVISION. <http://www.lavision.de/en/download.php?id=3>

Author: Nicholas DeMarchi  
Advisor: Christopher White

