Investigation into Sand Deposition and Transportation in Multiphase Pipelines – Phase 2

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Abstract

The depostion of sand particles in near-horizontal pipelines is a potential problem in the transportation of unprocessed reservoir fluids. The build up of sand beds can result in increased corrosion, erosion and flow assurance issues. This project will investigate the effects of a number of parameters including pipe incline, sand particle size, pipe roughness and pipe diameter on the crticical fluid velocity at which sand settling occurs. An experimental rig that is designed to emulate a stratified mutliphase flow, has been used to collect data. It is the aim that the data generated and relationships found in this project will improve the prediction of sand settling velocity, and be used by Woodside to assist in designing pipelines. Experiments to date have found a positive linear relationship between the critical velocity of sand settling and both pipe roughness and incline. Experiments have also indicated that sand particle diameter has an inverted parabolic relationship with critical velocity.

1. Introduction

Sand is a common undesirable by-product from oil and gas reservoirs, and its presence in the production and transportation of unprocessed multiphase reservoir fluids results in significant design challenges. Operational challenges arise when the sand particles entrained by the multiphase fluid drop out of suspension and form stationary or moving beds along the bottom of near-horizontal production pipelines. Operational risks that result from these beds include increased frictional pressure losses and increased erosion of the pipeline, along with corrosion of the pipe wall as a result of oxygen depletion beneath the bed (Danielson 2007). The development of sand beds can also potentially damage or block the passage of a pig, and may cause flow assurance problems within the pipeline (Bello, Oyeneyin & Oluyemi 2011). The presence of sand particles therefore requires the use of additional corrosion protection methods along with sand exclusion systems that increase the capital and operational costs of projects.

Should sand enter the production system, it is important that the system is designed such that the sand is not able to settle. To achieve this, it is necessary to know the critical velocity at which sand settles. The system must then be either designed to ensure that the fluid velocities stay above the critical velocity, or a periodic remediation such as pigging is done to remove the sand (Danielson 2007). This project aims to investigate through experimentation and research the critical velocity and variables that influence sand settling/transport in multiphase oil and gas pipelines.

1.1. Literature Review Key Findings

Multiphase transport in pipelines can exist in the form of a number of different flow regimes, depending on the local conditions. The two primary regimes that occur in horizontal sections are stratified flow and slug flow, with sand settling more prominent under stratified flow. Slug flow is superior to stratified flow at entraining sand as it tends to have a higher liquid loading and higher liquid velocity (Danielson 2007). This project has therefore investigated the critical velocity of sand deposition under the stratified flow regime, which can be expected to give a worst possible case of sand settling.

Under a stratified flow regime the sand will be carried in the water phase at the bottom of the pipe, as illustrated by Figure 1 below. The liquid phase velocity is therefore the major determinant of the sand carrying capacity of the multiphase flow, and is only indirectly influenced by the gas phase velocity (Danielson 2007). For these reasons, an open channel design of the experimental rig with only a water phase present has been justified. The experimental parameters that can be varied include the flow rate, water level, particle size, internal coating, pipe inclination and pipe diameter to build an extensive database or experimental results. From this database an analysis of the effect of the variable parameters on sand settling can be conducted.

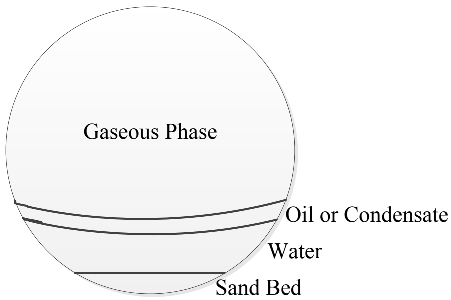

Figure 1 Section view of a stratified multiphase pipeline

The numerous predictive models for critical velocity of sand transport in multiphase flow are based upon two general approaches (Salama 2000). The Wicks model, and later modifications of it, are based upon analysing the forces acting on individual particles (gravity, buoyancy, lift and drag). The second approach was first presented in the Oroskar and Turian model (Oroskar & Turian 1980). This model was developed by balancing the energy required to suspend particles with that derived from dissipation of an appropriate fraction of turbulent eddies, and creating a prediction equation from a regression analysis of experimental data. There are a number of problems with the accuracy of such models as they are generally only valid for the parameter ranges for which they are generated, and often exclude key variables such as particle size or pipe inclination. This project aims to give a detailed investigation into the effect of a wide range of flow conditions on the critical velocity of sand settling, with the goal of improving the prediction of the critical velocity and aid in the design of sub sea pipeline systems.

