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ERT investigation on horizontal and vertical counter-gravity slurry flow in pipelines

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Abstract

The occurrence of separation and slippage of the two phases in settling solid-liquid flow in pipelines make the flow unpredictable and time dependent. Therefore it is paramount for the operator of slurry pipelines to monitor and measure the flow continuously, particularly from the local point of view. This paper reports the laboratory experiments carried out on an open flow loop and the use of Electrical Resistance Tomography (ERT) to interrogate the internal structure of horizontal and vertical counter-gravity slurry flow. The use of high performance dual-plane ERT system, which is called Fast Impedance Camera System (FICA), is attempted for fast impedance measurement of the media with a temporal resolution up to 1000 dual-frames per second (dfps). The internal images of the pipeline are captured along with the measurement of solids volumetric concentration for both orientations, while the dual-plane ERT is combined with cross-correlation technique to estimate axial solids velocity distribution. A set of experiments was carried out on coarse and medium sand-water slurry flow with 2% and 10% throughput volumetric concentration and the transport velocity range of 1.5-5 m/s. A flow diversion technique was used for validation of mean local solids concentration and solids axial velocity obtained from the ERT.

Keywords: Settling slurry; horizontal pipe flow; vertical upward flow; Dual-plane electrical resistance tomography; ERT system; cross-correlation

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1. Introduction

Settling slurry flow in pipeline is encountered in many industries such as energy, chemical, pharmaceutical, petroleum, wastewater processing and mining industry. It is worth mentioning that in some specific applications, such as dredging, hydraulic transport is the only mean of transportation of solids through pipelines. These mixtures are transported through different pipeline orientations, mainly horizontal and vertical. It is a very complex flow and has attracted considerable attention of many investigators across the world. A wide range of experimental results have been reported in the literature including different operating conditions, material type and shape and different flow orientations. In horizontal flow as the gravity acts at right angle to the flow, the separation of phases occurs and gives rise to several flow regimes, pseudo-homogeneous, heterogeneous, moving bed and stationary bed. The description of each flow regime is detailed in literature [1, 2, 3, 4]. Whereas in vertical flow, especially upward flow, the gravity acts counter to the dynamic forces, as a result the slippage of the phases occurs [5]. The occurrence of separation and slippage of the constituent phases in settling solid-liquid flow in both horizontal and vertical pipelines makes the flow unpredictable and time dependent. Therefore it is paramount for the operator of these pipelines to monitor and measure the flow continuously, particularly from the local point of view, i.e. the knowledge of internal structure of flow is necessary, so as to ensure safe transport and maintaining acceptable control limits. In order to understand the internal structure of such flows solids volume fraction and solids velocity distribution are of great importance. Therefore, this study focuses mainly on qualitative and quantitative measurement of these two parameters.

In the past, several intrusive methods, such as traditional probes, have been used to measure solids volumetric concentration and velocity. The disadvantages of using these probes have been reported, particularly for solid-liquid flow [6]. It is highly unlikely that these devices can survive the harsh condition inside the pipelines due to abrasive nature of slurry. In many cases solids may accumulate around them and cause pipe blockage. Also it is well known that intrusive devices introduce an undesirable physical disturbance and alter the internal structure of the flow [7]. In order to overcome this limitation, researchers across the world developed a variety of non-intrusive measurement techniques to highlight the internal characteristics of two or multiphase flows, such as optical, ultrasound, nuclear, conductance and electrostatic transducers. Nonetheless, each of the above techniques suffers from serious limitations, especially for solid-liquid flows. For example, since slurries are opaque and flow through opaque enclosures, then using optical techniques can be quite difficult if not impossible. Although nuclear techniques provide an accurate measurement, they are very expensive and suffer from low temporal resolution and environmental issues [8]. Amongst all of the above techniques Electrical Resistance Tomography (ERT), as one of the family of non-intrusive sensors, has attracted the interest of many researchers. This is due to the fact that the ERT offers many advantages, such as non-intrusive, relatively low cost, no environmental restrictions, providing quantitative and qualitative on-line measurement, fast etc. Within the last two decades the ERT has seen a significant development and has been applied to many industrial process involving two/multiphase systems. Particularly the application of the ERT to solid-liquid flow has been reported by many investigators [9, 10, 11, 12, 13, 14]. All of the above studies have been carried out on vertical and/or horizontal flows used the conventional ERT system, which acquires up to 200 images per second [15]. To the authors' knowledge no attempt has been made to measure solids volume fraction and solids axial velocity using the combination of high performance ERT system in conjunction with cross-correlation technique. It is evident that measurement of the two parameters, especially velocity, in fast evolving processes requires high frame rates (fast) of milliseconds. Therefore, this study uses a high performance dual-plane electrical resistance tomography system, which is called Fast Impedance Camera System (FICA) and is capable of acquiring data at a rate of 1000 dual-