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Flow enhanced corrosion of water injection pipelines

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ABSTRACT

A pipe spool from the subsea water injection piping network for oil operations at Eastern Desert was retrieved and internal corrosion and grooving were observed at the 6 O'clock position, in one section of the pipe, and not in the other. Two cuts from the sited piping were received for analysis to establish an overview of whether the failure is related to materials aspects or operating conditions. Results of visual inspection, chemical analysis, metallographic examination, SEM/EDX analysis, and mechanical testing showed that the corrosion resistance against flow for the quenched and tempered structure of the first cut was better than that of the cold rolled structure of the second cut. This is largely due to the uniform distributed polygonal ferrite and the small volume fraction of pearlite. Continuous removal of the loose adhered scales by electrochemical dissolution and mass transfer resulted in creation of fresh surfaces for further corrosive attack. This reduced the pipe wall below the critical thickness required to support the operating pressure and resulted in ductile failure of the pipe. Such mechanism of failure is known as the flow enhanced corrosion (FEC) mechanism. Failure in such mechanism is a catastrophic one that usually results in serious damage and injuries if not detected before undergoing.

1. Introduction

Water injection/flooding of the reservoir, is the primary method of enhanced oil recovery in Eastern Desert operations. There are two onshore water treatment plants at the site, where sea water is deoxygenated. These water plants then supply water to the various offshore fields via a subsea piping network. The piping network which was 1 km length is composed of seam welded pipes of 200 mm diameter and 11 mm thickness, was used for injecting the deoxygenated water with 10 MPa inlet pressure. Over the last few years, the pipeline has experienced numerous failures (extensive corrosion and grooving/rupture/holes at the 6 O'clock position). Recently, a pipe spool (24 m in length) was retrieved and internal corrosion and grooving were observed at the 6 O'clock position, in one section of the pipe, and not in the other.

The most common way to control corrosion in oil and gas lines is by chemical inhibition and addition of scale inhibitors in small concentrations in water to delay or prevent scale formation deposits [1]. Fluid flow has been reported to cause a type of erosion of a surface through the mechanical force of the fluid itself. This process is called impingement, where flowing fluid causes high wall shear stress which can remove the loose adhered corroded surface layer on the metal surface. Such erosion can take place in case the fluid is forced to turn its direction at pipe bend or when high shear stress exists [2,3]. The low velocity flow allows loose adherent solid corrosion products to form on metal surfaces and allows debris to collect, which facilitates further corrosion damage. In closed systems, if a corrosion inhibitor is used, its effectiveness is often reduced where the water is stagnant or quiet. Swift-moving water may carry dissolved metal ions away from corroding areas before

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the dissolved ions can be precipitated as protective layers. Gritty suspended solids in water scour metal surfaces and continually expose fresh metal to corrosive attack [4]. In freshwater, as water velocity increases, it is expected that corrosion of steel first increases, then decreases, and then increases again. The latter occurs because erosive action serves to break down the passive state [5].

In absence of mechanical effect of flowing fluid, and the process was primarily a corrosion one enhanced by electrochemical dissolution with mass transfer, the failure does not proceed by erosion–corrosion but likely to proceed by flow enhanced corrosion (FEC). In practice, there may be some contribution from the mechanical factors that lead to removal of corroded scallops on material surface to become loose and flow out with the high velocity process fluid. This might accelerate the overall flow enhanced corrosion rate but would not become a factor for thinning by itself. FEC is affected by many parameters, like material composition, pH, dissolved oxygen content, pipe geometry, flow velocity, and temperature [6]. Laboratory tests have also shown that the fluid velocity required for mechanical removal of the oxide is higher than that required for dissolution of an oxide layer [7,8]. Components undergoing FEC have definite signature pattern of a wavy shape while in erosion corrosion, grooves and rounded holes are formed. The signature pattern cannot be defined in components where FEC degradation has just initiated. The signature patterns become evident only after the degradation has occurred to a large extent. Erosion corrosion can occur in metals and alloys that are completely resistant to a particular environment at low flow velocities unlike FEC degradation [8–11]. The present investigation will focus on discussing the failure cause of the water injection line and its mechanism of failure.

2. Experimental procedure

Two cuts from the lower half of the failed line i.e. 3–6 O'clock position, were received for investigation. Several types of tests were performed, namely; visual inspection and non-destructive testing, metallographic investigation, chemical analysis, mechanical testing, SEM and EDX analysis.

3. Results and discussion

The two cuts contain no signs for weld lines but it was reported that the weld line was at the 10 O'clock position. Fig. 1 shows optical overview for the as-received cuts where black varnish coating exists over the external surface of the second cut and traces remained of the varnish still existed on the outer surface of the first cut.

The external surfaces contain no foreign materials and are not damaged either mechanically or chemically. The internal surfaces have no coating or foreign materials except for corrosion products with more aggressive attack in the first cut. Corrosion is more severe in certain areas of the two cuts in the form of grooves, recesses, scales, and pitting. Thinning took place from the inner surface and the maximum reduction in thickness inside the grooved portion of the first cut is (53%) higher than that of the second cut. Fig. 2 shows stereographic views for the internal surfaces of the two cuts. The inner surface contains shallow recesses filled with brown oxides. These recesses are surrounded by loose adhered scales. This observation suggests the combined action of both corrosive environment and aggressive flow.

Fig. 3 shows polished and etched micrographs for a specimen from the first cut. The polished structure contains linear inclusions and the inner surface contains several shallow-wide recesses and pitting.

The etched micrograph shows very fine structure consisting of polygonal ferrite and tempered pearlite with bianite and some precipitates of carbides. This also is shown in the SEM image of Fig. 4.

Fig. 5 shows polished and etched structure for a specimen from the second cut. The structure of the as-polished specimen shows grooves and recesses. The etched structure shows typical ferrite–pearlite bands in the as rolled condition.

Table 1 shows the results of chemical analysis for both cuts, from which it can be noticed that the carbon and sulfur contents of the first cut were lower than those of the second cut suggesting better performance in resisting corrosion.

Measurement of mechanical properties for the two cuts was performed by using both tensile and hardness tests. Table 2 shows the results of tensile and hardness tests for both cuts.

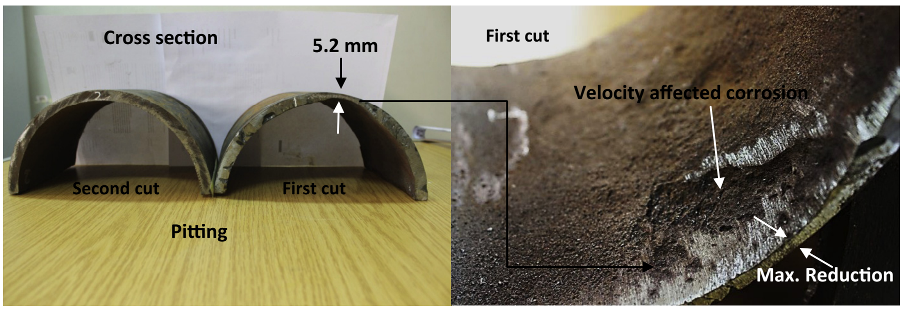

Fig. 1. General views for the as-received pipe cuts.