2. Experimental Process

2.1. Experimental Setup

The design and construction of the experimental rig was undertaken in Phase One of the project. However, the current project has required a number of modifications to facilitate the experiments. These have included the widening and deepening of the weir in the collection tank, implementing a method for sand collection, and installing a water gate at the end of the pipe to allow for variability in the water flow depth. An ultrasonic flowmeter has also been supplied by Woodside to provide direct flow rate measurements, thus improving the accuracy of the recorded results.

A photo of the experimental rig is shown in Figure 2 below. Water flows in a continuous loop from the reservoir, through the pipe and into the collection tank from where it is pumped back to the reservoir. Sand is introduced in the final 2m section of the 4.25m pipe, to allow for an entrance length permitting a fully developed velocity profile, taken at roughly 10 times the pipe diameter (Rajaratnam, Katopodis & Sabur 1991).

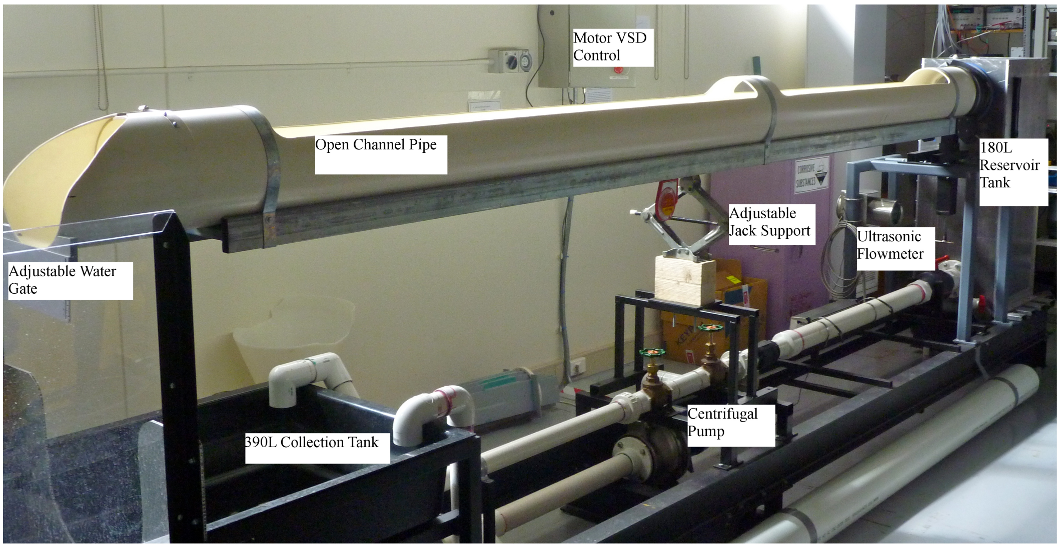

Figure 2: Experimental rig

2.2. Methodology

A significant amount of time was spent experimenting with different methods of sand injection or sand bed formation, to determine a systematic and reliable testing procedure that could be repeated for the different experimental conditions. Previous research papers on the topic of sand transport in pipelines have classified the critical velocity under two situations. The more popular definition is the velocity at which the transition occurs from sand being entrained by the fluid to forming a stationary bed (Oroskar & Turian 1980). The alternative definition is the transition between moving dunes to a scouring moving bed at the bottom of the pipe (Salama 2000). The first definition accounts for the critical velocity at which bed formation occurs, while the second definition accounts for the critical velocity at which bed break up occurs.

Sand particle settling was decided as more relevant to the research project and to Woodside than sand bed re-suspension, and so for the purpose of gathering experimental data the first definition was adopted. Another issue with previous papers on sand transport in pipelines is that their experimental data and predictive models were developed for high solids loading situations. For off-shore systems, typical sand loading is much smaller, from negligible amounts to 5 lb of sand per 1000 bbl of produced liquid. A solid loading of this level would equate to sand being transported in a layer not much thicker than a single layer of particles (Danielson 2007). Therefore the final experimental procedure to test the critical velocity involved introducing a small number of sand particles into the water stream, so that only a single layer of particles formed on the bottom of the pipe. The water flow rate is then incrementally decreased until the velocity is reached at which the majority of sand particles transition from scouring down the pipe to remaining stationary. The flow rate at which this transition occurs is recorded from the ultrasonic flowmeter, and the width of the water section is measured to calculate the cross sectional area of the water flow. From these two values the superficial velocity can be calculated by dividing the flow rate by the cross sectional area.

