

THE EFFECTS OF PARTICLE SIZE ON SOLID PARTICLE EROSION OF ELBOWS IN LOW LIQUID AND ANNULAR MULTIPHASE FLOWS

Ghulam Haider, Jun Zhang and Siamack A. Shirazi*
Erosion/Corrosion Research Center
The University of Tulsa,
800 S Tucker Drive
Tulsa, OK, 74104

ABSTRACT

During production of oil and gas, sand is produced as an unwanted by-product. Sand particles of many sizes carried by the multiphase flow can severely affect the integrity of fluid transportation structure such as pipelines, elbows, reducers and other pipe fittings. Sand production is managed via sand screens and gravel packs. These methods are successful in handling relatively larger sand particles. However, fine particles (< 100-micron size) can pass through most of these controls which can block the openings of sand screens which in turn causes higher velocities in other portions of the sand screen. Because of these higher velocities beyond the intended design velocities, the other portions of the sand screen become eroded, lose their effectiveness, and let larger particles pass through them. Furthermore, these small size particles cannot be detected with traditional acoustic monitoring techniques. Moreover, these small particles are highly susceptible to be entertained in high turbulent regions of flow and can cause severe erosion in those regions. Hence, it is critically important to understand erosion caused by small particles along with larger particles. This paper describes the effect of particle size on erosion. Small particle erosion is more severe in gas than liquids because in liquid there is a large momentum exchange with particles. The experimental setup consists of two elbows in series in a flow loop for horizontal and vertical flows. Paint-removal and erosion experiments are conducted in annular flow for different particle sizes as well as different superficial gas and liquid velocities for a 4-inch pipe. The effects of particle size on erosion are discussed with the validated CFD model and flow visualization experiments.

Keywords: Solid Particle Erosion, Fine Particles, Low Liquid Loading, Elbows

INTRODUCTION

Production of oil and gas from wells may contain solid particles such as removed scales or sand. Sand particles, present in this multiphase flow, can impact inner walls of transportation infrastructure (straight pipelines, elbows, T-junctions, flowmeters, valves, and reducers) multiple times. Moses et al.[1] showed this for a quarter-inch ball valve. The reduction of the wall thickness of process equipment because of surface degradation is known as solid particle erosion. This issue becomes increasingly challenging with the aging of gas wells as more sand gets detached from the reservoir and travels with the flow, in turn causing more damage to piping infrastructure. This damage requires more periodic maintenance which causes production interruptions. Moreover, the presence of sand particles in liquid dominated flows causes inaccurate prediction of multiphase flow which leads to inefficient production. In short, the

presence of sand particles in multiphase flow causes problems both from the design and operational point of view.

Accurate prediction of erosion pattern and erosion magnitude is needed in order to effectively manage sand particle erosion in multiphase flow. However, erosion resulting in multiphase flow is a complex phenomenon involving various variables such as flow pattern, sand size, the geometry of pipe, material of pipe and fluid properties. Among various multiphase flow regimes, annular flow is often observed in oil and gas production systems. This kind of flow regime has high gas flows at the center of the pipe and a liquid film is formed around the pipe wall. It has been shown that the mechanism by which the liquid droplets are entrained in the gas core may cause the sand particles entrainment as well. Hence, sand particles entrained in the gas core also move with high velocity and impact the inner walls of pipe geometry and can cause severe damage.

