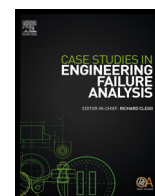


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# Case Studies in Engineering Failure Analysis

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## Case study

# Failure analysis of firewater pipeline

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## ABSTRACT

This paper presents the failure analysis of a fire water pipe line from a petrochemical industry. Leakages were noticed at the top portion of the pipeline. Severe deep pits were observed at the top inner surface and deposits found at the bottom inner surface of the pipe line. Visual inspection, microscopic examination, chemical and water analyses were employed in the present failure analysis. The analysis results showed that the failure occurred due to the severe oxygen corrosion attack at the top portion of the pipe while the bottom surface of the pipe suffered from under deposit corrosion. The fire water pipe line was made of low carbon steel.

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## 1. Background and introduction

A portion of the leaking pipe from the fire water system was received as representative sample from a Petrochemical Industry. This failure was occurred first time after commissioning the pipe water line system about 25 years. Leaking was noticed on the top side of the pipe as shown by arrow (Fig. 2). The material of construction of the pipeline is carbon steel. The pipeline is operated only twice a week during the call fire under a batch flow rate. Potable water is used in this fire system.

There are two identical storage tanks, 56 P6 and 56 P7, with two main pumps. Jockey pump which is located close to 56 P6 tank, plays major roles of this system as maintaining the constant system pressure and a continuous circulation of the water inside the pipe. Schematic diagram of fire water line piping system is shown in Fig. 1 and it is representing the two tanks, pumps and location of the leakages. These leakages were located only in the area after the discharge of the pump as reference 56 P7 tank.

## 2. Investigation

### 2.1. Visual examination

Fig. 2a and b shows the location of leakages of the water pipe line. The representative failed section pipe was received for investigation is shown in Fig. 3a. Visual examination revealed severe localized pitting attacks at the inner surface of the

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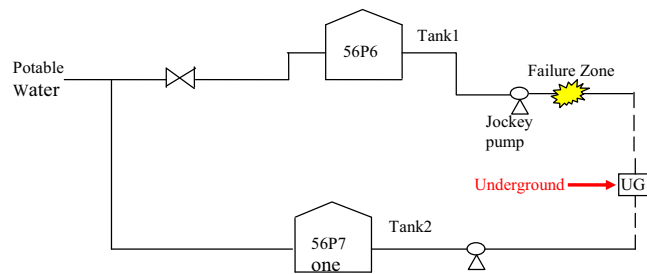


Fig. 1. Schematic diagram of the firewater piping system.

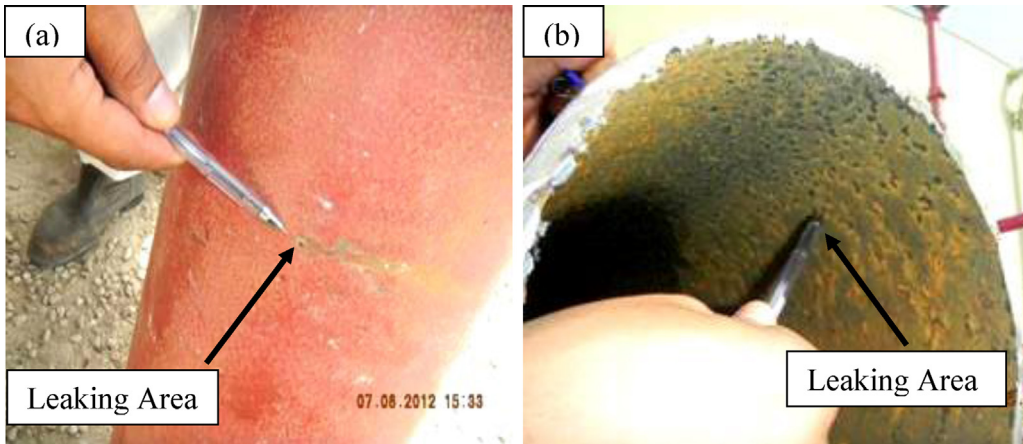


Fig. 2. Images showing the failed section of the pipe with the exact location of leakages.

