PURE Award Final Report 2018

Multiphase Flow Analysis Conducted on a Small-Scale Sand Separator

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Date of Submission: September 24th, 2018

Project Duration: May 7th, 2018 – August 24th, 2018

Location: Laboratory for Turbulence Research in Aerodynamics and Flow Control

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Introduction

The purpose of this project was to experimentally validate Computational Fluid Dynamics (CFD) performed on a small-scale sand separator, referred to in this document as a 'desander', as part of a PhD Thesis. The design of the original desander that is used by Specialized Desanders Inc. is meant to separate sand from a four-phase system consisting of frac sand, air, water and oil. As part of a PhD thesis, CFD analysis is to be performed on a small-scale prototype. Initially, a two-phase air-water system was analyzed in order to study the behavior of water prior to the addition of sand. Then, frac sand was systematically added to study the sand bank evolution. The main areas that were explored in this project are key quantitative information which can be used to validate a CFD model: (i) the velocity field of water at the inlet and weir locations, (ii) characterization of the air-water interface wave frequency and amplitude, and (iii) the three-dimensional settling behavior of sand as well as the transient development of the sand bank when sand is injected at a controlled rate into the air-water system.

Experimental Methods and Results

The experiments that were conducted during the duration involved conducting PIV experiments to generate velocity fields of the water phase in the desander. In addition to this, interfacial waves of the air-water interface were studied to generate frequency spectra. PIV experiments were first done without sand injection. Following this, sand was introduced, which occluded the PIV imaging setup and thus it was not possible to quantitatively measure the velocity field. However, it is expected that for low sand volume fraction, the velocity field of the water and air is not significantly affected by the introduction of sand.

Generating the instantaneous velocity fields

Particle Image Velocimetry (PIV), a state of the art and well developed quantitative velocity measurement technique, was used in the project to obtain instantaneous velocity fields at the inlet and weir locations of the desander (See Appendix). An optical system consisting of converging-diverging lenses was built in order to direct the path of the laser from a high repetition rate, high energy Nd:YLF pulsed laser (Photonics DM20 Laser) to a cylindrical lens that creates a ~7 inch wide planar laser sheet along the axis of the desander. Particle motion is captured using high-speed cameras capturing images which are synchronized with the laser. In order to visualize the flow field, the laser light from the sheet reflects off neutrally buoyant 10μm hollow glass spheres, called seeding particles, in the flow field. Since the spheres are neutrally buoyant, they act as water particles and a result, the generated flow field of these particles accurately depicts the water field. Camera images were recorded at a rate of 40 [Hz] for approximately 50[s], or a total of 2045 images. Figure 1 shows a sample image depicting the flow field taken using the PIV apparatus 5 inches downstream from the inlet section of the desander.

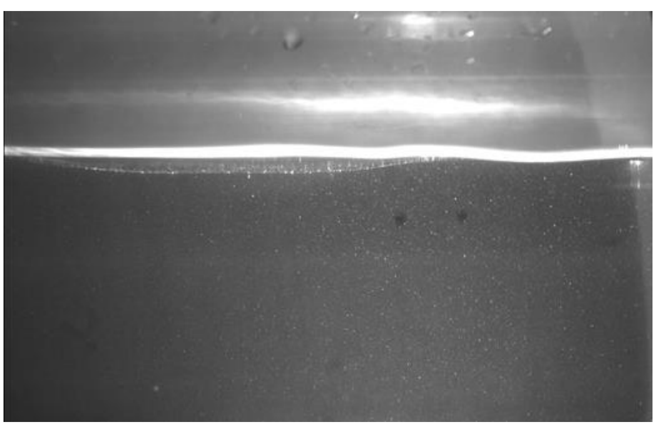

Figure 1. Sample raw PIV image taken at the inlet section

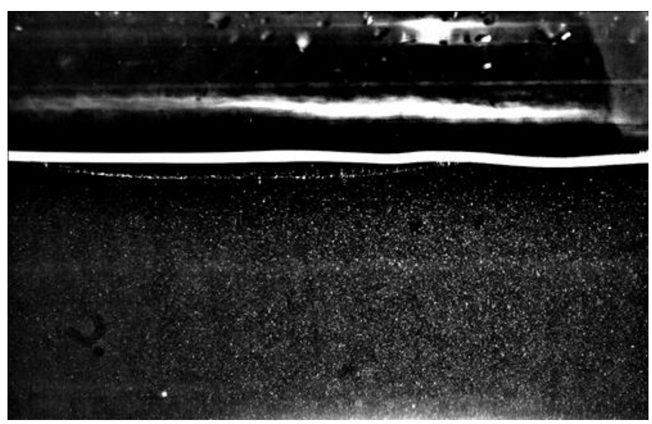

Figure 2. Filtered image of the same flow field as Figure 1

Following the acquisition of the PIV images using the high-speed camera, the images were

