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PARTICLE TRACER VISUALISATION AND VELOCITY MEASUREMENTS IN AERATED DENSE HORIZONTAL SLURRY PIPELINE

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This study used a pilot-scale slurry flow loop at Alberta Innovates - Technology Futures (AITF) to qualitatively investigate solid particle behavior in an aerated dense slurry in a horizontal pipeline. A CMOS sensor-based high speed camera was used to record solids and bubble trajectories at the wall of a transparent pipe spool. The study was done in a 200 mm (8 inch) pipe flow loop with mixture velocity and solids concentration of 4.5 m/s and 20 %v/v, respectively. The aeration was achieved by injection of oxygen to a concentration of 30 ppm. Particle concentrations were found to vary along the pipe circumference at the wall. There were strong interactions among the particles, particles and bubbles, and particles and pipe wall. Both the particle trajectories and velocities were also found to vary along the pipe circumference with lower velocities and high variation in trajectory angles at the lower section of the pipe wall. The converse was observed at the upper section of the pipe wall. Further studies and anlysis of the smaller particles are required.

KEY WORDS: hydrotransport, horizontal slurry pipeline, aerated slurry, wear, visualization

1 INTRODUCTION

Most oil sands extraction processes are open to atmosphere resulting in significant air entrainment within slurry pipelines used to transport mine ore and tailings. In addition, for short hydrotransport slurry pipelines, the slurry is conditioned by air to create bubble-coated with bitumen film called “air-sacks”. These air-sacks are formed by the coalescence of air bubbles and bitumen droplets that both move in the dense slurry (Sanders et al., 2000). A better understanding of the interaction between these air sacks and the solids in the slurry are vital to the optimisation of this system. Our recent work (Fuhr et al., 2014) has also shown that, the pipe wall loss depends highly on the flow regime and the amount of gas (oxygen) present. This pipe wall loss phenomenon can also be found in the mining and dredging industries. Therefore, the purpose of this work is to qualitatively assess particle-wall interactions in the near-wall region of an aerated dense horizontal slurry pipeline using a high speed video camera. The high speed video is intended to further our understanding of the effect of a third phase in slurry pipelines.

Previous visualization works (e.g. Ponnaganti et al., 1980; Hutchings, 1977 and Sheldon et al., 1977) provided some insight into particle-wall interactions. Unfortunately, these studies were done in either gas-solid two-phase flows or dilute systems of solids that do not resemble any of the mentioned dense slurry pipeline applications. Also, two-dimensional or three-dimensional flow field mapping instruments (see Mudde, 2010) provide particle dynamics information in an Eulerian reference frame, in which the actual trajectories of particles at the wall are not captured. In the present work, a CMOS sensor-based high speed camera was used to visualize solids and bubble trajectories at the wall of a dense slurry flow in a horizontal pipeline. Third-party software was then used to track and quantify several representative particle trajectories and velocities.

2 EQUIPMENT AND EXPERIMENTAL PROCEDURE

An experiment was conducted using a state-of-the-art slurry flow loop facility at an AITF laboratory (AITF-SFL) in Devon, Alberta, Canada. A detailed description and technical specifications of the AITF-SFL are given in the authors' previous work (Fuhr et al., 2014). Here, only a summary is provided. The AITF-SFL is an 8-inch (200 mm) horizontal flow loop with a transparent acrylic flow visualization section. It has a control system to maintain the operating temperature during the test. Bubbles were generated by directly injecting oxygen gas into the AITF-SFL main pipeline, with the concentration measured in an ancillary slip-stream.

The flow visualization section was made from transparent acrylic. This transparent section allowed the flow through the loop to be visualized using a commercial Photron FASTCAM-X 1280PCI monochrome high speed camera. The camera was used to record videos at the near-wall region at several pipe wall circumferential positions, using an o'clock labelling convention, as illustrated in Fig.1. The selected locations possessed visually interesting particle-wall interactions. All recorded videos were taken at 2000 frames/second with a resolution of 1280 x 256, which allowed for smaller particles to be viewed in greater detail. The field of view of the video was 100 mm x 20 mm at each recording location.

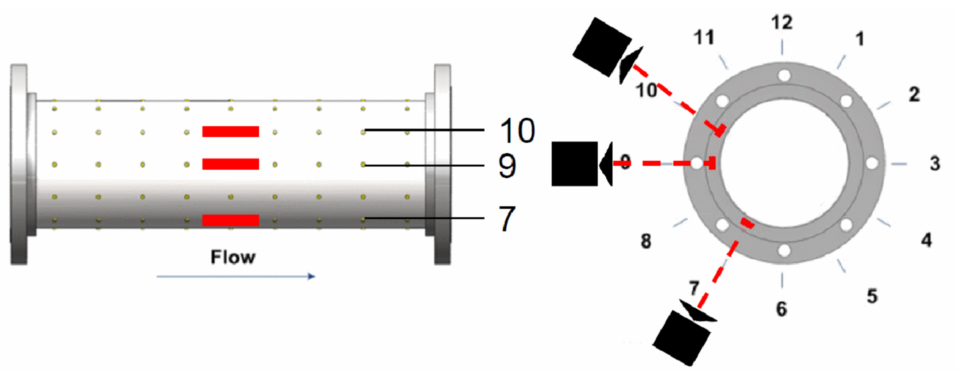

Fig.1 Sketch of visualization spool with marked locations

The test flow conditions are: mixture velocity of 4.5 m/s, 20%v/v of solids concentrations, and 30 ppm of oxygen concentration. Silica sand and rocks with bulk density of 2650 kg/m^3 were used as the solids phase. A commercial CAMSIZER instrument, which is based on an automated particle imaging technique, was used to characterize the solids. Finally, an automated gamma ray densitometer was used to determine *in-situ* solids concentration.

