Multi-Functional Inhibitor: a Novel Solution for Steel Corrosion in CO_2-Enriched Environments

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Abstract
A recent advance in corrosion-resistance technology overcomes the problem of steel corrosion in CO_2-enriched environments. At an inhibitor concentration of 10^{-3} M, the inhibition efficiency exceeded 98% where the steel corrosion rate is decreased by a factor of at least 100.

Keywords: Steel Corrosion, Multi-Functional Inhibitor, Corrosion Resistance

The Chinese oil pipeline explosion that occurred in November 2013 was a tragic disaster that has created a variety of serious environmental issues. The reason behind this disaster is well understood.[1] The oil pipeline, made of carbon steel, usually corrodes after decades of use in corrosive environments.[2] The steel corrosion can cause a sizable economic loss. For example, steel corrosion in the global petroleum industry costs more than $4 trillion annually.[2] Fortunately, a large amount of corrosion loss can be saved via implementation of a corrosion-resistance technique using novel multi-functional corrosion inhibitors. This advance was recently published in *Corrosion* as a cover paper by a postdoctoral researcher Huiwen Tian and his advisor Frank Cheng.[4]

What is a corrosion inhibitor? A corrosion inhibitor is an additive agent that, when added to a liquid or gas, is able to decrease the corrosion rate of the container. Many organic compounds containing nitrogen, sulfur, and oxygen heteroatoms can be used as corrosion inhibitors.[5] The strong adsorption of these heteroatoms on the container leads to the formation of a protective film against corrosion. Conventionally, a corrosion inhibitor is designed by attaching a single functional group (such as triazole, thiadiazole, furan, acylhydrozone, etc.). Adsorption of inhibitors on the container surface prevents the corrosion from acids or brines. This strategy was proven effective and has been commercialized. However, the corrosion resistance performance of conventional inhibitors is poor for natural gas and crude oil in steel pipeline. This is because carbon dioxide (CO_2), which is a naturally occurring element, is very corrosive to the steel.[6] A previous study indicated that CO_2 in aqueous solutions in a specific pH range could be more corrosive than hydrochloric acid.[7] Thus far, the conventional inhibitor molecules are not sufficient to inhibit corrosion in CO_2-enriched environments. This points out the importance of Tian's work,[4] in which they improved corrosion resistance in CO_2-enriched environments (oilfield formation water) by using a wisely designed corrosion inhibitor molecule involving multi-functional groups, as shown in **Figure 1**. They characterized the corrosion resistance performance by using electrochemical methods, scanning electron microscope, and scanning vibrating electrode technique. Surprisingly, at an inhibitor concentration of 10^{-3} M, the inhibition efficiency exceeded 98% where the steel corrosion rate is decreased by a factor of at least 100. Although

the concentration is somewhat high, the addition of inhibitors at a millimolar concentration costs only 4 ‰ of the crude oil price. More importantly, the reported inhibitors are natural and non-toxic, guaranteeing the feasibility and safety in industrial applications.

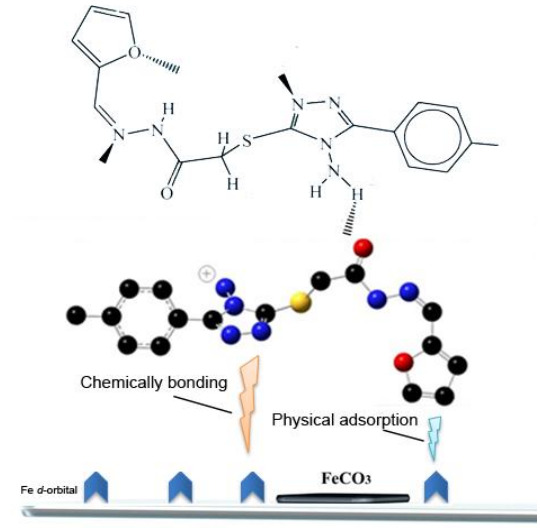

Figure 1. The molecular structure of inhibitor (upper) and a proposed physical picture of corrosion inhibition. An inhibitor molecule containing N, S, and O heteroatoms in the functional groups has multi-active centers. The azole group could chemically bond to the steel surface while the furan group is associated with the physical adsorption. The multi-active adsorption sites lead to the formation of a compact, oriented, and uniform inhibitor film, resulting in an effective barrier to corrosive species.

Tian et al. also performed electrochemical quartz crystal microbalance and X-ray photoelectron spectroscopy measurements to study the essential mechanism of this surprising improvement. They found "the formation of a film that consists of an insoluble complex containing inhibitor film and ferrous scale".[4] Moreover, the inhibitor molecules preferentially adsorb at sites with intensified corrosion. Interestingly, this phenomenon conceptually agrees with heterogeneous adsorption of proteins at solid/liquid interfaces that exhibit strong adsorption sites sparsely distributed at the interfaces.[8,9] Although the origin of adsorption heterogeneity remains elusive, the results presented by Tian et al. have evidenced that the strong sites could be a result of the presence of topographical heterogeneity.

In summary, I believe that this study has provided a great design strategy of corrosion-resistance techniques in CO_2-enriched environments. The results also provided a deep insight into the adsorption heterogeneity. I expect that this study will attract attention from industries as they can use this technique in many applications involving CO_2-induced corrosion.

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