CMD 2026 Conference
The 3rd International Online Conference on Corrosion and Materials Degradation
In Memoriam of Prof. Dr. Digby Macdonald
30 June – 2 July 2026 Online
MDPI

Mechanism of SO_2 Effects on the Formation, Evolution, and Corrosion Behavior of CO_2 Corrosion Product Films on Carbon Steel

Xinhui Jiang, Min Qin, Kexi Liao
Petroleum engineering school, Southwest Petroleum University, ChengDu, 610500, China

INTRODUCTION & AIM

As global warming intensifies, the control of CO_2 emissions has become a broad consensus within the international community. Carbon capture, utilization, and storage (CCUS) technology is regarded as one of the key pathways for achieving the dual carbon goals of "carbon peaking and carbon neutrality" In industrial applications, amine-based absorption is widely employed for CO_2 capture, while sulfur dioxide (SO_2) is an unavoidable impurity. However, the influence of SO_2 on the evolution of corrosion product films and their protective mechanisms on carbon steel remains insufficiently understood. This study systematically investigated the effect of SO_2 on the corrosion behavior of Q345R carbon steel in CO_2-loaded MDEA-PZ (methyldiethanolamine-piperazine) amine solution.

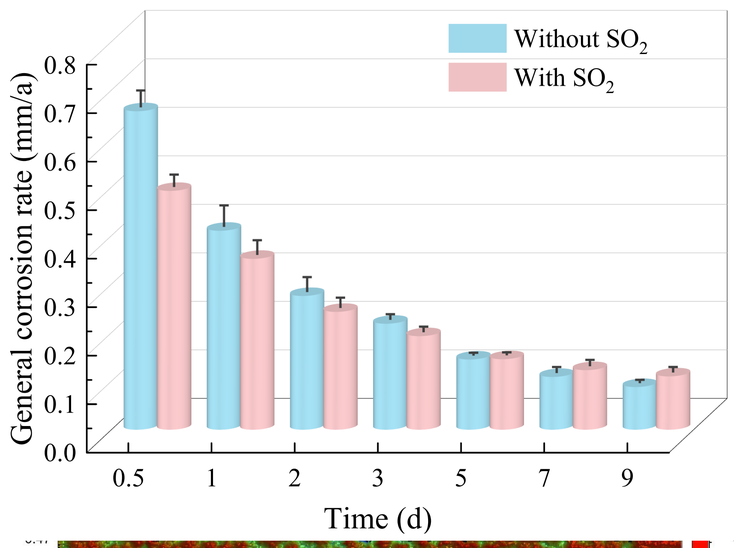
METHOD

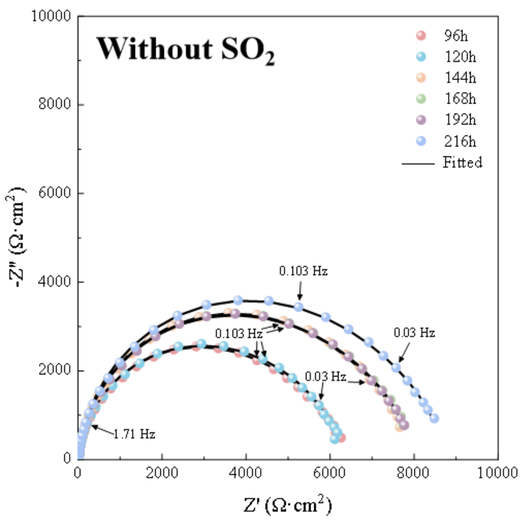
Electrochemical testing was performed using an electrochemical workstation and a three-electrode system. Electrochemical impedance spectroscopy was conducted over a frequency range of 10^5 to 10^{-2} Hz with an alternating current sinusoidal disturbance amplitude of 10 mV. Mott-Schottky analysis was conducted at a scan rate of 0.5 mV/s. Field emission scanning electron microscopy and energy-dispersive X-ray spectroscopy were employed to examine the morphologies of the corrosion products and the elemental distribution. X-ray photoelectron spectroscopy was conducted to further determine the phase composition of the corrosion products. The three-dimensional optical microscopy was employed to characterize the localized corrosion morphology of specimen surfaces after removal of corrosion products.

