Investigation of Corrosion Behavior of Drain Pipes of Process Compressors in Direct Reduction Unit

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Abstract

Corrosion is a natural destruction process of industrial components. Process compressors were employed to meet the gas pressure and flow of the process in the direct reduction unit, while carbon steel pipes were used to separate water from the gas. However, the pipes were punctured and had water and gas leakage in a shorter time than the other units. In order to examine the destruction causes, several samples of the destructed pipe were studied by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The results showed that, in addition to regular factors such as high temperature and acidic medium, microbial corrosion by sulfate-reducing bacteria and H_2S gas worsened local and sub-sediment corrosion so that the component would be destructed in a shorter time. The presence of the FeS layer would result in severe local corrosion.

Keywords: Corrosion, Drain Pipes, Process Compressors, Direct Reduction.

1. Introduction

Sponge iron is produced in various ways, a common one of which is the direct reduction method, i.e., the Midrex method. In this method, the oxide pellet and reducing gas (H_2 and CO) enter the furnace from the top and bottom, respectively. The pellet's oxygen is removed by implementing reducing reactions, and sponge iron exists through the bottom of the furnace. Also, the exhaust gas, containing CO, H_2, CO_2, exits from the top of the furnace. The pressure of the exhaust gas declines to 0.3 bars; however, it is elevated to 2 bars with the help of three compressors. The water in the gas, as well as the water used to wash the compressor lobes, is transferred to the water and gas separation wells through plain carbon steel pipes and then is sent to the cooling tower system for cooling and reuse purposes. These pipes are subject to corrosion, and the unit should be switched off to replace the pipes [1)]. Corrosion can cause damage to equipment and machinery and impose exorbitant costs on repairs, leading to production and even human losses. The corrosion products, in the case of plain carbon steel, such as $Fe(OH_2)$, $Fe_2O_3(H_2O)$, $Fe_3O_4.H_2O$, and Fe_3O_4 , can undergo contact with oxygen and water. Although plain carbon steel is applied to most industrial equipment, it has a very high tendency to undergo corrosion, especially in acidic media [2-5)]. It is a suitable approach to use corrosion inhibitors in order to mitigate corrosion. Increasing the temperature would heighten the kinetic energy of the metal surface and reduce the adsorption of anti-corrosion substances onto the surface. The dependence of the corrosion rate on the temperature can be expressed by Arrhenius and transition state equations, according to which the

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corrosion rate increases as the temperature rises [6-10]:

$$\rho = \frac{RT}{Nh} exp \frac{\Delta S}{R} expRT$$

where ρ is the corrosion degree, R is the universal gas constant, T is the temperature, h is the Planck constant, N is the Avogadro number, ΔS is the activation entropy, and ΔH is the activation enthalpy. Microbial corrosion can occur in aqueous media. Most metals, including Fe, Cu, Ni, Al, and their alloys are somewhat sensitive to microbial corrosion. Only Ti and its alloys seem to be resistant to microbial corrosion. For instance, iron-oxidizing bacteria can make a 5-mm deep hole in a month within a 316 stainless steel container. Microbial corrosion is more complex than non-biological corrosion. Hence, there should be cooperation between a corrosion engineer and an industrial microbiologist to investigate such corrosion. The feed of the direct reduction furnace is an oxide pellet with up to 0.01% sulfur content in the chemical composition. The sulfur content engages in the process gas in the form of H_2S in oxide pellet reduction. It is worth mentioning that this gas is corrosive. Corrosion under fluid flow is a major challenge in oil and gas production as it would cause wall thinning and even pipeline perforation. Corrosion under fluid flow usually induces the premature failure of flow components, leading to oil and gas enterprise bankruptcy, tremendous pecuniary losses, environmental pollution, and security issues. The bend connects pipes to each other and changes the fluid flow direction. It is an indispensable component in the oil and gas field. When solid particles are subject to a corrosive flow medium, the pipelines undergo erosion and corrosion simultaneously, aggravating the erosion-corrosion (E-C) condition [12-17].

This study investigates the causes of the early destruction of the drain pipes of the process compressors in the direct reduction unit and seeks to develop a suitable solution to decrease the corrosion rate and pipe destruction. This challenge remains to be tackled in factories that produce sponges as it can interrupt production and impose high costs on the unit. Also, in addition to unit interruption, it can cause problems in other parts due to thermal doubts. Therefore, investigating the mechanism of this destruction can allow for avoiding interrupted production and such problems.

