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ABSTRACT

The study addresses particle hydrodynamics in three-phase air-water-sand pipe flow. Measurements for particle velocity, particle holdup and pressure drop were performed and analyzed for over 400 combinations of gas and liquid volume flow rates at different sand loading conditions. A computational model was developed to predict the observed sand particle transport parameters, which are key factors to design, optimize and control flow assurance and erosion risks in gas-oil-sand multiphase pipe flow.

SUMMARY

Sand particle transport in multiphase production and transfer systems has attracted considerable attention since the advent of subsea tieback and horizontal well technology. The prediction of the sand particle transport and hydraulic parameters are the key factor to design, optimize and control flow assurance and erosion risk issues in gas-oil-sand multiphase pipes. This study investigates the particle hydrodynamics (velocity and holdup) in three-phase air-water-sand pipe flow systems using both charged couple device and particle image velocimetry techniques. The measurements are performed for over 400 combinations of gas and liquid volume flow rates at different sand loading conditions. The hydrodynamics of the sand particle in gas-oil-sand pipe flow is also theoretically analyzed. A computational model is developed and applied in predicting the particle velocity, particle holdup and pressure drop in the three-phase gas-oil-sand mixture flows.

The new data obtained from the experiments are compared with the proposed and existing models for particle velocity and holdup. Calculated values for particle holdup show good agreement with the newly developed equation and a published industrially used model (Danielson, 2007) for gas-oil-sand pipelines. For the particle velocity, the proposed model shows a better performance over the existing correlations. The performance of the proposed model is attributable to its phenomenological approach, which makes it not confined to the limits imposed on the applicability range of the existing methods.

INTRODUCTION

The majority of the newly discovered fields with high recoverable reserves are situated in less accessible environments with unconsolidated formations (Gulf of Mexico, North Sea and Gulf of Guinea). The conventional downhole sand completions (such as expandable sand screens, gravel packs, resin consolidation, frac- and pack) strongly affect the overall well performance due to additional pressure drops (skin effects) and several other drawbacks (installation and operation costs). As a result, sand management technology is largely gaining attention due to increased reserve recovery, elimination of downhole sand exclusion, minimization of problems associated with formation damage and impaired productivity. This generates significant profits and cost savings. However, it is generally recognised that one of the major issues to be addressed before more wide spread use of sand management technology in the petroleum industry is particle transport in the subsea multiphase tie-back systems. Inefficient particle transport may lead to numerous problems such as sand deposition and bed development, increased pressure loss, enhanced pipeline erosion and corrosion, frequently expensive cleaning operations and increased. To stimulate greater use of the sand management technology, sound technical basis must be established for the adequate understanding of the hydrodynamics of oil-sand multiphase flows through subsea flowlines, risers and pipelines.

However, a careful analysis of the existing literature on the subject of sand transport in oil-gas multiphase pipe flows reveals the following major issues and large gaps in knowledge (Bello, et. al. 2005a; Bello, et. al. 2005b; Bello, et. al. 2005c; Bello, et. al. 2006, Bello, et. al. 2008a Bello, et. al. 2008b, Bello, et. al. 2008c): (1) knowledge about the physics of sand particle in gas-oil multiphase pipeflow systems (2) identification and quantification of the influence of the local multiphase fluid dynamics on the particle behaviour in gas-oil-sand multiphase production and pipeline system performance objectives (3) ability to measure and predict the hydrodynamic and particle transport behaviour in gas-oil-sand multiphase pipe flows (4) development of predictive tools for hydrodynamic parameters and hydraulic estimation (5) validation of existing published predictive methods.

OBJECTIVES

The objectives of this work are therefore:

- To explore the possibility of using particle tracking velocimetry and particle image velocimetry techniques (in contrast to the classics) in unison to the fundamental investigation of particle transport problems in three-phase pipe flows
- To develop a phenomenological model for the prediction of particle transport characteristics in three-phase gas-oil-sand flows
- To compare experimental data with proposed model predicted results and existing empirical correlations.

PROJECT STATUS

- Experimental work has been completed
- Development of a phenomenological model has been completed. The model can estimate sand particle transport characteristics (particle velocity and holdup) and pressure drop in the three-phase gas-liquid-solid pipe flow systems
- Proposed model results are compared with experimental data. Experimental measurements are also compared with model results, empirical correlations and semi-mechanistic equations
- A PhD dissertation has been completed

SUMMARY OF RESULTS

Sand particle transport is of considerable interest for three-phase gas-liquid-solid flow management in many sand management well completion applications. While liquid-solid hydrodynamics have been studied in the past, knowledge of sand particle transport in two-phase gas-oil flows is very limited for vertical wells, and even less understood for horizontal and inclined wells. Using the principles of mass and momentum conservation with constitutive models, a phenomenological model is developed and presented. The governing equations are numerically solved using the fourth order Runge-Kutta method for the in-situ particle velocity, particle holdup, slip velocity and pressure drop. A detailed experimental study on sand particle is conducted using the TUC petroleum engineering institute multiphase flow loop covering vertical, inclined and horizontal pipe configurations. A broad range of sand particle loading is investigated using 0.02% to 3.0% of the liquid flow rates. Two-phase air-water flow patterns are identified using visual observation and video analysis of flow images of the vertical, inclined and horizontal pipe configurations.