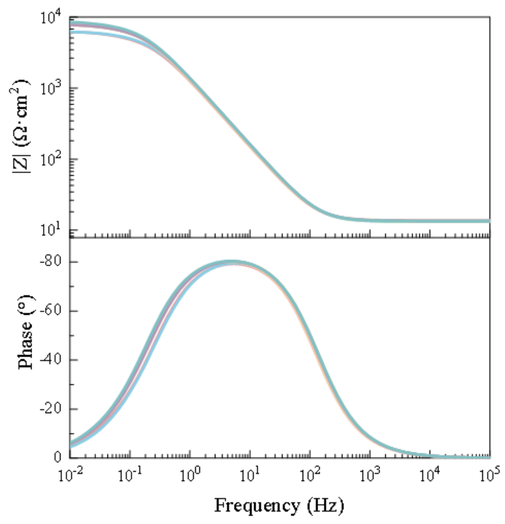
RESULTS & DISCUSSION

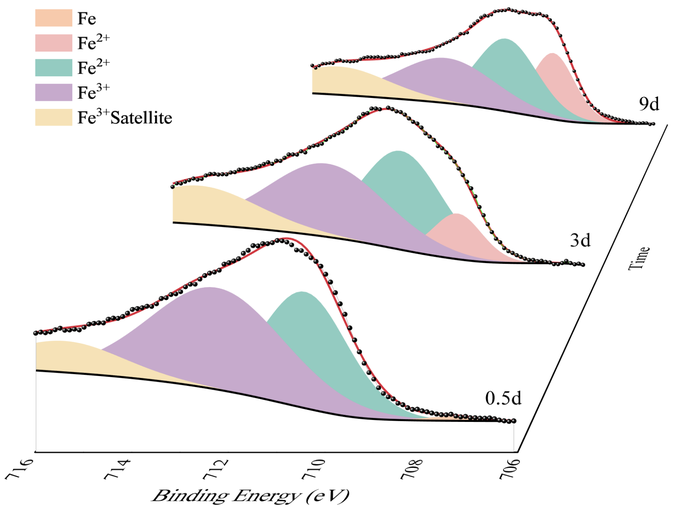
In CO_2-amine solutions, the corrosion product film on Q345R carbon steel is dominated by $FeCO_3$. Initially, Fe^{2+} nucleates rapidly on the metal surface, and with prolonged exposure, $FeCO_3$ crystals grow, coalesce, and interlock to form a continuous, compact, and stable layer. This film exhibits low porosity and high integrity, effectively hindering the transport of corrosive species to the metal interface and reducing the substrate's active reaction area. Without SO_2, protection is governed by the stable $FeCO_3$ film, explaining the gradual decline and eventual stabilization of the uniform corrosion rate.

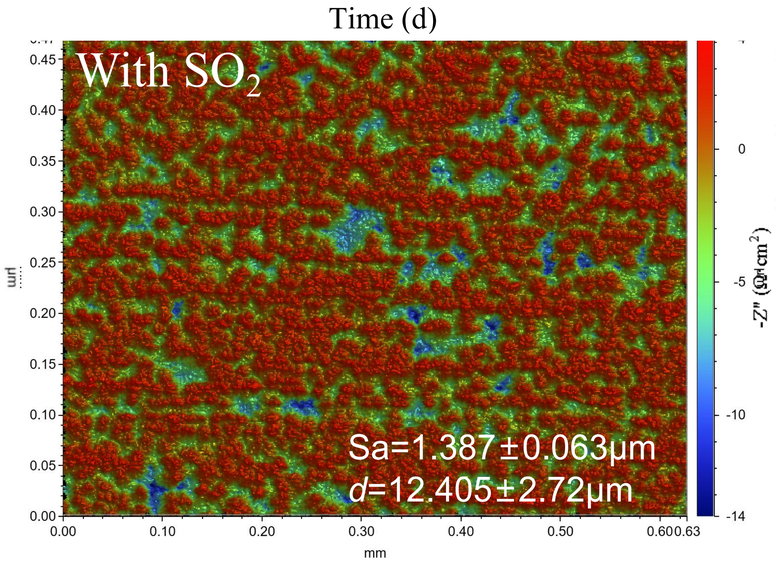
When SO_2 is introduced, the film's formation and protective behavior change significantly. Sulfur-containing species preferentially precipitate to form a continuous but porous layer, offering only short-term inhibition by reducing metal-electrolyte contact. Due to high porosity and structural instability, this layer provides limited resistance to ion and charge transfer. As corrosion proceeds, sulfur species undergo dissolution, oxidation, and redeposition, causing structural instability and localized enrichment at the film/substrate interface. They also interfere with $FeCO_3$ nucleation and growth, inducing Ostwald ripening that coarsens grains and reduces packing density, further compromising film integrity. In the late stage, despite increased thickness, the film remains loose, porous, and stratified. Overall, SO_2 disrupts the structural integrity of the corrosion product layer and alters interfacial reaction pathways, shifting corrosion control from barrier protection to charge transfer kinetics inhibition, thereby significantly reducing the film's long-term protective capacity.