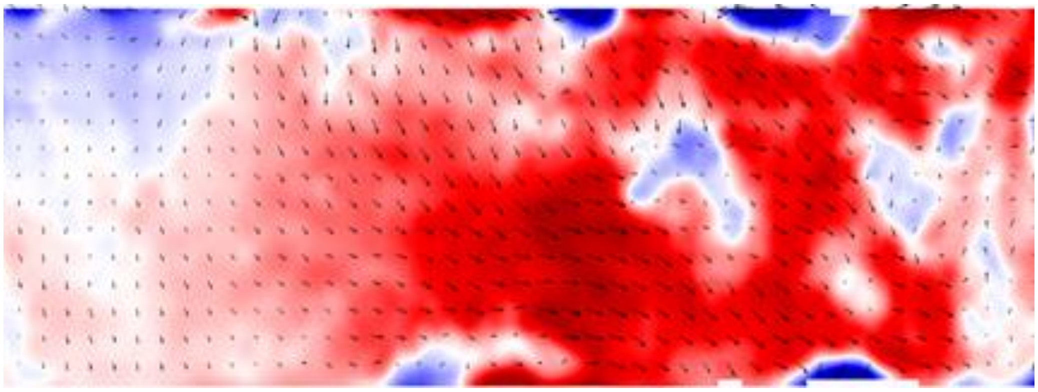

Figure 3. An instantaneous velocity field generated via cross-correlation. The red regions indicate high velocity regions with velocity vectors pointing to the right (indicating flow is moving to the right) whereas the blue region represent high velocity regions that indicate left-moving flow. The white regions represent still particles, or regions where laser light was too dim for particles be detected by the camera. Velocity ranges between -0.08[m/s] and +0.08[m/s].

filtered using the DaVis software in order subtract background noise to highlight the seeding particles. Figure 2 shows sample images after filtering.

Following this, cross-correlation was used in order to generate multiple velocity fields. Cross-correlation is an image processing technique that uses two consecutive images taken at the same position at known discrete time intervals, determined by the image rate of the camera, to form a single velocity field. Figure 3 shows a sample velocity field after cross-correlation was used.

Analysis of the Interfacial waves

Analysis of the air-water interface involved the use of MATLAB to process the filtered PIV images. The white band of light highlighted in Figure 4 below in the filtered images is caused by the reflections at the air-water interface from the laser sheet. This was used to an advantage to study the 2D interfacial wave behavior at different horizontal locations (referred to as ‘x locations’ in this document) over time.

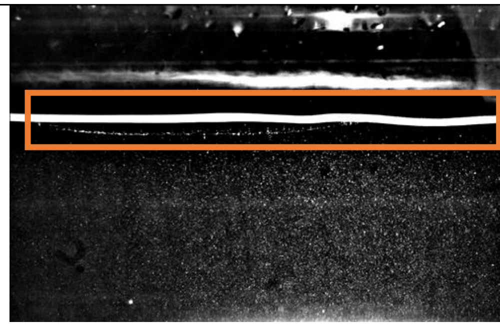

Figure 4. Air-water interface (highlighted) of several images was analyzed to model the behavior at different x locations across the field of view.

In MATLAB, the imread function was used on each of the images to isolate every 3 pixels span wise at the approximate range where the white band lies for the rest of the 2045 images. Then, for a given set of 3 pixels, the code finds the mean vertical location of the white band in this set. This was then repeated for all 2045 images and a plot of the vertical position with respect to time was produced for this set. This was repeated across the entire span of the image so that a clear understanding of the interfacial behavior was extracted. (See Figure 5)

To understand the spectral behavior of the interface, frequency plots of each corresponding position vs. time curves were plotted using the Discrete Fourier Transform. Figure 6 below shows the spectral behavior of the wave in the midsection of the images.

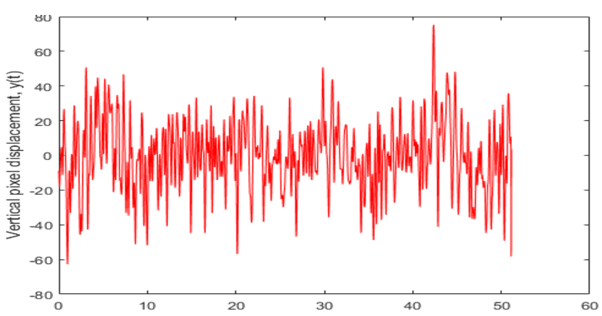

Figure 5. Vertical position of a 3 pixel-set in the midsection of the images' field of view across a 50[s] time span.