Experimental results are presented in the form of graphical plots showing the variations of the sand particle velocity or holdup versus superficial velocities at different sand particle loading rates for the two-phase air-water flows in the vertical, inclined and horizontal pipes. The experimental results show that the distribution of sand particle velocity and holdup are not uniform along the axial direction in the three-phase air-water-sand pipe flow systems. Moreso, the sand particle velocity in the air-water slug flow is signifcantly higher than that in the bubble, dispersed and liquid pipe flow systems. For a sand particle with an equivalent particle diameter of the order of 0.0006m and pipe diameter of 0.04m, the ratio of particle velocity to gas-liquid mixture velocity is roughly 0.58. the ratio increases with decreasing particle diameter. The experimental data are used to verify results from the proposed phenomenological model. The new model is capable of estimating the sand particle velocity and holdup within an error index of 15% in most cases. In addition to the new model, two other existing correlations performance characteristics are also evaluated using the new and existing experimental data. The proposed phenomenological model provides the best overall predictions of the sand particle characteristics.

CONCLUSIONS AND PRACTICAL APPLICATIONS OF THIS RESEARCH

The major conclusions from the experimental and theoretical studies are as follows:

- Visualization of the internal flow structure and video analysis provided a better understanding of the transport processes influencing the particle motion. It also reveals that variation of key operating and geometric parameters that could be used to control solid phase hydrodynamics during three-phase gas-oil-sand production operations

- Particle transport characteristics in steady state gas-oil-sand multiphase production and well systems can be described using one-dimensional phenomenological modelling approach with closure equations. The proposed model is general and unified, which can be applied to three-phase gas-liquid-solid flows as applied to production, gas-lift and aerated fluid sand unloading problems

- The proposed model shows better performance over a broader range of system, operating and geometric conditions compared with the existing state-of-the-art methods. The model can be applied within an error index of 15%.

- Implementing the research finding will lower the costs of sand deposition problems in multiphase production operations, thereby encouraging operators to keep sand management wells and to initiate new three-phase gas-oil-sand pipeline projects despite sand transport issues

- The research findings may also help regulatory agencies to improve guidelines for design and operation of three-phase gas-oil-sand flowline and well systems

FUTURE WORKS

There are currently no engineering or research tools for investigating and classifying transient characteristics (behaviour) of three-phase gas-liquid-solid flow find in deepwater drilling (dual density drilling) and production riser systems.

Formulation of advanced dynamic (predictive and classifying) models for three-phase gas-liquid-solid deepwater drilling and production riser system design and performance analysis will help develop a real-time tool to for assessing and optimizing deepwater drilling and production system conditions. These ultimately help prevent or avoid severe and catastrophic deepwater drilling and production system instabilities with its huge financial implications.

A few of the promising research directions to address the aforementioned issues are listed in form of topics as follows:

- Investigation of the impact of high pressure and/or high temperature on bubble transport, particle transport and hydraulic characteristics in a large-scale three-phase gas-oil-sand flow test facility

- Development of hydrodynamic models for three-phase gas-liquid-solid pipe flows two-dimensional steady state and one-dimensional transient state conditions)

- Integration of hydrodynamic equations with thermodynamic model (PVT properties of gas and liquid as a function of pressures and temperatures)

- Simulation of the coupled hydrodynamic-thermodynamic models using finite element method (MATLAB-based)

- Verification and validation of the overall performance of the model (capability for predicting pressure, phase velocity and phase volumetric fraction distributions under transient operating conditions) with comparison to published experimental data, published field data and published existing models

- Parametric study to gain insights of the impact of various parameters (system, operating and design variables) on pressure, phase velocity and phase volumetric fraction profiles

- Demonstration of field applicability of the new tool

PUBLICATIONS

Bello, O. O., Reinicke, K. M. and Teodoriu, C., 2008a, Prediction of flow regime effects on the particle velocity in three-phase production and well systems. Canadian International Petroleum Conference/SPE Gas Technology Symposium, June 17-19, 2008, Calgary, Alberta, Canada.

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