Materials and Methods

The perforated pipe was replaced in the monthly repairs of the unit, and several samples of the damaged parts were taken in the workshop. The sample preparation process attempted to avoid damage to corrosion products and sample surface. The samples were then sent to the laboratory for further analysis. Also, in order to study microbial contamination and analyze the water, a water sample drained from the pipes was sent to the laboratory. To investigate the destruction causes, the microstructure was analyzed by using the scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) techniques. In order to study the bacterial aspects, the sulfate-reducing bacteria (SRB) and total bacteria count (TBC) tests of the drained water sample were performed through the destructed samples. Then, the main test was performed.

Results and Discussion

Figure 1 shows the SEM images of the corroded sample. As can be seen, the formation of corrosion products is illustrated. Given the pipe material and EDX results (Table 1 and chart 1), the corrosion products include iron oxides. Furthermore, given the presence of sulfur in the gas, there are some compounds, including FeS, in the test results. These products cannot be protected from metal layer bitumen due to the lack of continuity and inadequate adhesion to the metal substrate. Therefore, they are peeled from the surface by inducing cracks on the substrate, leading to the local corrosion exposure of a new surface.

The SEM images indicate the other parts of the destructed area (Figure 2). As can be seen, there are colonies of the bacteria along with the corrosion products, indicating bacterial corrosion.

For further investigation, a sample was prepared from the water drained through these pipes and sent to the laboratory for microbial tests, as shown in Table 2. As can be seen, there were sulfate-reducing bacteria (SRB). Figure 3 indicates the SEM images of the samples after the removal of the corrosion products. According to Figure 3, there was severe corrosion underneath the metallic layer and many rough spots on the surface. The presence of pitting and local corrosion is clear. The input water to wash the compressor lobes had a pH of approximately 8 to 8.5, while the pH of the drained water was approximately 6. The input water temperature varied in the range of 25-35°C and increased up to 40-55°C after compression due to increased pressure. The increased temperature worsened the corrosion rate by raising the rates of the chemical reactions. It even greatly affected the efficiency of the corrosion inhibitors in the water, reducing their adsorption onto the surface and preventing the formation of a protective layer on the metal surface [6-9].

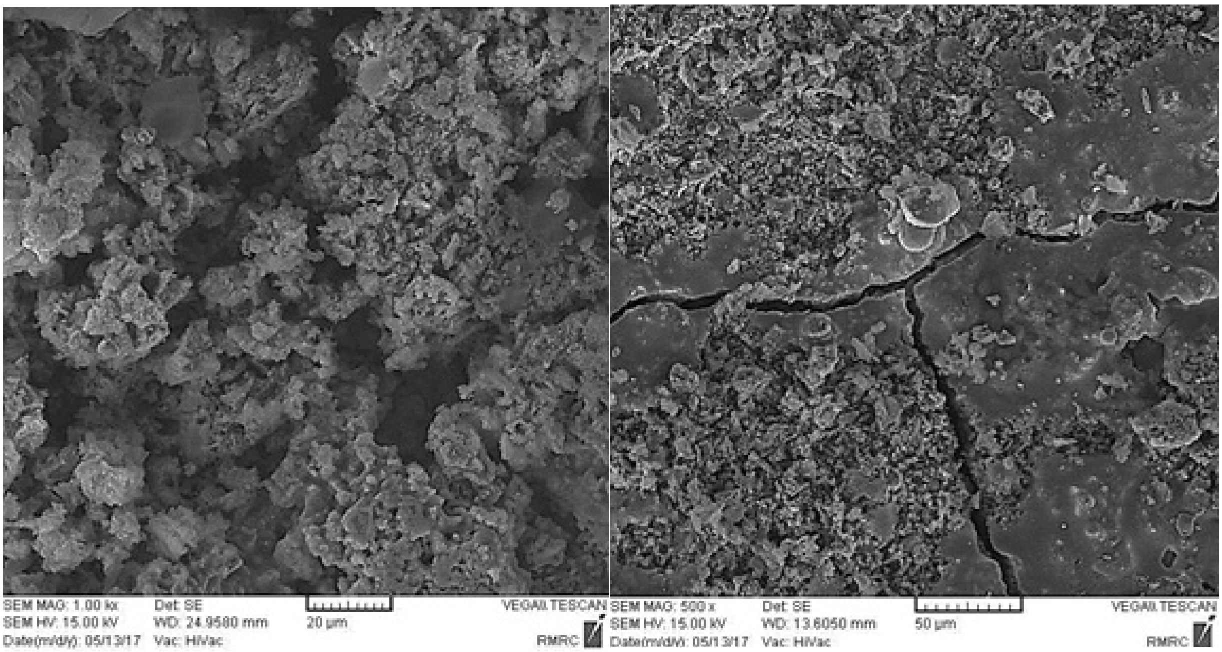

Fig. 1. SEM images of the corrosion products.

