Flow transients in multiphase pipelines

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Abstract

Multiphase pipelines may exhibit a range of transient flow conditions, including unstable flows (severe slugging) and operator induced transients (shut-in, start-ups, ramp-ups, pigging). OLGA is a flow simulator which is in widespread use for analysis of transients in multiphase flowlines. Although OLGA has been applied for a very broad range of flow problems, there is still a need for careful validation against experimental data taken under controlled conditions. This paper details the experimental set-up and method used for the validation of the particular flow problem of flushing an air filled, undulating pipeline with a liquid stream, and outlines some of the observations of the bubble turning process from the experiments.

1. Introduction

The case presented in this paper is the transient flushing of a pipeline with a liquid stream. The base flow problem has similarities with liquid purging by a gas stream, but gas purging is experimentally much simpler. The base problem relates to the propagation of bubbles, and the particular problem of bubble turning in downwards inclined pipe sections. The case is being reveiwed in partnership with Scandpower Petroleum Technology (SPT), the publishers of the software, and they have supplied the OLGA software for the purposes of this validation.

The main objective of the work is to develop a small scale experimental system to investigate a transient slug flow scenario as a test case for the multiphase flow simulator OLGA. Experiments will focus on the problem of flushing an air filled, undulating pipe with an inlet water stream at constant pressure. It is expected that when the pressure is sufficient the water will maintain a high enough velocity to displace all the air in the pipeline. However, lower pressures, corresponding to lower velocities, will leave residual air in the pipeline. The experimental data will be compared with predictions from the flow simulator OLGA, with and without the front tracking options.

2. About the OLGA model

The OLGA model has been in development since 1980 out of a desire to simulate the slow transients exhibited in flows in oil and gas pipelines. Previously, models simulating multiphase flow transients were based on the fast transients in nuclear applications (Bendiksen et al., 1991). The OLGA model is a dynamic two-fluid model using equations governing the conservation of mass, conservation of momentum and an energy equation that incorporate properties of the gas, liquid and liquid droplet phases that may be exhibited in a multiphase pipeline, to simulate the transient behaviour of the flow (Bendiksen et al., 1991). As temperature and pressure of the fluids vary along the flow the OLGA model accounts for the changing fluid properties by extracting data from a user defined Pressure, Volume, Temperature (PVT) file (Bendiksen et al., 1991). In their 1991 paper describing the OLGA model Bendiksen et al. compare the predictions of the OLGA model with data from several experiments and field data with good general agreement when the boundary conditions are correctly defined. However, they do acknowledge that there are many more scenarios that need to be tested to verify the model.

3. Experiments

3.1 Experimental set-up

The general layout of the experimental set-up is shown in Figure 1. The experiment rig consists of five 1.83 m lengths of clear acrylic pipe with an inside diameter of 19.05 mm. These lengths are joined by transparent, blue tinted, smooth flexible hose of similar inside diameter, 20 mm, and length 110 mm. Clear flexible pipe would have been preferred, however there was none available at the time experiments were being undertaken. The pipeline is supported by stands that allow the inclination of the pipes to be varied at discrete steps between 10° and 20° to the horizontal. A constant head reservoir provides water to the pipeline. The reservoir is supported by a stand that allows the tank height to be adjusted so that the static water height, relative to the base of the pipeline, can be changed in discrete steps from 0.23 m to 1.95 m. The supply line from the tank is made of interchangeable PVC pipe sections with a 44 mm inside diameter, allowing the supply line to be longer or shorter depending on the variable tank height. Coupling this with the larger pipe diameter reduces friction effects from the supply piping. There is a 20 mm ball valve at the end of the supply line to stop flow at the end of each experiment run so that the pipeline can be cleared ready for the next run. A 200 mm long straight section of 20 mm inside diameter PVC pipe exits the ball valve and connects to the pipeline to ensure flow entering the pipeline has a uniform velocity profile.

