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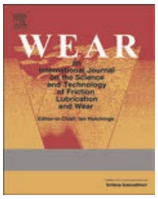

Ultrasonic measurements of sand particle erosion in gas dominant multiphase churn flow in vertical pipes

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ABSTRACT

Solid particle erosion can result in major pipeline failures, economic losses and more importantly safety and environmental issues. Erosion in multiphase flow is not widely understood and previous work has mostly focused on cases where the carrier fluid is single phase. There are different multiphase flow regimes, and amid them, churn flow appears frequently in piping systems such as risers, jumpers and flow spools. Furthermore, elbows have broad applications in the oil and gas industry, and they are subject to sand particle erosion damage. Therefore, the study of erosion in elbows, while the superficial velocities of the carrier fluids are in the range so that the flow pattern is churn flow, is of utmost importance. Experimental tests were carried out in order to investigate sand particle erosion in a 76.2 mm ID standard vertical–horizontal (V–H) elbow. A novel non-intrusive ultrasonic device was implemented to attain erosion patterns under different flow conditions. The effects of superficial gas and liquid velocities, particle size and liquid viscosity on erosion rate were investigated. The results are compared to the available data of erosion rates in a horizontal–horizontal (H–H) elbow with the same size of the elbow employed here. The most striking outcome to emerge from the comparisons is that erosion rates in the V–H elbow are significantly higher than those in the H–H elbow.

1. Introduction and background

The process of material loss of pipeline inner walls due to mechanical action is called erosion. In clean services, erosion can occur due to liquid droplets impingement [1,2]. In non-clean services, the presence of solid particles in flow is the main reason of the occurrence of erosion, since pipeline components can be severely abraded as a consequence of repeated solid particle impacts. Erosion can cause failure of pipes as well as other components found in production and transportation facilities eventually giving rise to financial losses and environmental problems.

Effects of particle shape, hardness and size on erosion have been discussed in the literature. It has been reported that particle shape can drastically alter the erosion rate by an order of magnitude [3]. Angular particles bring about higher erosion rates in comparison to round particles [4]. The impact angle which results in maximum erosion magnitude also depends on particle angularity [5]. When the target material is harder than impinging particle, erosion increases as particle hardness increases [6].

In general, an increase in particle size increases erosion rate [7]. A linear relationship between particle size and erosion rate has been reported [8–10]. Generally, an accepted form of the correlation between particle size and erosion rate is as follows:

$$\text{Erosion rate} \propto (\text{Particle size})^n \quad (1)$$

where "n" can acquire a value from 0.3 to 2.0 depending on particle properties, velocity and size distribution [11].

Various solid particle erosion mechanisms have been discussed in published materials. The literature survey of Meng and Ludema [12] highlighted four main wear mechanisms: cutting wear, fatigue (cyclic failure), brittle fracture (non-cyclic failure), and melting wear.

A variety of erosion equations incorporating a large number of physical parameters has been postulated by many investigators [13–18]. However, none of the available erosion equations can be considered as a general equation and their functionality is variable under different circumstances.

Carrier fluid viscosity has a significant influence on erosion [19]. Turbulence can enhance particles dispersion [20,21] and consequently affect erosion.

It can be concluded that erosion is a complex phenomenon, in as much as it is affected by many factors governing particle behavior. Amid these factors, particle shape, size, and material; fluid properties;

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particle impact speed and angle; and target wall properties might stand out above all.

The literature survey up to this point is related to the studies where there is just a single carrier fluid. When it comes to multiphase systems in which there are more than one carrier fluid, particles behavior is more complex and so is erosion. The reason being is the existence of different configurations in which different phases are distributed (flow regimes).

Previous experimental investigations concerning sand particle erosion and distribution in multiphase flow are reviewed here. Dosila [22] conducted a series of experiments to investigate the effect of superficial liquid velocity and pipe diameter on erosion rate in annular flow in standard 50.8-mm and 76.2-mm elbows. To measure erosion rate along the outer radius at the 45° position, Dosila [22] used an Electrical Resistance (ER) probe. Fig. 1 shows the effect of liquid flow rate on the measured erosion rates. The points with a superficial liquid velocity of zero belong to gas–sand flow. Dosila's [22] data show that the injection of a small amount of liquid into the gas–sand flow results in a significant decrease in erosion rate. Accordingly, erosion rate decreases as liquid flow rate increases. However, after a critical superficial liquid velocity (approximately 0.008 m/s), with an increase in liquid flow rate, erosion rate slightly increases. Understandably, erosion rates are higher in smaller pipes.