Table 1. EDX test of corrosion products.

Element	C	O	Al	P	S	Cr	Fe	Ni	Cu
%wt.%	3.99	60	1.06	1.05	3.05	1.22	24.9	0.8	0.73

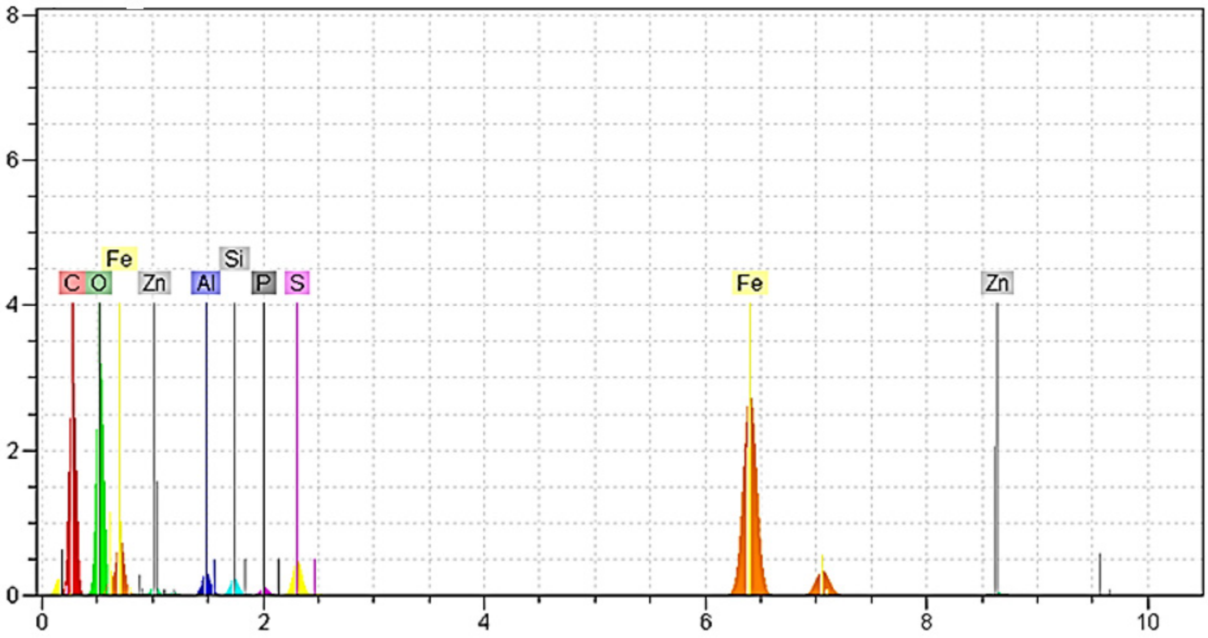

Chart 1. EDX test results of the corrosion products.

