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Localized pitting corrosion of API 5L grade A pipe used in industrial fire water piping applications

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ABSTRACT

In this present paper, failure analysis is conducted for a pipe used in fire water applications. In petroleum industries many failures were observed in API 5 L grade steel pipes. The past inspection history records were observed, which reveals that failed pipeline is poorly maintained since construction. Visual inspection, macroscopic and microscopic examinations were conducted for the failed pipe. The microscopic analysis reveals that the pitting corrosion is a root cause of failure which perforates the wall thickness at 6′o′ clock pipe position. The mechanism of pitting corrosion is correlated with ferrite matrix dissolution. The Cu, Co & Zn ions were detected in scale deposits reveals that the fire water is severely contaminated by various makeup water sources which results in under deposit corrosion. The various sources of foreign elements are discussed in detail. The copper deposits identified at suspected location attributed to galvanic corrosion. Moreover, the severity of pitting is aggravated by grain boundary attack which acts as an anode during corrosion process. Based on various experimental evidences, the conclusions were drawn and further recommendations are discussed to mitigate the corrosion failure.

1. Introduction

The corrosion of carbon steel is a critical concern for various major chemical processing industries particularly in fire piping network system. Although various pipe line materials are available in the market but still carbon steel is a candidate material for transporting chemicals, acids, hydrocarbon products and water. In processing industries 98% of pipelines are constructed from variety of tubular carbon steels. The allowable stress for carbon steel pipe is designed based on pipe wall thickness and it will be 0.4 times of specified yield strength (SYS) considering (FOS = 2.0) factor of safety [1]. After certain period of time, the wall thickness of the pipe gradually decreases uniformly throughout the pipe or in localized area due to corrosion leading to increase of hoop stress. These hoop stress mechanically react with pipe wall to produce bulging, buckling, deformation and rupture [2, 3]. The various causes for reduction in wall thickness of the pipe after certain time frame are due to corrosion, erosion, wear, mechanical dent or any of the above combinations. Many literatures were published regarding various pipeline grade materials. However, still carbon steel pipelines failures are pertaining in petroleum and petrochemical industries. These pipelines undergo several failures such as uniform corrosion [1], galvanic corrosion [2], erosion corrosion [3], pitting corrosion [2] and microbiological corrosion [4–6]. Also many authors have shown that corroded portion of the pipe was obtained in reduced wall thickness. Although, welding defect [7, 8], stress corrosion cracking and hydrogen cracking [9] cause serious damages in the pipe; they were not observed to reduce wall thickness.

The failure of fire water pipe line during an emergency may lead to uncontrolled situations resulting to social-economic losses. The fire water piping is a part of firefighting systems in petroleum refineries and petrochemical plants. For example, the fire water pipeline supplies huge amount of water which mixes with polar solvent compound in ratio of 97:3 to form foam at room temperature.

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Furthermore, the foam will be supplied in compressed manner to tank externals by sprinkler system. While spraying, the foam forms aqueous film layer on hydrocarbon source and insulate the fire from an environment containing oxygen, cooling the fuel to protect and control the fire in tank. The solvent compound is alcohol resistant in nature and fire water is supplied at room temperature. These tanks primarily contain any intermediate or final hydrocarbon products and fire source from these combustible hydrocarbon or petroleum based products is classified as class B fire. The recent advancements in automation system automatically supplies water and solvent to form foam in foam tank, and releases the foam if smoke detector detects any fire or smoke in or nearby tank location. Therefore, the pipeline carrying fire water mix with solvent to form foam will protect and control fire, and availability of these fire piping systems is extremely important to hydrocarbon industries round the clock. Frequent inspections and testing of these pipelines is a fundamental requirement in any asset integrity programmes of hydrocarbon industries. J Sorbel et al. proposed that frequent inspection of firefighting equipment's reduces the failure [10]. Yulong et al. established functional analysis system technique (FAST) through which he concluded that the fire equipment frequently failed during an actual emergency operation. In his paper he classified the firefighting equipment's as minor, major and significant emergency failures [11].

