TCR Advanced Engineering P. Ltd

Experts in Metallography, Failure Investigation and RLA

Metallurgy for Industries

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Carbon dioxide corrosion of steel tubes

Fundamentals of corrosion.

Oil and gas wells containing CO_2 as the primary corrosive gas are termed as "sweet" wells. Carbon dioxide, CO_2, corrosion is noticed in case of steel pipelines and tubes used in the extraction, production and transport of oil and gas, disrupting the oil/gas production from such wells. As a matter of fact, CO_2 is naturally present in the ground, but it is also injected into the wells as one of the methods to increase oil recovery. However, the presence of CO_2 causes internal corrosion of steel pipes & tubes due to the formation of carbonic acid (H_2CO_3) which is corrosive in nature. The carbon dioxide acts in two ways - it increases the amount of hydrogen liberated at the cathode lowering the pH of the medium and can also form protective carbonate film on the surface of the metal.

When CO_2 is dissolved in water it is partly hydrated and forms carbonic acid (H_2CO_3) as per following reactions. The CO_2 concentration in the water varies significantly within an individual well at different depths because of large differences in temperature and pressure.

CO_2 (gas) = CO_2 (aqueous) ---------- (gas dissolution reaction)

CO_2 (aqueous) + $H_2O \Leftrightarrow H_2CO_3$ (aqueous) ----- (hydration reaction)

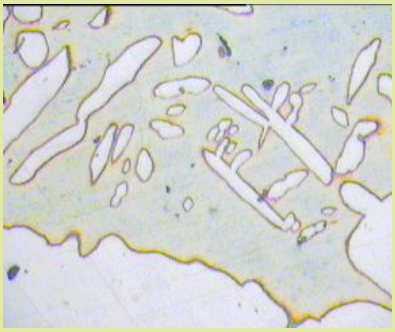
Carbonic acid being diprotic, it dissociates into bicarbonates and carbonates as shown by following cathodic reactions:

$$H_2CO_3 \Leftrightarrow H + HCO_3$$

$$HCO_3 \Leftrightarrow H + CO_3$$

The resulting pH is a function of the CO_2 partial pressure. As shown in Fig. 1 as the CO_2 partial pressure increases the pH decreases, leading to corrosion. The corrosion rate also depends on the factors like pH, solution chemistry, metallurgy of the steel, etc.

Microstructure of the Month



Magnification: *400 X*

MOC: *ASTM A182 Gr. F 51*

Composition of Laves Phase: *Fe2Mo, Ti21Mo9, Fe50Cr5Si5*

Observation: *Microstructure shows austenite pools in ferrite matrix. Laves phase is observed as shown by arrow.*

Useful hints: *Color metallography is an important tool to reveal inter-metallic phases that may hamper the corrosion resistance of the high grade material like Duplex Stainless Steel.*

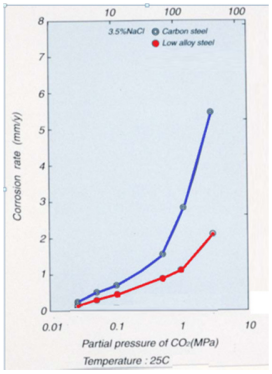


Fig.1: *Effect of partial pressure of carbon dioxide on the corrosion rate of carbon steel and low-alloy steels*

The corresponding anodic reaction is the dissolution of metal at the pipe/tube surface into Fe ions along with liberation of free electrons.

$$Fe(solid) = Fe^{+2}(aqueous) + 2e^{-}$$

Therefore, when the aqueous carbonic acid comes in contact with the steel tubing in a well the overall carbon dioxide corrosion reaction can be represented as:

$$Fe + CO_2 + H_2O = FeCO_3 + H_2$$

$FeCO_3$ further react to form the precipitates/scale on the surface of the steel.

$$FeCO_3(aqueous) + CO_3^{-2}(aqueous) = Fe(CO_3)_2(solid)$$

The following schematic (Fig.2) explains the mechanism of CO_2 corrosion of steel.

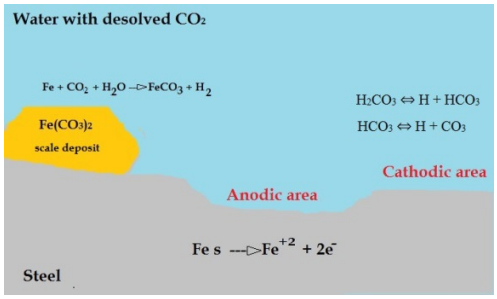


Fig.2: *Schematic showing mechanism of CO_2 corrosion in steel*

The protective scale of corrosion products such as ferrous carbonate ($FeCO_3$) and ferrous bicarbonate $Fe(HCO_3)_2$ formed on the surface over a period of time, partially passivates the corroding steel surface due to its limited solubility. The conditions favouring the formation of protective scale are high temperature, increased pH and lack of turbulence so that the film once formed remains intact.

Despite the fact that carbon steel has low resistance to CO_2 environments, it is widely used in the petroleum industry mainly due to economical reasons. It is the natural protective film of ferrous carbonate ($FeCO_3$) that makes the use of carbon steels feasible. Corrosion occurs when the protective siderite ($FeCO_3$) film is absent or gets damaged.

The ways to combat CO_2 corrosion are use of inhibitors, use of coated tubes & pipes or to improve the metallurgy of the material by going for alloy steels instead of carbon steels.

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