3. Results and Discussion

Initial experiments with forming sand beds and studying their break-up pattern, confirmed that sand transport in near-horizontal pipelines has four main regimes, depending on the fluid flow (Danielson 2007). Below the critical velocity, sand particles will become stationary and form a stable, stationary bed. As the bed builds over time, sand particles from the top of the bed are transported downstream increasing the length of the bed. As the fluid velocity increases, the bed breaks up into slow moving dunes that get progressively smaller and further apart. A further increase in the fluid velocity results in a complete break up of dunes into a scouring stream of particles.

The effects of water depth, particle diameter, pipe surface roughness and pipe incline have so far been tested, to determine their influence on the critical velocity of sand settling. These experiments were undertaken using the procedure described in the methodology section above. The following four figures summarise the results of these experiments. An adjustable water gate was used on the end of the pipe to allow for the cross-sectional area of water to be varied along with the flow rate. As Figure 3 illustrates, the water depth above the settling sand has no effect on the critical velocity.

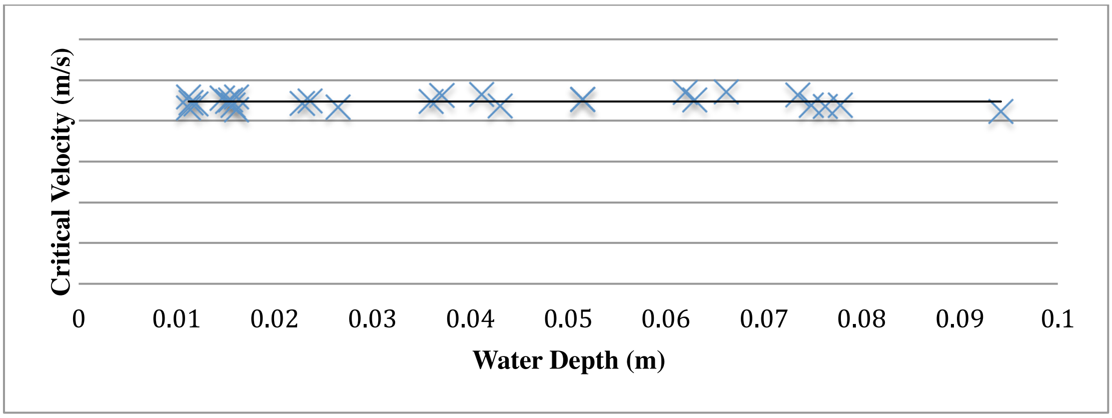

Figure 3: Effect of water depth

For particle diameter, sieve sizes of 75-150, 150-212, 212-300, 300-500 and 500-600 μm were used in the experiments. The systematic procedure was repeated with for particle size with results demonstrating an inverted parabola, with a maximum critical velocity occurring at approximately 375 μm.

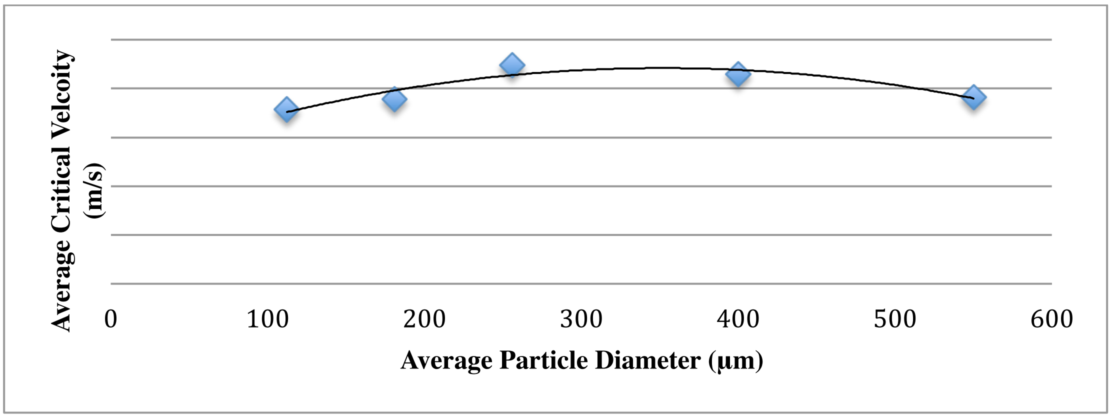

Figure 4: Effect of particle diameter

Data for variable pipe roughness was collected using sand paper of varying grit sizes, attached to the bottom of the pipe. From the grit sizes, the average particle size of the sand attached to the bottom of the pipe could be determined, which has been used as a measure of roughness. Future work will involve comparing these levels of surface roughness to those experienced in steel pipes, and repeating the experiments using a steel pipe.