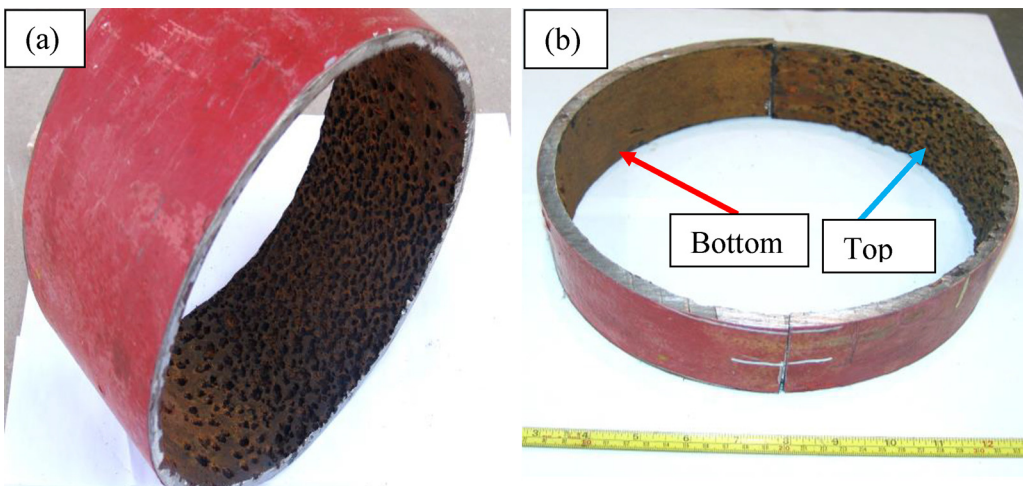


Fig. 3. Images of the sample received for investigation (a) failed section pipe, (b) two halves after cutting as top and bottom side by arrow.

pipe. These pitting attacks took place only in the upper half of the pipe inner surface between the 9 and 3 o'clock positions. Whereas, smooth deposits were observed on lower half of the inner surface of the pipe as shown Fig. 3b.

### 3. Microscopy analyses

#### 3.1. SEM and EDX analyses

##### 3.1.1. As received condition

Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX) techniques were used to analyze bottom and top inner surface of the pipe, using FEI Quanta 200 scanning electron microscope, Fig. 4a and b shows topography and elemental

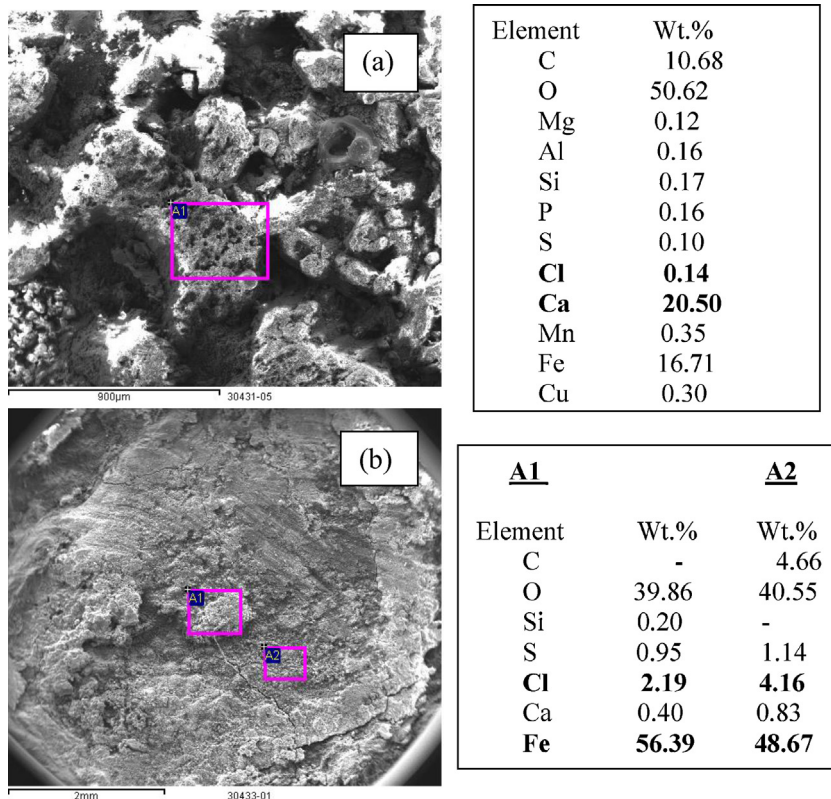


Fig. 4. SEM/EDX analyses for different locations on the bottom surface of the pipe.