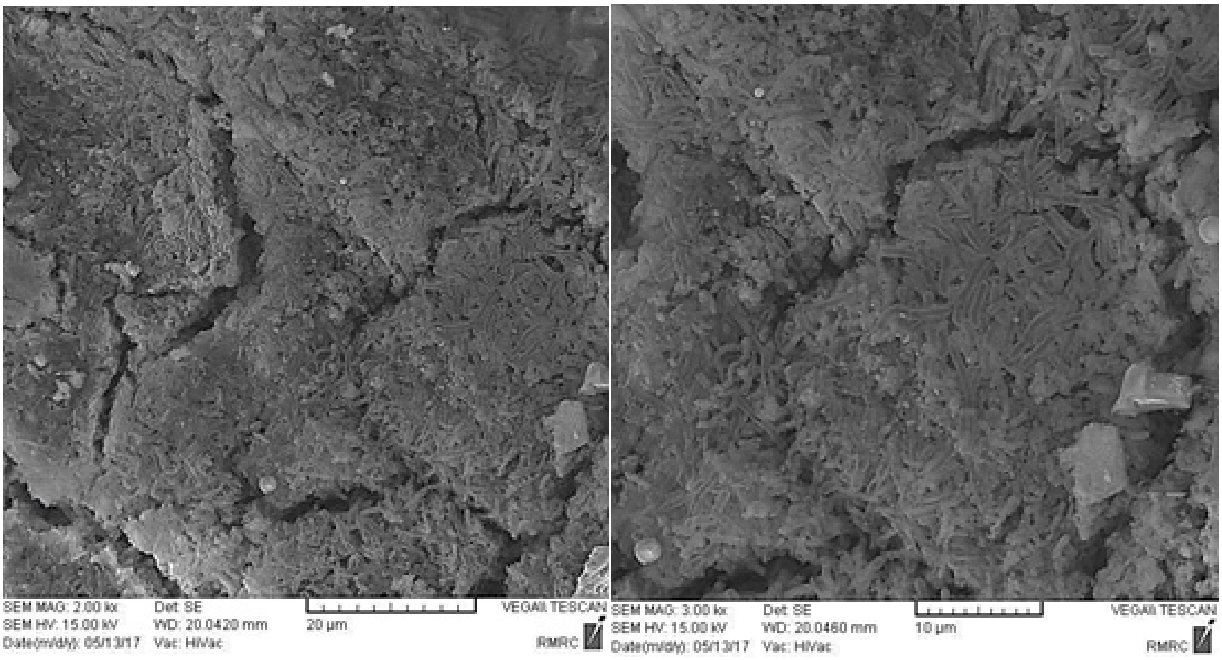

Fig. 2. SEM images of the corrosion products.

Table 2. Microbial test results.

Water	SRB (CFU/ML)	TBC (CFU/ML)
Machinery Basin	10000-100000	0
Compressor	100000-150000	1000

Moreover, the pH reduction of the drained water would bring an acidic medium and upsurge the corrosion rate of the pipe. These two inevitable factors stem from the nature of the system. It is possible to create an acidic Mmedium due to H_2S-water and CO_2-water contact. These gases are present in the direct reduction process. Many studies have been conducted on plain carbon steel corrosion in media containing H_2S and CO_2. For instance, Walter et al. experimentally studied the simultaneous effects of H_2S and CO_2 at a temperature of 25-38°C and a pH of 4.5-9 for 480 days. They observed the cathodic effect initiated from the formation of an FeS layer. This layer heightens the potential difference between the cathode and anode. Due to the formation of FeS, the cathode potential tends to be more positive. As a result, H2S can receive high current densities without polarization. This theory suggests that the corrosion rate uniformly decreases as the FeS layer continues to form. However, as it has insignificant adhesion to the substrate, it is locally peeled from the surface, causing local or pitting corrosion, as shown in Figure 3. Scott et al. reported similar results in the literature. Increased temperature and H_2S concentration raise the corrosion rate [10-11)].

Microbial corrosion (see Fig. 2) and bacterial cultivation (see Table 2) increase the corrosion rate. The accumulation and growth of microscopic organisms in aqueous media on surfaces lead to the formation of an adhesive biological layer, which is known as biofilm. The bacteria in this medium are anaerobic, i.e., they do not need oxygen to grow. SRB is available in media containing sulfide gas. S-2 ions strongly affect the cathodic and anodic reactions occurring on the steel surface. Sulfide disturbs the cathodic reaction and intensifies anodic dissolution, raising the corrosion rate. In these conditions, the corrosion products can contain sulfide [11)]. There are numerous reports on increased corrosion rate in the presence of SRB, especially in local or pitting corrosion. The results showed that the rate of sub-sediment corrosion increases locally. SRB broadens both anodic and cathodic reactions and intensifies corrosion. In this case, the anodic and cathodic reactions are iron solution and sulfate reduction, respectively.