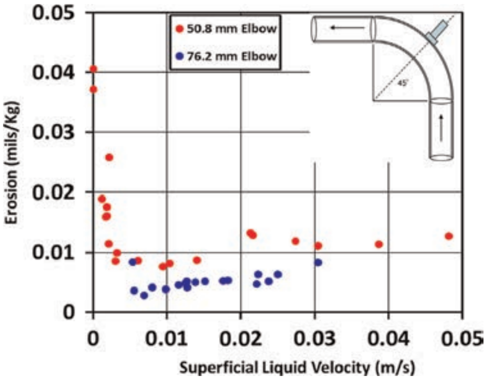

Fig. 1. Effect of superficial liquid velocity on erosion rate in vertical upward annular flow, $V_{SG}=29$ m/s, $d_P=150$ μm [22].

Fan [23] carried out erosion experiments in gas-low liquid flow in a 101.6 mm (4 in.) diameter pipe. He used 150 and 300 μm sands and employed two superficial gas velocities (15 and 23 m/s). Significant change in erosion rates was observed due to the addition of liquid to gas–sand only flow. Compared to horizontal flow experiments, higher erosion rates were obtained in vertical flow experiments for the same flow conditions. This was ascribed to the fact that more liquid droplets and sand particles travel in the pipe core in vertical flow in comparison to horizontal flow.

McLaury et al. [24] studied the effects of sand particle distribution on erosion in a 25.4 mm ID (1 in.) standard elbow in horizontal and vertical annular multiphase flow. They utilized different probes to carry out liquid and sand sampling in a pipe cross-section. It was shown that the distributions of the liquid and sands are nearly the same for all probe positions in both vertical and horizontal orientations. In other words, where there is more liquid there is more sand, suggesting that sand particles follow the liquid. They concluded that liquid entrainment can be used to estimate the entrainment of sand. While the distribution of particles is nearly uniform in vertical flow, in horizontal flow, due to gravity, there are more particles flowing toward the lower portion of the pipe where a slow moving film is present. The difference between erosion magnitudes in the vertical and horizontal configurations was attributed to the dissimilarities of sand and liquid distributions under these orientations. In all cases examined, they observed higher erosion rates in vertical flow compared to horizontal flow.

Vieira et al. [25] performed sand erosion measurements in low-liquid loading and annular flow conditions in a 76.2 mm ID (3 in.) standard elbow. The location of the maximum erosion was identified at 45° to the bend. Furthermore, it was found that erosion was an order of magnitude higher in vertically oriented elbows compared to horizontal elbows.

Kesana et al. [26] recently used a non-invasive ultrasonic measurement technique to evaluate erosion rate in horizontal slug/pseudo-slug flow in a 76.2 mm ID (3 in.) standard elbow. They employed 16 transducers to obtain erosion patterns on the elbow

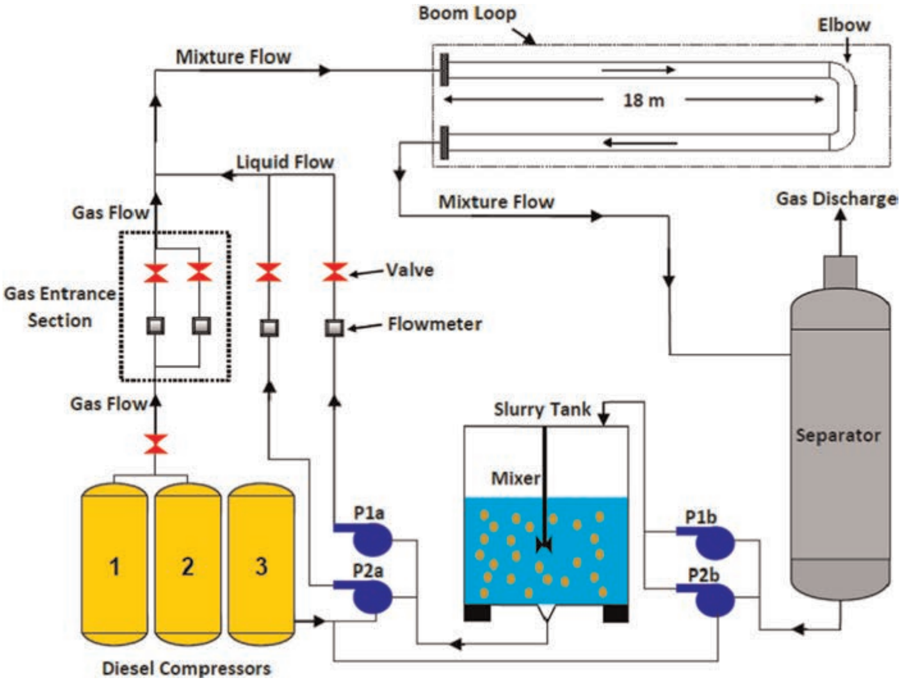

Fig. 2. Experimental facility.