compositions of the deposit formed on the bottom surface of the pipe, contains high amount of calcium and oxygen. Significant concentrations of Chloride ions (2.19 and 4.19 wt.%) were accumulated at the two areas within the corrosion product from bottom inner surface of the pipe is shown in Fig. 4c.

### 3.1.2. As polished condition

Further SEM and EDX analyses were performed on polished cross sections of samples previously prepared from the top and bottom surface of the pipe. Fig. 5a shows one area on the bottom inner surface of the pipe with cap of mound of corrosion product (iron oxide) covering the pit. Also, as confirmed by the EDX analysis, high concentrations of chloride ions were accumulated inside the pit, A2 location in Fig. 5a. SEM micrograph and the EDX results for the pit on the top inner surface of the pipe was shown in Fig. 5b, the result shows mainly iron oxides as corrosion product.

## 3.2. Metallography

Samples were prepared from top inner surface of the pipe line at different locations for metallography. Cross sectional views of the polished samples were revealed under stereomicroscope as shown in Fig. 6(a–b). Different shapes of pits were detected in inner diameter of the tube.

## 3.3. 3 XRF and XRD analyses

### 3.3.1. Pipe material

X-ray fluorescence (XRF) analysis was carried out to confirm the material of construction. The pipe material was found to be carbon steel within the specified range as shown in Table 1.

### 3.3.2. Deposit material

Both X-Ray Diffraction (XRD) and XRF analysis were carried out on deposit materials from the bottom inner surface of the pipe by Pan Analytical Instrument; the result is shown in Tables 2 and 3 (all tables are in separate sheet).

High percentages of Oxygen and Iron were found, suggesting Iron Oxide as a corrosion product. Also, 20.94 wt.% of calcium was detected. The XRD analysis reveals that the deposit material is a mixture of Magnetite ( $\text{Fe}_3\text{O}_4$ ), Calcite ( $\text{CaCO}_3$ ) and goethite ( $\text{FeO}(\text{OH})$ ), as well as high amount of oxygen, Table 3.

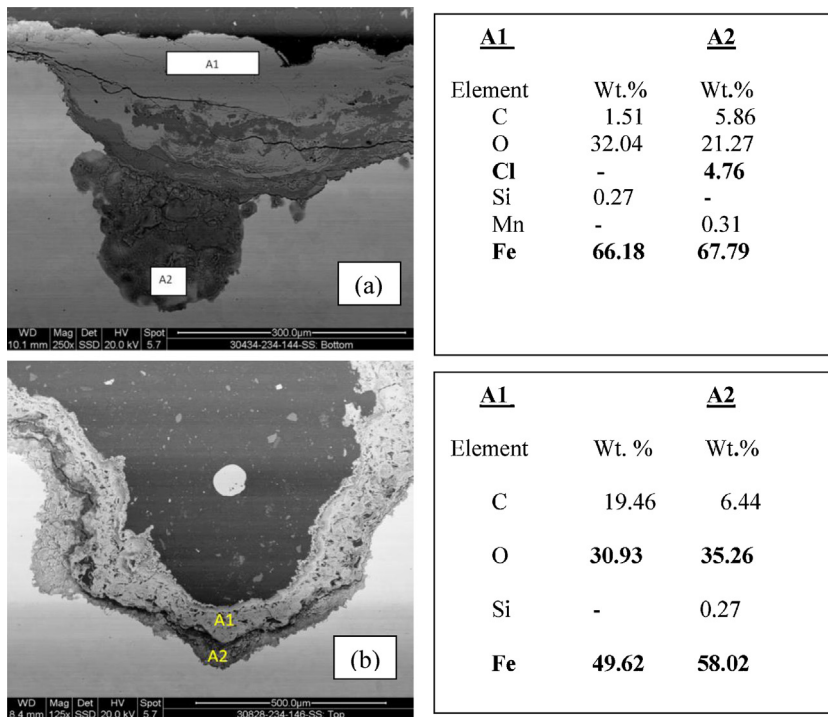


Fig. 5. SEM/EDX analyses for cross section (as-polished) at different locations of the pipe (a) bottom inner surface, (b) top inner surface.

