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Experimental and numerical studies on corrosion failure of a three-limb pipe in natural gas field

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ABSTRACT

A bursting incident occurred in a three-limb pipe, having 16Mn steel for the main pipe and 316L + L416 composite metal for the branch pipe, in a natural gas field. The failure analysis was performed by means of inspection, experiments and computational fluid dynamics (CFD) simulation. The CFD results indicated the radical change in the flow characteristics inside the three-limb pipe due to its upright structure and the formation of a low vortex in the downstream near the junction, which indicated the condensation of water vapor containing high salinity. The condensed brine saturated with CO_2 adhered to the inner wall surface of the main pipe. In such a corrosive medium, 16Mn steel acts as an anode and is preferentially corroded due to galvanic corrosion. In addition, the downstream area, covered by low vortex, exhibited high shear stress and droplet impingement stress, resulting in an increase in flow erosion. Thus, the failure of the three-limb pipe can be attributed to the synergistic effect of galvanic corrosion and flow erosion.

1. Introduction

Recently, a lot of effort was being devoted to exploit the underground resources at a depth of a few kilometers because of the richness in oil and natural gas in the west of China. During the exploitation process, the natural gas accompanied by CO_2 and produced-water was derived from strata and then, was delivered to the separation plant by transmission pipeline for producing high purity natural gas. The raw natural gas obtained from the west of China contains approx. 7.4% water vapor, 0.1 MPa of CO_2 partial pressure and a chlorine ion concentration of 150,000 mg/L. In order to minimize corrosion, the material of the main pipe was 16Mn steel, while the branch pipe was selected composite pipe consisting of 316L stainless steel and L416 steel, respectively. The design idea of the 316L + L416 composite pipe is based on the reasoning that the good corrosion resistance of the inner piping material (316L stainless steel) and high strength of the outer piping material (L416 steel) could simultaneously be utilized. The structure of the three-limb pipe is upright-type with 90° connection between the branch pipe and the main pipe along the direction of the entrance. The flow rates of the branch pipe and main pipe are 5.3 m/s and 5.6 m/s, respectively, and the corresponding flow temperatures are 95 °C and 61 °C, respectively. The structure schematic of the three-limb pipe is shown in Fig. 1.

After 40 months of production, a bursting incident happened in the three-limb pipe. Moreover, 32 other three-limb pipes in this transmission pipeline also suffered serious localized wall thinning, with a thinning rate of approximately 3–8 mm/a. Visual

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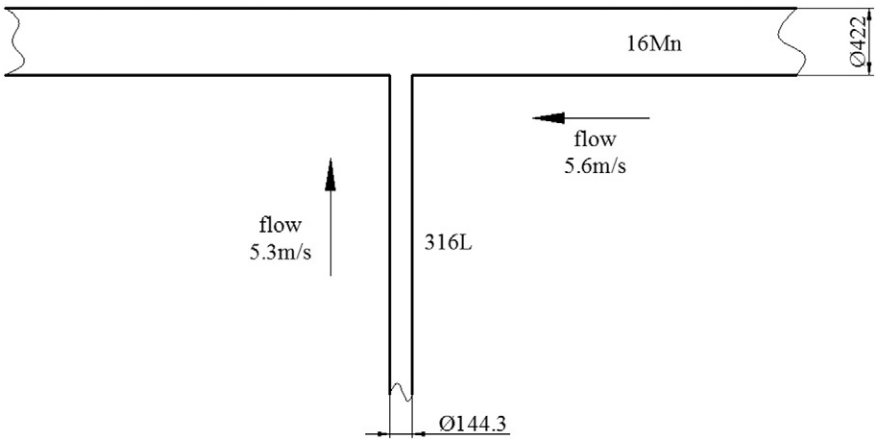

Fig. 1. Schematic of the structure of three-limb pipe.

inspections were carried out on the provided physical three-limb pipe specimen. A hole with a diameter of 8 cm was found to be located in the downstream of the failed three-limb pipe and 120° direction of the main pipe, as shown in Fig. 2. The obvious wall thinning area with the feature of hyperbolic shape was observed in the 30°–120° direction of the downstream main pipe near the fillet weld (Fig. 2b, c). However, very little wall thinning was observed on the outside wall surface of the main pipe facing the junction of the branch pipe (Fig. 2d).

Failures due to the degradation of piping material could induce serious economic loss and pose a threat to life and the surrounding environment [1,2]. Incidents of natural gas pipeline failures have been regarded as a catastrophe by the National Transportation Safety Board, USA [3,4]. Moreover, three-limb pipes, which are an integral part of the piping systems, are widely used as a means for convergence or separation of two pipe flows, changing the direction of flow and adding other chemical agents to the contents of the pipeline. Therefore, in the present work, experiments and computerized fluid dynamics (CFD) simulations have been conducted to study galvanic corrosion and flow erosion behavior through the three-limb pipe in natural gas transportation. The study is aimed to provide a more realistic and clear explanation of the failure mechanisms of three-limb pipe in the natural gas transport.

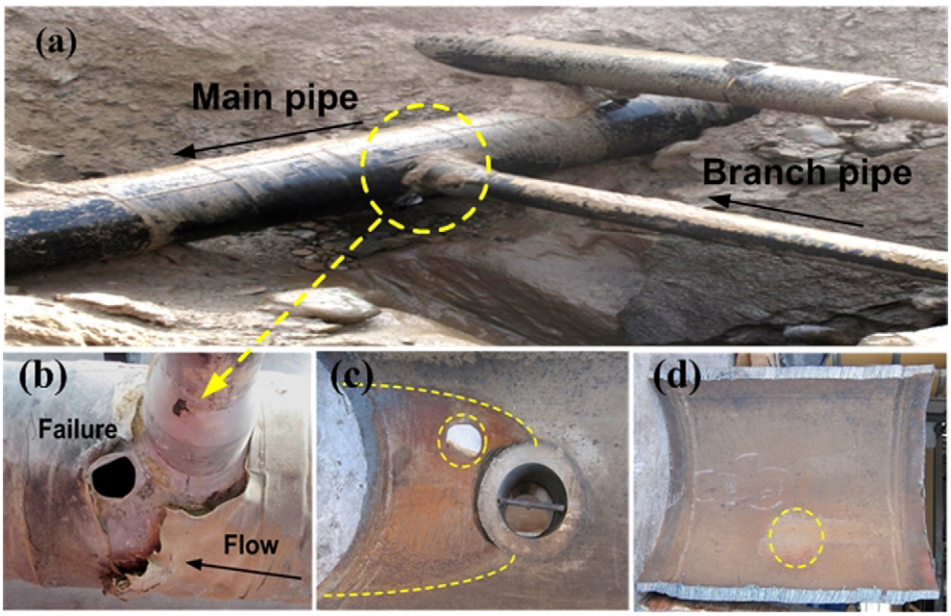

Fig. 2. Macro-photographs of failed three-limb pipe: (a) layout of main pipe and branch pipe; (b) bursting failure of three-limb pipe; (c) thinning area with the feature of hyperbolic shape in the downstream main pipe near junction; (d) outside wall surface of main pipe facing the junction.