Literature is available to model solid particle erosion [2] [3] [4] [5]. However, literature lacks on specific studies addressing the effect of particle size on erosion. However, research efforts had been made in the literature to investigate the effects of particle size on erosion predictions. Viera et al. [6] [7] conducted extensive erosion experiments utilizing electrical resistance probes and non-intrusive ultrasonic measurement techniques to determine erosion pattern and erosion magnitude in stable and unstable annular flows in a 3-inch elbow. Parsi et al. [8] [9] [10] conducted CFD simulations for gas-liquid multiphase flows to gain insights into actual physical behavior in complex multiphase flow regimes such as annular, slug and churn flow. The goal of these works was to evaluate the accuracy of CFD in predicting the complex flow patterns such as churn flow and CFD simulations of fine particles for these flow regimes. These results were compared with the experimental results gathered by Parsi et al. [11] using wire-mesh sensors. Their investigation revealed that the Multifluid VOF model was successful in capturing various liquid structures present within the flow. Zhang et al. [12] studied slurry erosion rates in a sharp bend for small and large sand particles. This study concluded that CFD simulations overpredict the thickness loss due to fine particles by about one order of magnitude. Kumar et al. [13] conducted an experimental and numerical study for fine particle erosion in a choke geometry and three elbows in series. The flow was gas-sand. This study also resulted in over-prediction of thickness loss. This over-prediction of erosion rate due to fine sand particles is a result of turbulence on tracking the particle paths and inappropriate setup of CFD models. Mansouri et al. [14] conducted experimental and CFD studies on erosion patterns in a submerged direct impingement geometry. Furthermore, many studies have been conducted for elbow geometry as this is a widely used component for fluid transportation and is highly susceptible to erosion damage. Flow direction changes in elbows but due to insufficient drag between sand and fluid, sand particles do not follow the flow streamlines especially for large particles and impact the elbow wall causing erosion. All these studies utilized gas-sand flows. Few studies have succeeded in predicting small particle erosion. The latest efforts by Zhang et al. [15] improved small particle erosion prediction by proposing a CFD-based erosion simulation guideline. But the studies are limited to particles in either gas or liquid flow.

In summary, the effect of particle size on erosion in annular flow has not been studied satisfactorily. The aim of this work is to investigate the effect of particle size on erosion predictions in annular flow.

RESEARCH METHODOLOGY

A systematic investigation (Figure 1) of this study starts with experimentation to visualize the erosion patterns via paint removal studies. These studies identify the location of maximum erosion for various test cases. The next step is to conduct thickness loss experiments. Information gathered from paint removal studies in terms of location of erosion hotspots is used here in this step. Ultrasonic thickness loss measurement sensors are placed on these hotspots to measure the pipe thickness. Thickness is measured before the experiment. An erosion experiment is conducted, and the wall thickness is measured again. The difference in the thickness (in mm) is caused by erosion. This thickness loss information can be converted into various measurement features for comparison and erosion modeling. Finally, the developed model can be validated in CFD.

EXPERIMENTAL PROCEDURE

Following are the details of the erosion test facility and test conditions. Large scale boom loop facility at the University of Tulsa's north campus was utilized to perform erosion experiments with small particles. A schematic of the test facility is shown below in Figure 2. The major components of this loop are the