The water in the tank contains green dye so that five Microsoft Lifecam VX-6000 web cameras connected to individual computers can capture the flow progression through the pipeline. The computers are using an open source code VirtualDub 1.8.3, for the capture process. Each test height is run twice with video captured at a resolution of 640 x 480 pixels at 30 frames per second (fps) for one run and 1024 x 768 pixels at 15 fps for the other, the video is saved as an uncompressed AVI file. Video captured from the USB web cameras was often inconsistent with the specified frame capture rate, especially when capturing video at a high resolution and the cameras' maximum frame rate of 30 fps. For future work Ethernet cameras would provide much more reliable video capture.

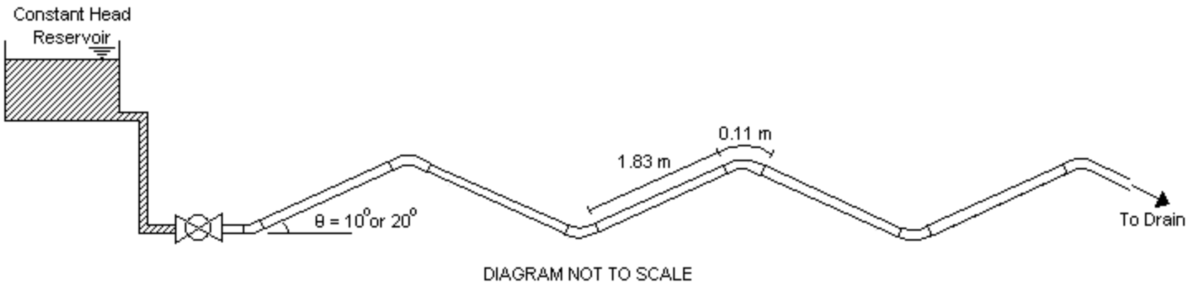

Figure 1 Schematic of experiment set-up

3.2 Experimental method

The air filled pipeline is flushed with water from the constant head reservoir by opening the ball valve at the end of the supply piping. The height of the reservoir is varied to investigate the effects of the static pressure head on the filling of the pipeline. There are seven test heights for pipe inclinations of 10° and seven test heights for pipe inclinations of 20°, each of the runs at these test heights are performed twice, in total 28 experiment runs were performed. The experiments were video recorded using the web cameras so that analysis of the images could be performed to track bubble propagation, growth and decay.

Simulations of the experiments, run using OLGA, are then compared to the experimental data. The accuracy of the flow simulations will depend on how well the bubble turning process is modelled in the downwards inclined pipes. Several OLGA geometry profiles have been created to investigate the influence of the detail of the model geometry on the accuracy of predictions. OLGA geometry profiles created include geometries with the 1.83 m pipes modelled in 10 and 50 sections, and the joining curved pipes modelled in 11 and 22 sections. Simulations are run with and without the OLGA Slug Tracking module active to investigate its effect on the simulations.

4. Discussion

Bubble turning occurs when the force of friction on the liquid flow becomes larger than the gravity force propelling the liquid flow. Observations from the recordings of the experiment runs have shown that at lower test heights, relating to lower flow velocities, bubble turning in the downwards inclined pipe lengths is more prevalent. These bubbles form sooner and are of greater length than those formed at higher test heights. At higher test heights the liquid front progresses with a sharp inclined front through the downwards sections of pipe, at lower test heights the liquid front is more curved, with a long shallow liquid stream preceding the curved front. This is shown in Figure 2. It was also observed that at the lower test heights residual air did remain in the pipeline once the flow had come to rest. Whereas at higher test heights, where the flow maintained sufficient velocity to exit the pipeline, the pipeline was completely flushed with liquid. Increasing the test height after the flow through condition was reached filled the pipeline faster with less slugging in the upwards inclined pipe lengths. As entrapped air from the bubble created in the downwards inclined pipe section escapes to the following upwards inclined pipe section slugging is generated. This phenomena is exhibited at lower test heights, however at higher test heights where no bubble is created in the downwards incline sections, slugging is not visible. This is shown in Figure 3.

Further analysis of the video data is required before definitive conclusions can be made about the accuracy of the OLGA predictions.