This paper focuses on metallurgical failure analysis due to poor maintenance of fire water pipeline made of carbon steel. In this case the cause of corrosion damage observed at the base metal of pipe is thoroughly investigated. The leak was observed at 6’o’ clock position of the pipe. The water flow was temporarily stopped after detecting leakage and water flushing was terminated. Subsequently the damaged pipe portion was replaced with new carbon steel material and the pipeline was again put to service. The sectioned portion of the failed pipe was examined further in detail through systematic root cause analysis for characterizing the damage features and to prevent similar failures in future. The detailed literature survey showed that corrosion product scale on top of pitting corrosion contains hematite (Fe_2O_3), magnetite (Fe_3O_4), goethite (FeOOH), wuestite (FeO), and calcite ($CaCO_3$) [2]. The literature survey also shows few reports on pit depth and its characterization using scanning electron microscopy. Zhiyong et al. investigated an isolated pit depth measurement in a failed gas pipeline [12]. However, literatures are limited for understanding a correlation between pitting mechanism across a transverse section of a pipe in fire water applications.

2. Background information

The water pipe line has failed for the first time since it was commissioned twenty years back. The entire fire water piping network was constructed with API 5 L Grade A carbon steel material. The material chemical composition and mechanical properties of the pipe were collected from a bill of material as a part of inspection verification programme given in Table 1 and Table 2 respectively. This seamless pipe was supplied from hot strip mill (hot rolled and normalized subsequently) of a steel plant. This pipe was produced via basic oxygen furnace (BOF) steel making route with a carbon equivalent (CE) approximately 0.253 max and then it was hot rolled. The carbon equivalent (CE) of a line pipe is obtained as stated in Eq. 1.

$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \tag{1}$$

The total pipeline engaged in fire water service within refinery facilities is approximately 50 km in length, with a dimensions of $\varphi 304.8 \times t\ 6.02 mm^2$. Welding procedure specification & qualification record of a pipe shows that the pipe edges are prepared for double V groove butt joint, subsequently welded by E-6010 electrode for root pass and E-7018 for remaining passes. Thereafter, each weld joints were accentuated to non-destructive tests (dye penetrant and radiography) and reports were stored. Further entire piping was subjected to hydro-test at 25 kg/sq.cm to assure a structural (welding) integrity and it was confirmed that neither leakage nor pressure drop was recorded during hydro test. Subsequently, a pipe was externally coated by zinc ethyl silicate primer of 160 μm, epoxy zinc phosphate of 160 μm and acrylic polyurethane of 120 μm serially to obtain 440 μm of total coating thickness. Similar coating was applied on internal surface of pipe. An external coating was applied to protect the pipe from atmospheric corrosion in an industrial atmosphere. Similarly, an internal coating was applied to avoid corrosion of pipe from fire water.

Each phase of pipe line construction complied with quality standards and there was no evidence of abnormality. However, poor maintenance was evidenced and inspection was never carried out on aforementioned piping resulting to leakage. On reporting of failure, it was confirmed from inspection history records that no prior inspection was carried out on entire pipeline of fire water network. The preliminary inspection on a leak pipe reveals that localized corrosion has attacked the base metal of the pipe but there was no abnormality on or near weld joint. Schematic representation of failed pipe within refinery complex is shown in Fig. 1. The corrosion allowance for the pipe is 1.5 mm and the design standard suggests replacement of the pipe if the thickness of the pipe is < 4.52 mm (critical wall thickness $t_{cr} \leq 4.52$ mm). In a suspected portion of the pipe the thickness was measured to be < 1.5 mm and hence replacement of failed pipe is recommended.

Table 1
Chemical composition of API 5L Grade A [1].

Elements weight percentage (%)	Carbon	Manganese	Phosphorous	Sulfur	Iron
ASTM Specifications	0.22 max	0.90	0.020 max	0.020 max	balance