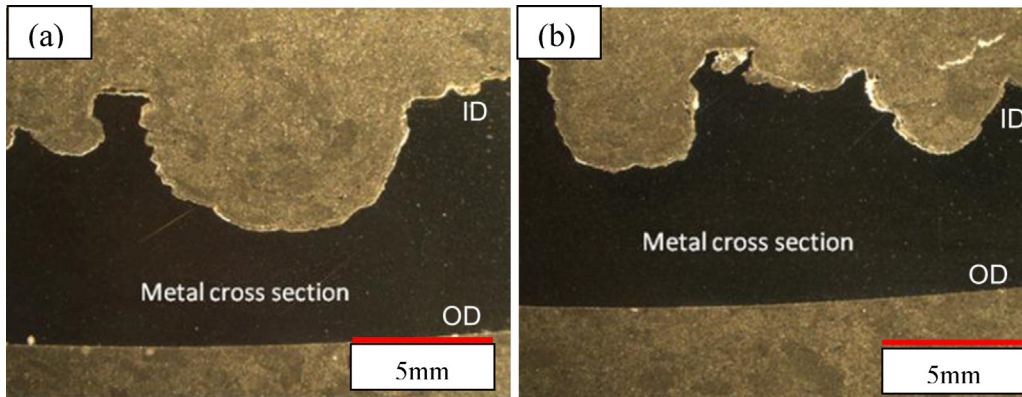


Fig. 6. (a–b) Shows stereomicroscope images at different location with different shapes of pits from top inner side of the pipe.

Table 1  
Material of construction identification by XRF.

| Element | Al   | Si   | P    | S    | Cr  | Mn   | Ni   | Cu | Fe      |
|---------|------|------|------|------|-----|------|------|----|---------|
| Wt.%    | 0.03 | 0.29 | 0.03 | 0.02 | 0.5 | 0.02 | 0.08 |    | Balance |

#### 4. Water analysis

Two water samples were collected from different locations in the firewater system as main potable water supply and fire water from 56 P7 tank. Both water samples showed similar physical and chemical properties, pH was 7.91, conductivity was in the range of 85–90  $\mu\text{S}/\text{cm}$  and hardness was in the range of 44–48 ppm. Detailed results are shown in Table 4 (Table is in separate sheet).

Chloride ion ( $\text{Cl}^-$ ) was very low in all the water samples, however calcium ( $\text{Ca}^{2+}$ ) was slightly high with about 17 ppm. Though, all these parameters are within the limits of the potable water specification.

**Table 2**  
Chemical composition of the deposits identified by XRF.

| Elements | Wt.%    |
|----------|---------|
| O        | 29.57   |
| Mg       | 0.09    |
| Al       | 0.13    |
| Si       | 0.13    |
| P        | 0.10    |
| S        | 0.16    |
| Cl       | 0.26    |
| K        | 0.01    |
| Ca       | 20.94   |
| Ti       | 0.013   |
| Cr       | 0.05    |
| Mn       | 0.24    |
| Fe       | Balance |
| Co       | 0.01    |
| Ni       | 0.04    |
| Cu       | 0.09    |
| Zn       | 0.14    |

**Table 3**  
XRD results for deposit collected from the bottom surface.

| Semi quant  | Compound name | Chemical formula               |
|-------------|---------------|--------------------------------|
| Major phase | Calcite       | CaCO <sub>3</sub>              |
| Major phase | Magnetite     | Fe <sub>3</sub> O <sub>4</sub> |
| 9           | Goethite      | FeO(OH)                        |
| 4           | Wuestite      | FeO                            |

