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Failure analysis and erosion prediction of tee junction in fracturing operation

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A B S T R A C T

Erosion wear in piping is an unavoidable degradation process in the oil and gas industry that causes pipe wall thinning and leads to economic losses and potentially produce personal injuries. The mechanism of pipe erosion remains poorly understood. This study focused on predicting the erosion of a tee junction (T) under various flow types during fracturing operation. The failure analysis of tee junction was determined from its macroscopic features and scanning electron microscope (SEM) images and allowed definition of the failure mode and failure mechanism were defined, which appeared to be significantly different from what has been considered to be traditional. The failure analysis and fluid mechanics theory were used to build a computational fluid dynamics (CFD) simulation method to predict the erosion of the tee junction. The model of two-phase flow in a tee junction indicated that the solid-phase flow is determined by combined effects of the main tube flow, the flow inertia, and the turbulent flow. The distribution of the erosion in the tee was significantly different for various flow types and the simulation results were consistent with the results of the failure analysis. This model of predicted local distribution of erosion wear can assist the monitoring of pipe walls to prevent accidents and reduce maintenance labor.

1. Introduction

As one of the primary mechanisms of material degradation, slurry erosion wear occurs frequently in process industry, which can result in equipment failures, economic losses and -even safety and environmental issues. Hence, the determination and prediction of erosion wear under different operating conditions is important (Parsi et al., 2015; Mazumder et al., 2008). The tee junction is the main transport pipe fitting used in pipeline ground equipment and the failure rate of these components due to erosion and perforation is increasingly annually (Edwards et al., 2001; Shah and Jain, 2008). The tee junction and elbow of high pressure manifolds in fracturing operation are shown in Fig. 1. In hydraulic fracturing operation, the high speed fracturing fluid carrying proppant (Fig. 2) can cause serious erosion destroy on the inner surface of pipes and other fracturing tools, leading to material loss and equipment failure (Fig. 3). As the flow types in the tee junction are more complicated than in the elbow, it is highly important to accurately forecast erosion wear distribution in the tee junction and determine appropriate monitoring and investigative measures under various flow conditions to maintain the safety of high-pressure pipe joints.

Because existing methods for inspecting the wall thickness of pipelines are expensive, there is considerable necessity for an accurate model for predicting pipeline erosion rates under working conditions. Recent studies have focused primarily on erosion in pipe elbows (Duarte et al., 2015; Macchini et al., 2013; Solnordal et al., 2015; Vieira et al., 2014). The research on measuring erosion wear in tee junctions still insufficient, compared with the elbow in process industry.

Charron and Whalley (1995) investigated the gas-liquid annular flow at a vertical tee junction. Some mechanisms of flow separation at a vertical tee junction with a horizontal outlet are examined in single-phase and two-phase annular flows. The predictions of several flow separation models are compared with the present data and the validity of some assumptions made in mechanistic models

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Fig. 1. The high pressure manifolds in fracturing operation.

is reviewed in relation with the observations provided by the present experiments. Brown (2002) examined erosion predictions in slurry pipeline tee-junctions and developed a 3-D computational fluid dynamics model to predict the motion of caustic liquor and bauxite particles through a tee-junction. They employed an Eulerian-Eulerian continuum approach in conjunction with the k-e turbulence model and the results demonstrated the effectiveness of the CFD techniques used to analyze industrial erosion problems. Zhang et al. (2013) examined the erosion of pipes and tee joints experimentally and with computational fluid dynamics analysis to predict erosion behavior in high-pressure pipe and tee geometries that are highly susceptible to erosion. The model effectively predicted the distribution of the wear sites that agreed well with the actual measurements in the plant. Chen et al. (2006) investigated the relative severity of erosion of plugged tees and elbows in dilute gas/solid two-phase flow conditions where the pressure was close to atmospheric pressure. A computational fluid dynamics-based erosion prediction model was used to predict the relative severity of the erosion. Experimental tests were conducted to verify the simulation results for gas/sand flows. Costa et al. (2006) studied the edge effects of the flow characteristics in a 90° tee junction. Measurements of a pressure drop were conducted for the flow of a Newtonian fluid in a 0° tee junction with sharp and round corners. The research shows rounding the corners reduced the energy losses by 10% and 20%, depending on the flow rate ratio due to the reduction in the branching flow loss coefficient, but the straight flow was unaffected. Lin et al. (2014) used an experimental method to predict the relative velocity factor of advanced internal tee erosion and the interaction between the velocity and erosion.

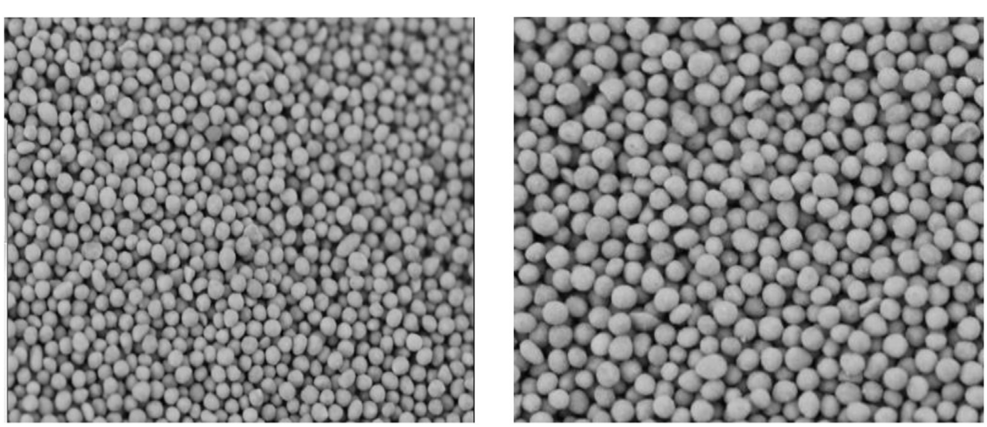
As mentioned in the above literature, despite the large volume of fracturing jobs performed in the industry today and the slurry erosion in pipeline systems of different geometry has been studied well by CFD so far (Graham et al., 2009). Research on the study and evaluation of slurry erosion in tee junctions remains insufficient, because:

- Different working conditions and varied pipeline materials lead to significant differences in erosion wear. The current results are limited to specific working conditions or structured pipelines. In addition, there has been little research on how the proppant present in the fluid influences pipe erosion.
- Recent research has focused on elbows rather than tee junctions. This is because the working conditions for the tee junction are more complicated than elbows due to different types of flow. However, it is necessary to fully understand how these different flow characteristics within tee junctions affect the stability of these components.
- With the recent development of oil and gas field deep wells, extra-deep wells, and horizontal wells, the requirements for pipe safety have become more stringent. This problem has become more serious as a result of the adoption of higher fracturing pressures and higher quantities of sand in the slurry. These conditions have increased the need for better abrasion resistance and safety during fracturing operation.

Given the above problems, this study focused on predicting the erosion of the tee junction under various flow types in fracturing operation using failure analysis and numerical simulation, and the technical roadmap of research is shown in Fig. 4. This work makes significant contributions to improve the safety of equipment in oil and gas industry.

2. Failure analysis of tee junction

The manufacturing material of tee junction in our research is 30CrMo, which belongs to low alloy heat-resistant bolting steel. It has good mechanical properties and hydrogen resistance at high temperature after heat treatment methods of quenching and high temperature tempering. The research use the universal testing machine to make material mechanical testing, the data shows that



(a) **(b)**

Fig. 2. Different size of proppant particles in fracturing fluid.