

The 14th international Congress
on Marine Corrosion and Fouling

**CORROSION OF STEELS INFLUENCED BY AEROBIC AND
ANAEROBIC BIOFILMS IN SEAWATER ENVIRONMENT**

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OUTLINE

- The main corrosion phenomena by aerobic/anaerobic biofilm
- The current main theory for explaining the phenomena
- Questions: How about the anodic reaction?

How about corrosion inhibition included ennoblement?

- An example: Ennoblement of Stainless Steel-- a possible explanation
- Summary



The main corrosion phenomena by aerobic/anaerobic biofilm

- Ennoblement of corrosion potential of SS (aerobic biofilm)
- Corrosion Inhibition by some kinds of biofilm (DIRB)
- Accelerated corrosion or localized corrosion damage (SRB)



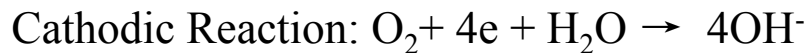
The current main theory for explaining MIC phenomena

Cathodic depolarization theory: accelerated or catalyzed cathodic depolarization by aerobic and anaerobic biofilm

Ennoblement:
biofilm catalyzed
oxygen reduction
(enzyme, etc)

Accelerated anaerobic corrosion:
SRB Biofilm(directly) or FeS
(indirectly)catalyzed electron
siphon or hydrogen reduction

Corrosion inhibition
Or acceleration:
oxygen deletion by
biofilm respiration
or by $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$
reduction

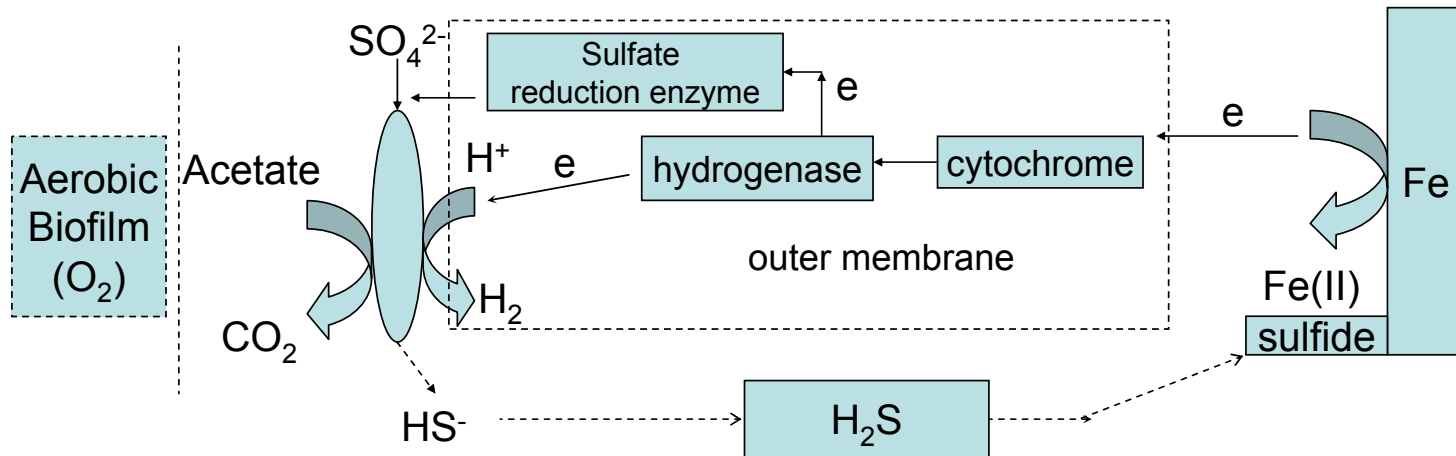
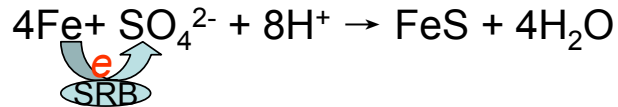


Question: How about anodic reaction in MIC on steel?

Accelerated anaerobic corrosion:

One of Answers: Extracellular Electron Transfer From Electrode to Bacteria

Direct anaerobic corrosion mechanisms (DINH et al 2004; SILVA S Da et al, 2004)



Question: How about anodic reaction in MIC on steel?

Corrosion acceleration or inhibition:

One of Answers: Biomineralization of iron oxide by SRB, DIRB, SOB.

B.Little, et al, 1997;

W.A. Hamilton, 2003.