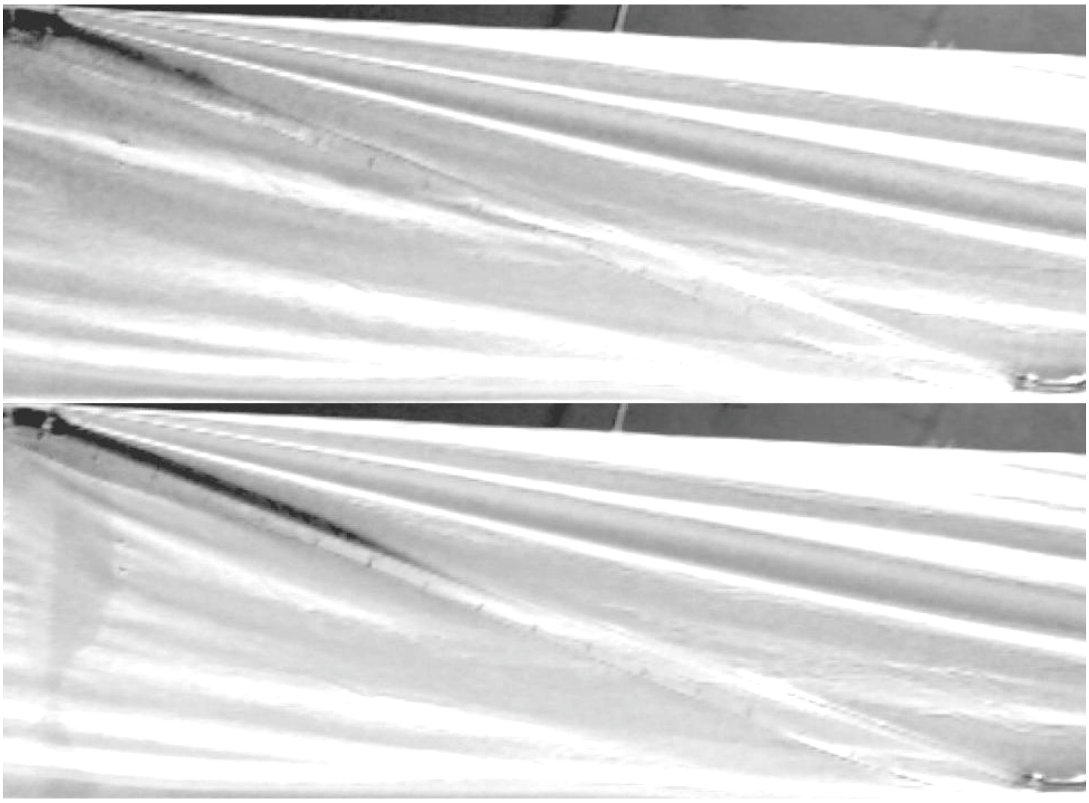

Figure 2 The top picture shows the bubble turning for a test height of 700mm at a 20° pipe incline in the second pipe section, the bottom picture is for a test height of 1950 mm, liquid is flowing from left to right.

Figure 3 The top picture shows the slugging in the third pipe section at a 20° pipe incline for a test height of 700 mm, the bottom picture is for a test height of 1950 mm, liquid is flowing from left to right.

5. Conclusions

The experimental set-up and method described in this paper have resulted in video footage being captured of an air-filled, undulating pipeline being filled by a liquid stream at a constant pressure. This pressure has been varied and fourteen different flow cases have been recorded and are under analysis. The bubble turning phenomena has been observed and its effects on the flow through the pipeline identified. Data gathered from the analysis will be compared to data predicted by the OLGA model, and conclusions from this validation can then be drawn. This is simply one case that has been investigated, and there is still further work to be done to validate other cases.

6. References

Bendiksen, K.H., Malnes, D., Moe, R. & Nuland, S. (May 1991) The Dynamic Two-Fluid Model OLGA: Theory and Application. *SPE Production Engineering,* pp. 171-180.