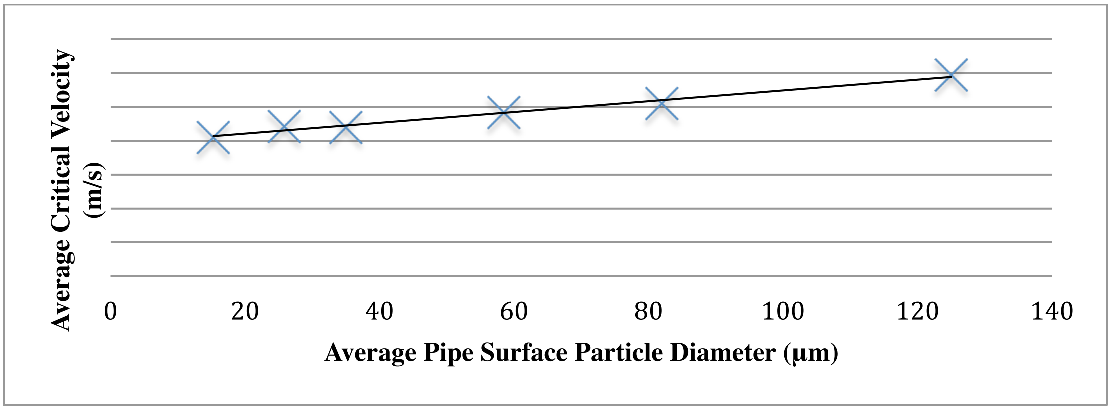

Figure 5: Effect of average pipe surface roughness

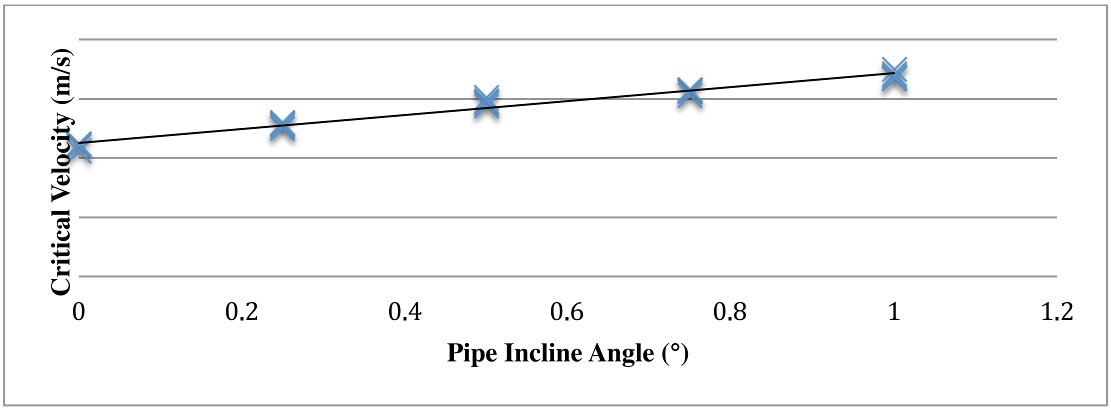

Figure 6: Effect of average pipe incline

Due to the limitations of the experimental rig, incline was only able to be tested between 0° and 1° however the linear relationship that is shown may be extrapolated out for larger inclines. Decline was also tested, with results indicating that sand will not settle under a pipe decline.

4. Conclusion and Future Work

The principal objective of the project, which was to build a database of experimental results to analyse the effects of variable parameters on sand deposition in pipelines, has largely been completed. Further experiments to still be performed include repeating the experiments in smaller diameter pipes of 110 and 156 mm to determine the effect of pipe diameter, and also testing in a steel pipe. An in depth analysis of the experimental results will then occur to explain and investigate the relationships illustrated in Figures 3-6. Other future experiments of interest to this project may look at using the ‘transition from moving dunes to scouring’ definition of critical velocity to analyse bed break up. As sand becomes more compacted and adherent to itself and the pipe surface with time, a higher flow rate is required to initiate movement of a bed than for the bed to settle (Salama 2000). The critical velocity for bed break up would be important in off-shore systems after a period of shut down or after a bed has already formed. Other future work to be carried out could investigate the dynamic similarities between the simplified water and sand used in these experiments, and more realistic gas, condensate/oil and water mixtures present in off-shore systems.

5. References

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