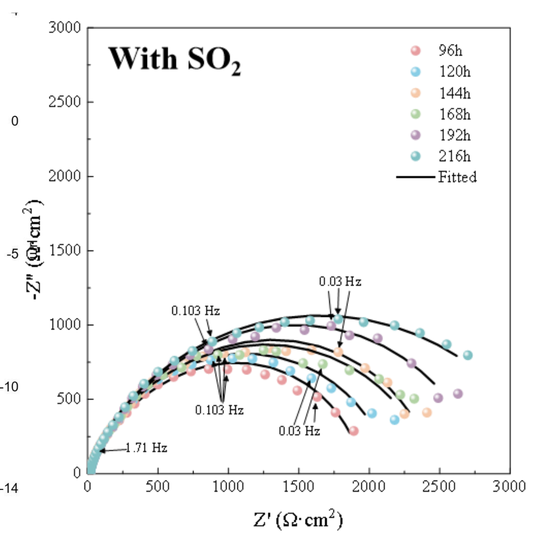


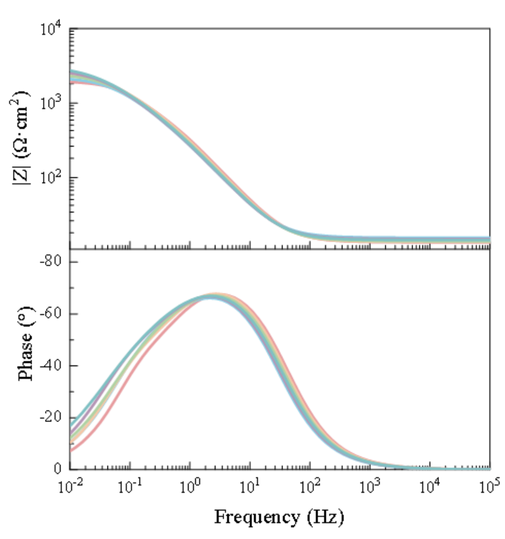




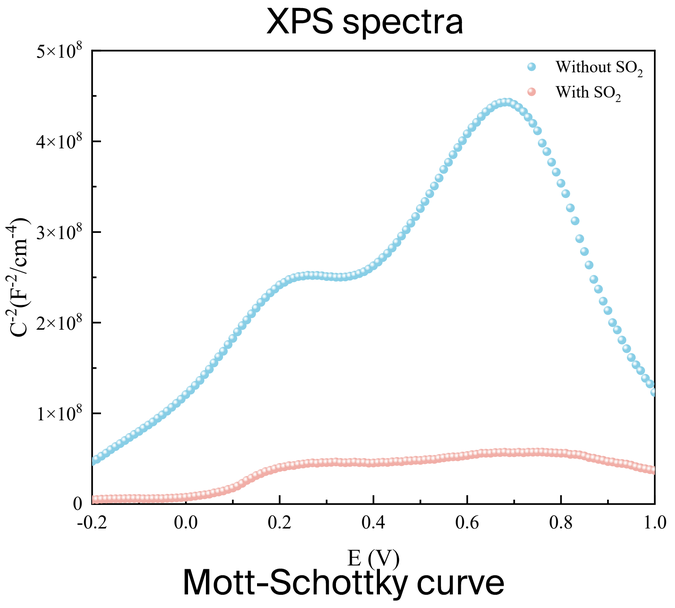


Corrosion Rate





Nyquist plots and Bode plots



Mott-Schottky curve

CONCLUSIONS

In the absence of SO_2, a protective corrosion product film dominated by $FeCO_3$ gradually forms on the carbon steel surface, which suppresses corrosion through the physical barrier effect of the film. SO_2 modifies the formation pathway of the corrosion product film by introducing species, transforming it from a dense $FeCO_3$ structure into a sulfur-containing, amorphous or low-crystallinity composite film.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China Youth Fund (Class C) 52504063, Sichuan Province Innovative Talent Funding Project for Postdoctoral Fellows (2025ZNSFSC1366) and China Postdoctoral Science Foundation (2025M772957), Sichuan Province Postdoctoral Innovation Talent Support Project.