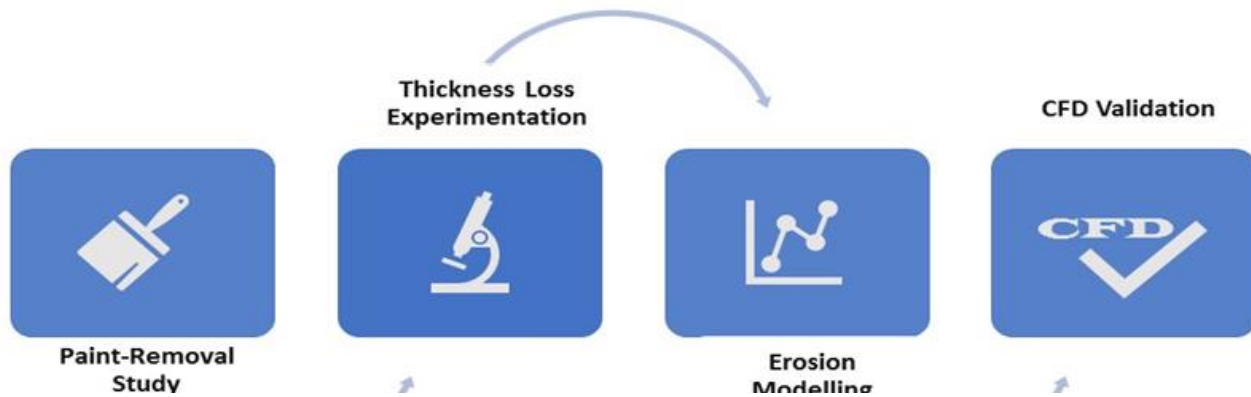


Figure 1: Research Methodology

slurry tank, diesel compressors, inclinable test section, diaphragm pumps, and separator. Compressed air is supplied by diesel air compressors which are used to develop the required gas flow velocity via a control valve in the flow loop as per test condition. The gas flow meter was measured by an electronic flow meter located between the compressors and the control valve. This flow rate along with the temperatures and pressures read directly from gauges mounted at the control valve (T1, P1) and at the elbow (T2, P2) were used to determine and control the gas velocity. After establishing the required gas velocity, slurry tank was filled with water. Water was introduced into the gas line via pump#1 and mixed with gas to form multiphase flow in the loop. The liquid flow rate and subsequently superficial liquid velocity were calculated by measuring the decrease of liquid volume in slurry tank for a given period. This multiphase flow pattern was observed in a transparent section of the loop. After the development of multiphase flow in the flow loop, sand was poured into the slurry tank. An agitator was used to keep the solution well mixed and prevent sand from settling in the bottom of tank. The sand concentration was varied as per test condition. This was a closed-loop set-up. In every pass, gas-liquid-sand mixture was returned to a separator where air was separated and discharged to atmosphere whereas the liquid-sand mixture was returned to slurry tank via pump#2 and the loop continued. Air and water were used as working fluids in all test conditions.

The elbows used for this investigation were of Stainless steel and were located 18 m downstream of the loop inlet. This large axial length was designed to ensure fully developed flow upstream of the elbow. Experiments were performed for 2-5 hours to remove measurable amounts of wall thickness.

The flow conditions for flow visualization and erosion tests are given in Table 1.

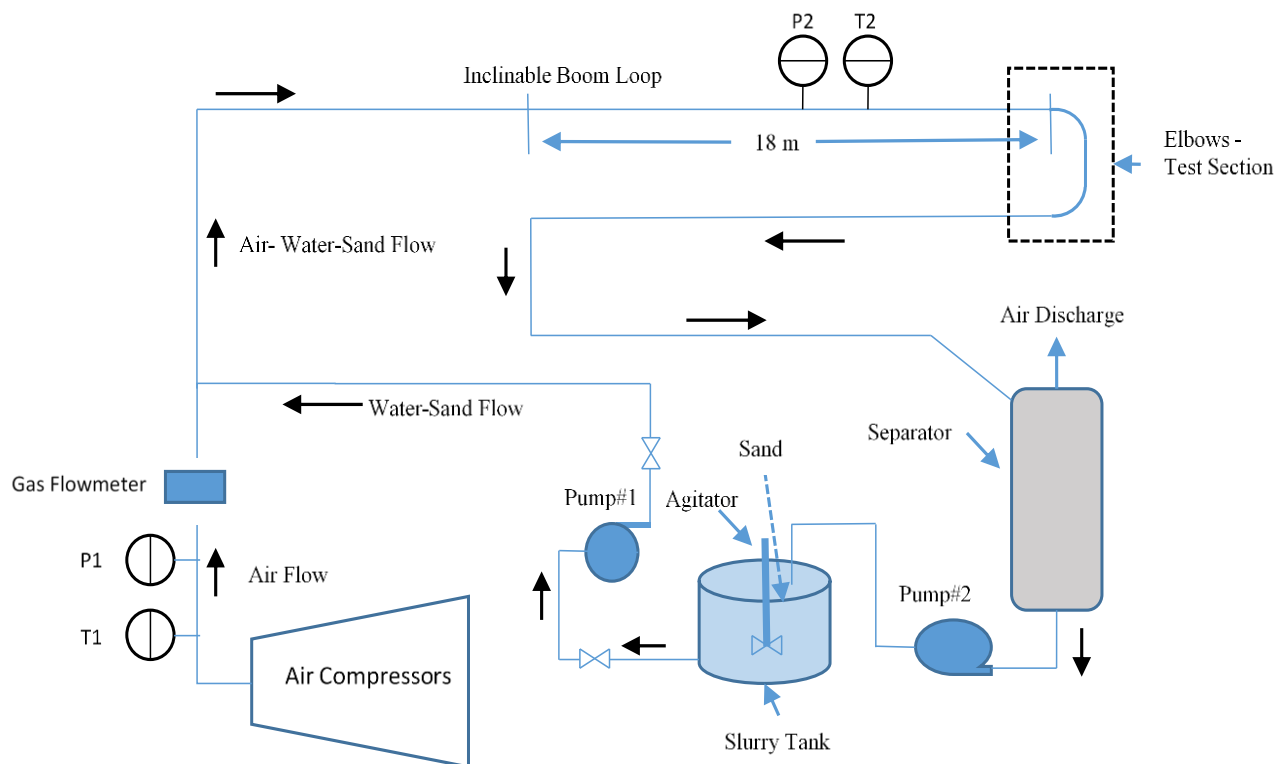


Figure 2: Schematic of the Experimental Facility

Table 1: Flow Visualization and Paint Study Conditions

Description	Particle Size (μm)	V_{sg} (m/s)	V_{sl} (m/s)
4-in elbow Zahedi (2018)	300	23	0.04
	300	31	0.05
4-in elbow Haider (2019)	25	31	0.04