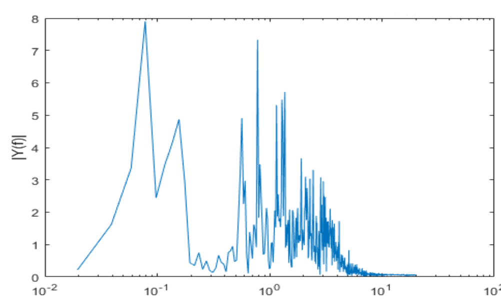

Figure 6. Single-Sided Amplitude Spectrum of a 3 pixel-set in the midsection of the images' field of view taken across a 50[s] time span.

Sand Bank Evolution

Finally, once the two-phase flow analysis was completed, frac sand was added to look at the three-dimensional settling behavior of sand as well as the transient development of the sand bank. This was done by systematically injecting sand at a controlled flow rate of 459[gal/min]. Figures 7 and 8 show the resulting formation of the sand bank.

Figure 7. Sand bank after 1.2[kg] of frac sand was injected into the desander.

Figure 8. Side view of the sand bank.

What I learned

This summer research experience was an enlightening experience in my academic career. It enabled me to explore Mechanical Engineering research, exposed me to tackle challenges faced by researchers in experimental Fluid Mechanics, solve problems quickly and efficiently, use state of the art research equipment, employ image processing and data analysis to process and analyze experimental data to draw useful conclusions. Additionally, I was able to make several connections with graduate students, industry professionals, as well as professors. I developed a strong work ethic, honed my hands-on manufacturing skills and improved by professional etiquette in the process.

Appendix

Figure A1. Wide-angle view of the 10-feet long desander.

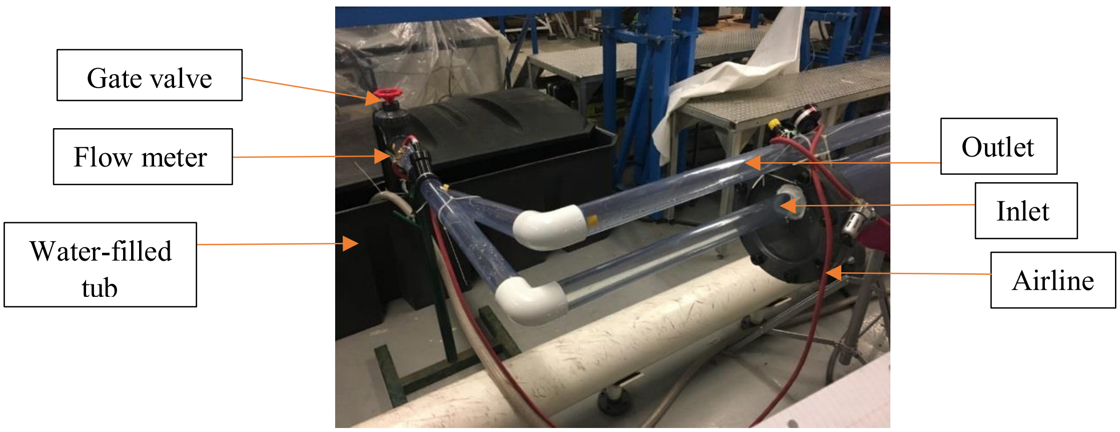

Figure A2. Inlet section of the desander.

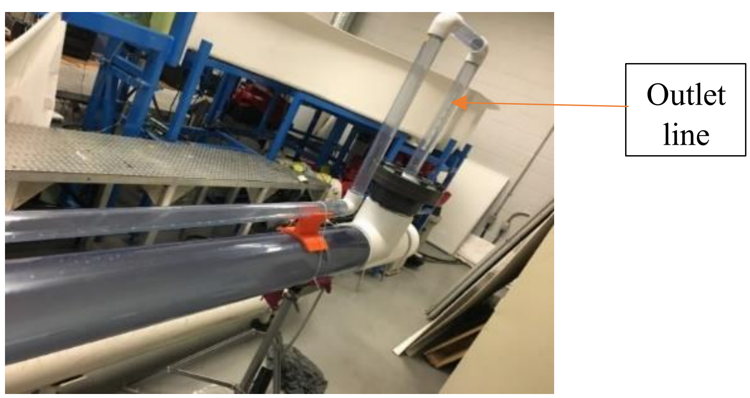

Figure A3. Outlet section of the desander.