3 DISCUSSION

In this section, highlights of the solids flow visualization at the near-wall regions, as well as particle trajectory and velocity statistics at all the three locations shown in Fig.1 are presented. The acquired images were processed using Photron FASTCAM Viewer 3 (PFV) for image brightness and contrast balancing. Photron FASTCAM Analysis (PFA) software was then used for semi-automated particle tracking to analyze particle kinematics (trajectory and velocity). Two main challenges of the PFA software are that particle identification must be done manually and the tracking algorithm used by the software has difficulty tracking particles smaller than approximately 1 mm in size. Therefore, the kinematics of small particles are not included in the present study. However, analysis of these particles is ongoing.

3.1 Particle Motion Visualization

Fig.2 shows snapshots of the particles at the 7, 9, and 10 o'clock locations. A solids concentration gradient was clearly visible between pipe top and bottom. A high solids concentration was visible near the pipe bottom (7 o'clock), while a low concentration was visible near the pipe top (10 o'clock). Fewer solids were also observed at the 10 o'clock versus 9 o'clock location.

As shown in Fig.2, the dark, round visible objects are bubbles. Unlike the solids, there appears to be an approximately even distribution of bubbles among the recording locations. The videos (not shown here) demonstrate strong interactions between the solids and bubbles, and among the bubbles. Interestingly, collisions between solids and bubbles did not lead to visible bubble breakage.

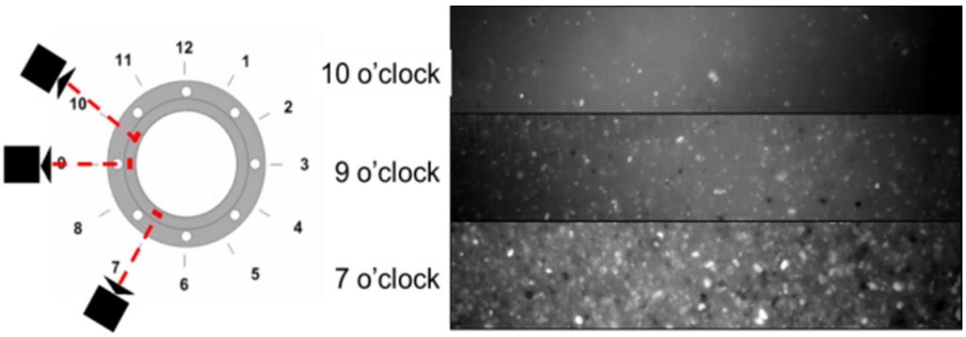

Fig.2 Snapshots of the flow field at the 7, 9 and 10 o'clock locations

3.2 Particle Kinematics

Fig.3 shows a still frame image with sample tracked particles. At least 10 particles were tracked at each visualization location. Particle trajectory angles were reported in the range of -180° ≤ θ ≤ 180°, with $\theta = 0$ in line with the horizontal in the direction of flow and $\theta > 0$ directed toward the top of the pipe. Table 1 summarizes the particle trajectory angle and velocity results. The particle trajectory depended strongly on the circumferential location. As shown in Table 1, the large range of angles observed for particles at 7 o'clock and small range at 10 o'clock indicated that there were more forceful and more frequent particle-wall interactions at 7 o'clock as compared to the 10 o'clock position. Because of strong and frequent particle-wall and particle-particle interactions at 7 o'clock, solids at this location moved slower on average than at 9 or 10 o'clock as shown in Table 1. Particle velocity fluctuations were strongest at 9 o'clock. This was a likely indication of intense flow turbulence as well as strong particle-particle and particle-bubble interactions. It is not clear if these observations will be influenced by bulk velocity, solids concentration, or bubble concentration. Future work will explore each of these flow parameters.

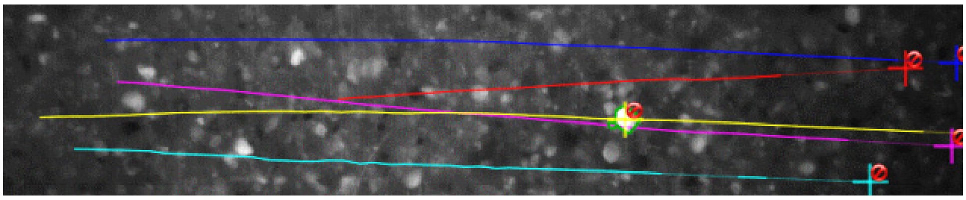

Fig.3 Sample of tracked particle trajectories

Table 1

Tracked particle trajectory angle and absolute velocity statistics

Location [o'clock]	Max.	Min.	Average	Standard Deviation
Particle Trajectory Angle (relative to horizontal), θ [degrees]				
10	7.6	-6.6	1.1	3.0
9	11.7	-7.6	1.1	4.6
7	18.3	-23.0	-1.5	4.2
Particle Absolute Velocity, V_P [m/s]				
10	4.3	2.2	3.8	0.3
9	4.8	2.8	3.7	0.5
7	4.6	2.5	3.2	0.4

4 CONCLUSIONS

Solid particle movement was visualised and tracked in the near-wall region of aerated dense slurry flow in a horizontal pipe using a high speed camera at three circumferential locations (7, 9 and 10 o'clock). For the flow conditions studied, a dense concentration of solids was observed in the bottom half of the pipe. It was observed that bubbles were evenly distributed with strong particle-bubble and bubble-bubble interactions. Particles tracked at 7 o'clock had a lower velocity on average than particles at 9 and 10 o'clock.

Though the average particle velocity at 9 o'clock was lower than at 10 o'clock, stronger particle velocity fluctuations were measured at 9 o'clock. These more extreme velocities were ascribed to strong three-phase interactions; however, further study is recommended.

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