Finding an Effective Way to Inhibit Carbon Dioxide Corrosion of Ferrous Metals in Oil-and-Gas Production Media

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Abstract—Main ways to control the carbon dioxide corrosion, type of inhibitors employed, reasons for choice of the inhibitors, and various factors determining the efficiency of inhibitors of different types in carbon dioxide oil-and-gas production media are considered.

When solving problems related to carbon dioxide corrosion, which are encountered in oil and gas fields, it is particularly important to determine the most effective protective method [1, 2]. Inhibition is an efficient and, in many cases, rational protection technique [1–5]. Previously, mechanisms of carbon dioxide corrosion in single- and double-phase oil-and-gas production media at various pH values have been analyzed [6, 7].

The aim of this study was to continue investigations aimed to choose the most promising ways to control the carbon dioxide corrosion and to consider main types of inhibitors and factors determining their efficiency.

An analysis of the mechanism of action of CO₂ revealed its main specific features (Scheme 1). Primarily, the accelerating effect of CO₂ is due to enhanced hydrogen evolution (monitoring at $t \leq 60^\circ C$) and formation of carbonate-oxide films or depositions (monitoring at $t > 60^\circ C$).

**Scheme 1.**
Effect of CO₂ on the corrosion of steel

![Scheme 1](image-url)
enhanced evolution of hydrogen and formation of carbonate-oxide films on the metal surface (which may have good or poor protective properties) [8-16]. Hence follows that an effective protection can be achieved, first, by hindering the cathodic process and, second, by forming protective carbonate films on the steel surface [12-14]. These films preclude penetration of depolarizers (H₃O⁺, HCO₃⁻, H₂CO₃) and activators (Cl⁻, SO₄²⁻) to the metal surface and(or) migration of iron ions across the film [16-19].

The cathodic process can be effectively hindered (1) by lowering the concentration of depolarizers in solution and in the surface layer by their chemical binding with derivatives of aminoformic acid: amides, carbamates, hydrazides, organic carbonates, neutral acyclic carbonates, and carbonic acid esters [20]; (2) by displacing depolarizers with ions or molecules of inhibitors (competing adsorption) with the use of ethylene imine, and ethers or esters (PIK 12, SNPKh-6302, Minkor-2) [20, 21]; and (3) by forming protective oxide-carbonate, inhibiting, or mixed films that preclude migration of depolarizers and activators to the metal surface or that of Fe²⁺ ions across the film by using compounds with an active adsorption group or a long hydrocarbon radical, such as SZhK, OR-2K, GIPKh-3A, SNPKh-6011B, Neftegaz, Tarin, KRTs-3G, or organophosphorus compounds: FAN-403M, F-741, etc. [1-3, 22-24].

In the last case, films or deposits formed on the metal surface can affect both the anodic and cathodic processes. The extent of this influence is determined by the composition and structure of the films and by presence and size of pores in them [12-19]. When a carbonate-oxide film or deposit with poor protective properties is formed on the metal surface, its hindering action can be enhanced by introducing into the medium a specially selected inhibitor, which is not only adsorbed but also can penetrate into the pores in the film.

The hindrance of the anodic process in carbon dioxide corrosion, which is closely associated with the formation of protective siderite films or deposits, can be achieved by raising the pH of the medium (by shifting the pH to the alkaline region) or elevating the temperature (to 40–60°C) [8-19, 23-27].

The pH of the medium can be adjusted by using inhibitors that shift the pH to the alkaline region to 8–10, which favors formation of a protective siderite layer on the metal surface, the so-called neutralization method [12, 15, 18, 28-31].

It should be noted that the pH of water can change with temperature and strength of an external electromagnetic field [32, 33]; thermochemical reactions can be used to maintain the temperature of the medium in a prescribed temperature interval. In particular, the possibility of a thermohydrodynamic adjustment of the pH of water in the range 5.7–8.6 was demonstrated in [32]. It was established that the pH of water grows as the number of cycles of hydrodynamic cavitation becomes greater. After 9 to 10 cycles, pH = 8.6. Adjusting t thermochemically and pH by physical methods in systems for production, gathering, and transportation of oil and gas is, presumably, possible only in separate localities.

The main ways to control the carbon dioxide corrosion, including that with the use of inhibitors, are shown in Scheme 2.

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Scheme 2.
Main ways to control the carbon dioxide corrosion of steel

- Effective hindrance of the cathodic process by lowering the concentration of a depolarizer at the metal surface and in the surface layer
- Removal of a depolarizer from surface
- Interaction of the depolarizer (HCO₃⁻, H₂CO₃) with an inhibitor in the adsorption layer
- Formation of a barrier (films of mixed type with inhibitor molecules) impermeable to depolarizers

- Formation of protective carbonate-oxide deposits by adjusting the pH of the medium and temperature
- Shift of the pH into the alkaline region (neutralization method)
  - Inorganic neutralizers (reachable pH level 8–10)
  - Organic neutralizers (reachable pH level 9)
- Organic inhibitors that react with components of the medium (or with specially introduced reagents) with an increase in temperature