**Table 4**  
Results of water sample analysis collected from different location of the fire water pipe line.

| Parameter                                | Unit  | Potable water supply | Fire water 56P7 |
|--|-------|----------------------|-----------------|
| pH                                       | –     | 7.91                 | 8.13            |
| Conductivity                             | μS/cm | 88.0                 | 86.0            |
| Hardness                                 | ppm   | 44.0                 | 46.3            |
| <i>Anions</i>                            |       |                      |                 |
| Chloride (Cl <sup>-</sup> )              | ppm   | 2.4                  | 2.1             |
| Nitrate (NO <sub>3</sub> <sup>-</sup> )  | ppm   | ND                   | 0.36            |
| Sulfate (SO <sub>4</sub> <sup>-2</sup> ) | ppm   | 0.3                  | 0.2             |
| <i>Cations</i>                           |       |                      |                 |
| Sodium (Na <sup>+</sup> )                | ppm   | 3.9                  | 4.2             |
| Magnesium (Mg <sup>+2</sup> )            | ppm   | 0.2                  | 0.2             |
| Calcium (Ca <sup>+2</sup> )              | ppm   | 17.2                 | 18.2            |

## 5. Discussion

At ambient temperature, water of neutral pH containing and with no dissolved oxygen is not regarded as a significantly corrosive to the iron or steel material [1,2]. However, when oxygen is trapped within the water system, it becomes available and reacts with the metal surface. As a result of this reaction between the dissolved oxygen and the metal surface, the metal dissolve into the water and leaves a void in the metal surface or the metal immediately forms a corrosion product which in the case of iron and steel is commonly known as rust [2].

Mostly, the chemical reactions (anodic and cathodic) that are occurred in the *near neutral pH water system* are as follows:

Anodicreactions :  $\text{Fe} \rightarrow \text{Fe}^{+2} + 2\text{e}^-$  (metaldissolutionreaction)[3]

Cathodicreaction :  $2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^- \rightarrow 4\text{OH}^-$  (dissolvedoxygenreduction)

The overall reaction of the above tow reactions will be:

$\text{Fe} + 12\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_2$

Excess of dissolved oxygen in the water causes the hydroxide(s) to oxidize further to produce final corrosion product, iron oxide [4,5].

In the present case, dissolved oxygen in the system accelerated the pitting corrosion of the top portion of the pipe. This was evidenced by the rusty appearance of most of the inner surface of the pipe and presence of pits/tubercles, classic oxygen corrosion features, along the lengths of upper inner portion of the pipe.

Hence, due to gravity effect, the corrosion product produced by the oxygen attack fell down to the bottom surface of the pipe. Analyses of the deposits collected from the inner surface of the pipe showed high amount of oxygen and Iron as iron oxides (corrosion product). Furthermore, high amount of calcium ( $\approx 20.94$  wt.%) that was detected suggesting that the deposit covered the bottom surface of the pipe was mainly corrosion product as iron oxide and calcium carbonate ( $\text{CaCO}_3$ ). Deposits can cause restricting water flow problems (water stagnancy) but corrosion, especially under deposit corrosion can lead to some significant damage of tubes. This type of corrosion occurs at sites where deposits allow a localized concentration of a specific chemical such as chloride or oxygen.

In the present case, deposition of corrosion product and other scale forming species at the bottom surface is an evidence of stagnancy in this area of the piping system due to lack of circulation of water through the pipe which led to a ring of orange and brown precipitated rust usually surrounds each pit [6]. Presence of any deposit forming particles in the piping system can cause and/or accelerate corrosion by forming oxygen depleted area under deposit, which can achieve anodic character compared to the adjacent area [2]. Consequently, corrosive attack under the deposit will become more aggressive and pitting attack of the pipe wall will occur.

## 6. Conclusion

The severe pitting attack at the top inner portion of the pipe was due to highly oxygenated water. While, the bottom surface of the pipe suffered from under deposit corrosion problem. The deposition on the bottom surface of the pipe is an evidence of stagnancy or a very low flow rate of water in this area of the system. No material upgrade is required as the carbon steel is suitable material for this application however, stagnant conditions or very low flow rates must be avoided. In addition, corrosion severity can be reduced by maintaining a proper circulation and flow rate in the system. As the corrosion took place in part of the fire system, appropriate inspection must be carried out for all fire water piping system. Also, special measures shall be made to check any plugging problem of sprinkler/nozzles in the system.

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