RESULTS

Paint-Removal Study

To visualize the erosion patterns and qualitatively identify the locations of maximum erosion caused by particles (As described above), paint removal studies were performed. Two halves of a clear acrylic elbow of 4-inch diameter with a radius of curvature (r/d) of 1.5 were prepared (Figure 3). The inside of the elbow halves was painted with a light layer of primer. When these two halves are connected, they make the inner walls of the elbow. The idea is that paint is removed from those locations which are impacted the most by sand particles. Hence, those locations are directly correlated with the locations of maximum erosion.

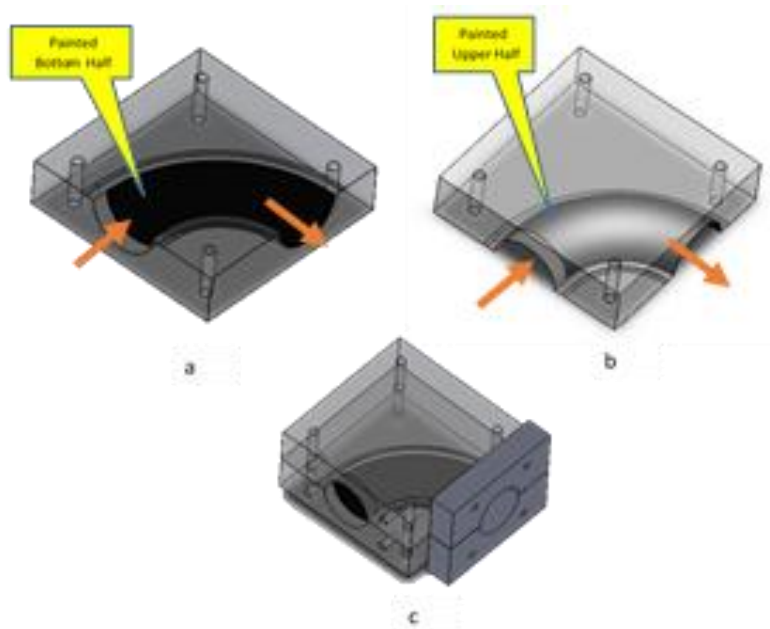


Figure 3: a) Bottom Half b) Top Half c) Complete

This paint removal study was conducted for 60-120 minutes for vertical loop orientation and paint removal pattern was recorded via a video camera. Comparisons of 300 μm large and 25 μm small particle erosion behavior via paint study are presented in Figure 4a-4d. These pictures show the evolution of paint removal patterns at different time intervals during the experiments. Comparing Figure 4a (gas only) to Figure 4b (with liquid), the addition of liquid leads to the formation of a liquid film around the elbow, which protects the elbow from particle impacts. Hence, paint-area removed by the gas-liquid-solid flow is significantly reduced as compared to gas-solid flow. Furthermore, liquid also affects particle trajectories under this low liquid loading condition. Unlike the gas-only condition, the severely eroded area is much less in annular flow due to the protection provided by liquid film.

Figures 4b and 4c present the effect of particle size on the erosion behavior under almost the same flow conditions. One interesting observation is that for the 300 μm particles for both cases shown in Figures 4a and 4b, the paint removal patterns start from the center of the elbow on the outer radius. But for the 25 μm particles, the paint removal pattern appears to start from two sides adjacent to the center and the paint removal pattern is initially more spread than the 300 μm particle results. Similar observation is seen in the CFD results as discussed below. Hence, 25 μm shows dispersed erosion patterns with two relatively long tails on each side of the elbow centerline. This may be due to the lower momentum of small particles that are unable to penetrate through the film to remove the paint as is the case for 300 μm . This results in different erosion patterns.

Figure 4d shows the final paint removal pattern at the end of experiment¹. The paint study provides valuable information on how the size of the particle and the addition of liquid affects erosion behavior in a 4-in elbow.

¹ Experiment run time was approximately 2 hours.