F.Mansfeld et al, 2002

I.B Beech et al., 2008(ALWC corrosion)

For carbon steel immersed in seawater*:

- Two kinds of bacteria, SRB (*D. dechloracetivorans*) and DIRB (*Clostridium sp*) were found in the rust layer on steel immersed in natural seawater.
- Green rust is a key corrosion products. The formation of green rust is a kind of biomineralization influenced by the mixed anaerobic bacteria.
- The SRB can accelerate the corrosion rate. The mixed anaerobic bacteria can inhibit corrosion.

*Jizhou Duan, et al., *Electrochim. Acta*, doi:10.1016/j.electacta.2008.04.085



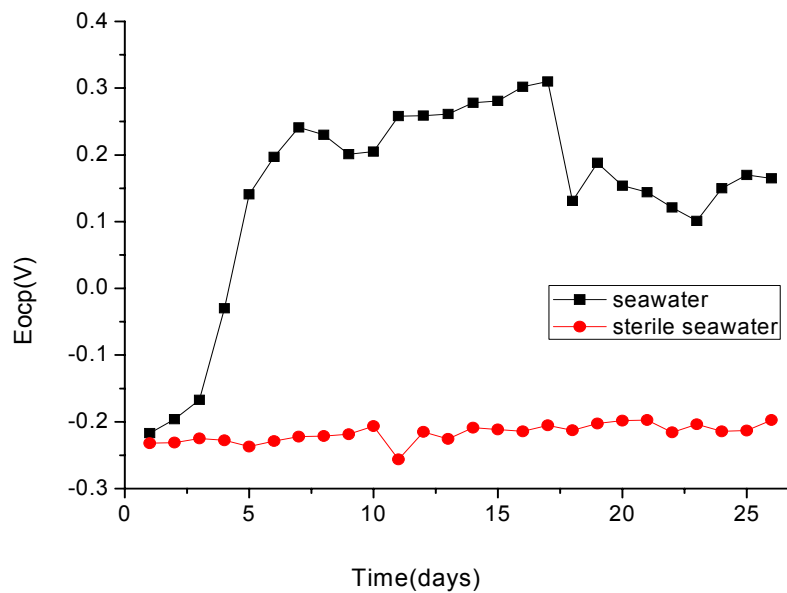
An example:
Ennoblement of Stainless Steel-- a possible explanation*

Influence of Ennoblement on corrosion rate and its possible reasons?

