Turbulent Dynamics of Particle-laden Pipeline Flow

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Abstract

Multiphase, multicomponent flow is a common occurrence in oil transport and handling processes. This regime of multiphase flow is a relatively poorly studied flow condition, and one largely based on empirical fits to limited data. As a start on a more complete understanding, two-phase experiments consisting of solid/liquid suspensions have been conducted to study the detailed turbulent flow behavior of two-phase multicomponent flow (liquid/solid), and their resulting coupling effect on the equivalent single-phase flow. Advanced quantitative imaging techniques of particle image velocimetry (PIV) for multiphase systems has been used to provide instantaneous measures of the constituent phase geometry, volume fraction, and velocity, which can then be averaged to examine the detailed turbulence properties of the flow and the important inter-phase transport terms in the equations of motion describing the system. Results of these measurements are used to explain the suspended concentration of particulates and their effect on the effective wall stress.

1. Introduction

Pipeline flow conditions for oil extraction vary widely with the reservoir fluid composition and geology. Often the flow can consist of immiscible liquids (oil/water), which can be further complicated by the presence of a vapor phase and/or solid particulates (sand, asphaltene aggregates, paraffins and diamondoids)[1]. For reliable and efficient fluid handling operations, one needs to have predictive capability for the frictional losses associated with these wide ranging conditions, as well as to be able to predict the occurrence of deposition or fouling and possible phase separation. Currently, such two- and three-phase flows are only qualitatively understood, typically in the form of regime maps and correlated pressure drop data that are guided by phenomelogical scaling models. A more comprehensive understanding of the flow is needed, particularly through studies which can examine the detailed interaction of the phases to help elucidate the momentum exchange mechanisms between the phases. Our laboratory has been conducting work to study the details of particle-turbulence interaction in liquid/solid suspensions, which we report here as a rational basis to move forward into later studies of two-phase, multicomponent conditions.

2. Experiments and Techniques

The experiments were performed in a transparent, horizontal, planar water channel with a height (2h), width and length of 4 cm × 36 cm × 488 cm, respectively. The measurements were conducted at a location approximately 60 cm upstream of the channel exit, allowing for a development length of over 100 channel heights. The channel flow was supplied by a 2 hp centrifugal pump, which emptied into a free-surface inlet settling chamber upstream of the channel. A stack of open-cell foam (pore size approximately 3 mm) and a stainless steel screen were used to provide uniform entrance conditions to the channel.

A two-phase PIV method[2] appropriate for studying dispersed solid/liquid flows was used to acquire data concerning the two phases. The technique utilized a single camera and a median filter to separate the images of the dispersed phase from those of the tracer particles for tracking the fluid motion, allowing for the simultaneous measurement of the velocity for both phases, as well as the location of the particles within the fluid.

3. Results

As can be observed, the particles are largely ejected from the near-wall flow by bursts of slow-speed fluid that appear as a characteristic of the so-called hairpin vortex structures that have been identified as the dominant coherent building block of turbulent channel flow. Figure 2 shows the effects of the particles on the carrier fluid motion, specifically a noticeable alteration in mean fluid velocity and in increase in the turbulent Reynolds stress approaching the wall, consistent with an increased skin friction associated with the particle loading on the flow. Examination of the particle-fluid cross correlation shows that the dynamic

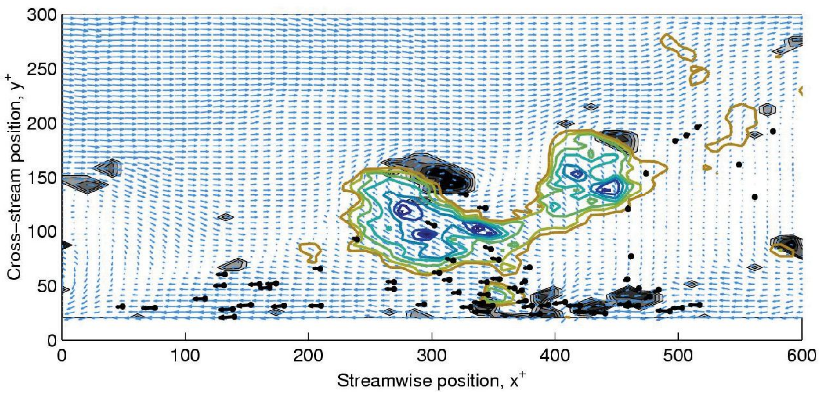
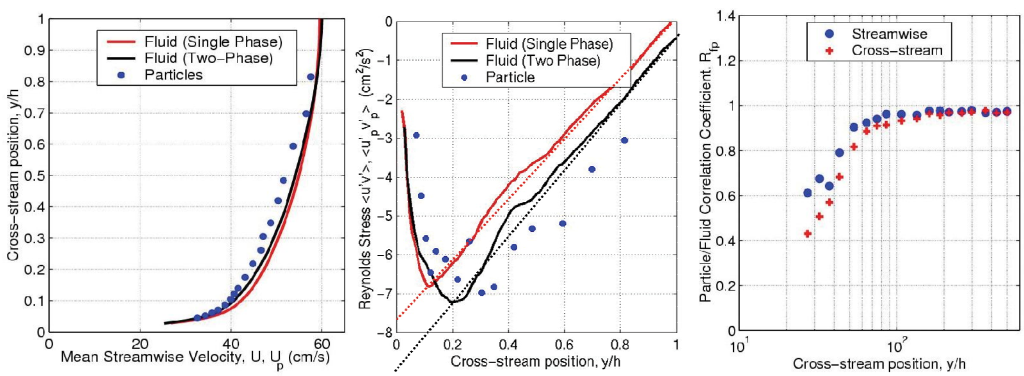


Figure 29. Instantaneous snapshot of fluid (blue) and suspended particle (black) motion. Color contours represent Reynolds stress while filled contours show local swirl strength.



a) b) c)

Figure 30 a) Mean velocity profile, b) turbulent Reynolds stress profile and c) particle-fluid cross-correlation coefficient.

momentum exchange is largely happening in the log-layer where the shorter time-scales of the fluid motion prevent the particles from following the flow completely. In the outer flow, the particles are observed to move as near passive tracers similar to a fluid particle, with the exception of a constant vertical drift velocity due to pull of gravity.

4. References

1. Escobedo, J., and Mansoori, G. A., "Solid Particle Deposition During Turbulent Flow Production Operations," SPE paper #29488, *Production operation symposium*, Oklahoma City, OK, April 2-4, 1995, pp. 439-446.
2. Kiger, K. T. and Pan, C., "PIV technique for the simultaneous measurement of dilute two-phase flows," *ASME J. Fluids Eng.*, Vol. 122 (2000), pp. 811-818.

Author Biography

Dr. Kenneth T. Kiger received the B.S.A.E. and M.S.A.E. degrees from the University of Southern California, Los Angeles, in 1991 and 1993, respectively, and the Ph.D. degree in applied mechanics from the University of California, San Diego, in 1995. In 1995, he joined the faculty of the Department of Mechanical Engineering, University of Maryland, College Park, where he is currently an Associate Professor. He has published more than 50 technical papers. His research interests include a broad range of fluid mechanics, heat transfer, and experimental techniques, specifically in the topics of multiphase flows, particle/turbulence interaction, and development of two-phase particle image velocimetry methods. Dr. Kiger is an associate editor for *Experimental Thermal and Fluid Sciences*, and a regular referee for the National Science Foundation, *Journal of Fluid Mechanics*, *Physics of Fluids*, *International Journal of Multiphase Flow*. He received the National Science Foundation CAREER Initiation Award in 1997.