$$SO_4^{2-} + 9H^+ + 8e^- \rightarrow HS^- + 4H_2O$$

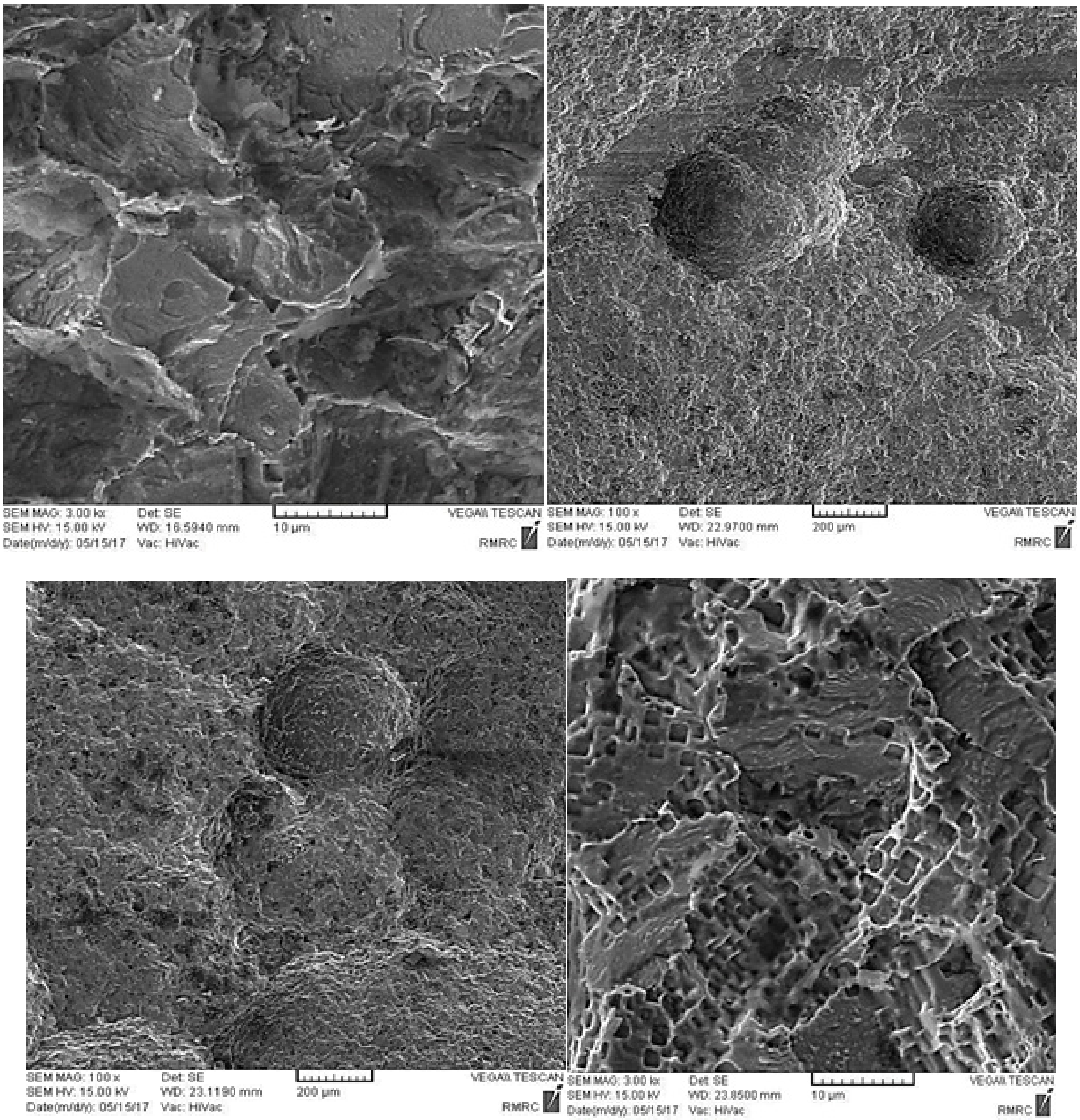

Fig. 3. SEM images of the samples after corrosion product removal.

This implies that the rate of the cathodic reaction is controlled by the sulfate reduction rate with the help of SRB, and the increase in the potential difference, which is initiated from sediment formation (biofilm), leads to the spread of sub-sediment local corrosion. Figure 3 demonstrates the local corrosion of the substrate after the removal of the corrosion products. Moreover, SRB corrosion through the S-Fe reaction and FeS formation can indirectly increase the corrosion rate of steel [12]. To cope with this problem, the pertinent pool of water was periodically chlorinated in the monthly repairs, and microbial corrosion was temporarily avoided. However, in the annual repairs, the pool was completely drained, and the bottom mud was entirely removed. The elimination of microbial corrosion prolonged the service life of the pipes to up to one year.

Conclusion

The results can be summarized as:

- Several factors, including temperature increase, pH reduction, and microbial corrosion, affect the destruction of compressor drain pipes.
- The FeS layer interrupts the cathodic reaction and causes severe local corrosion due to the lack of continuity and sufficient adhesion.
- SRB exists in media containing sulfide gas. S^{-2} ions strongly affect the cathodic and anodic reactions on

the steel surface. The results revealed a local increase in the rate of sub-sediment corrosion. Furthermore, SRB electrochemically promotes both anodic and cathodic reactions.

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