**J.Duan, F.Xu, B.Hou, in prepared.*



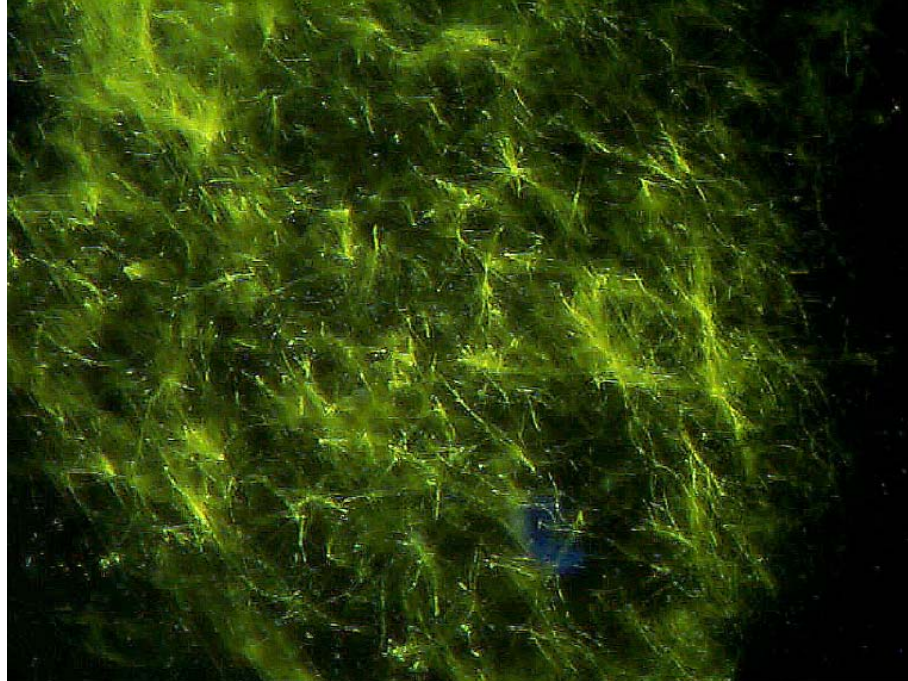
OCP measurement



Open current potential of 316L SS immersed in seawater

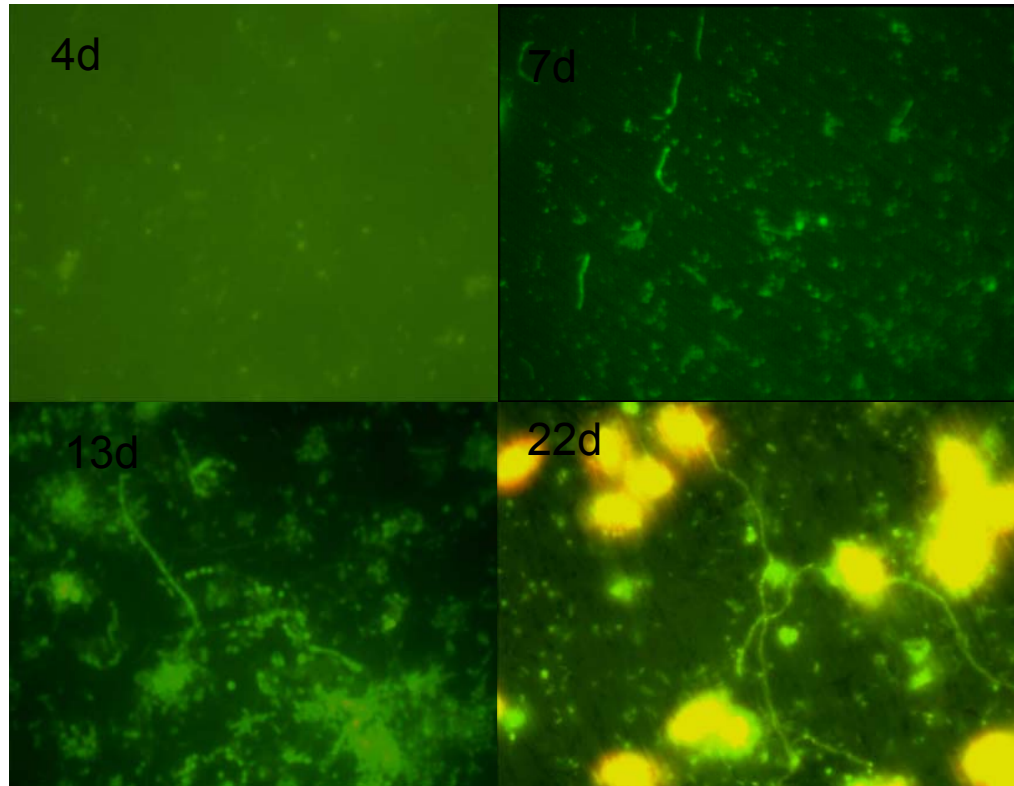


Biofilm observation



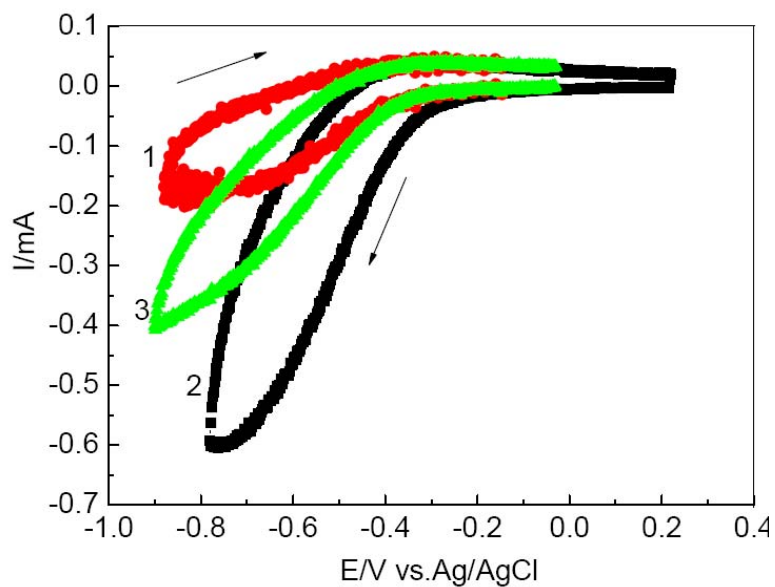
Epifluorescence image showing the biofilm development on 316LSS exposed to aerated natural seawater(DAPI, 400X) .Time collection after immersion was 6days.

OCP measurement



Epifluorescence images of 316LSS immersed in seawater for 4d, 7d, 13d and 22d .
Fixed with 4% glutaraldehyde, stained with DAPI (1000X)

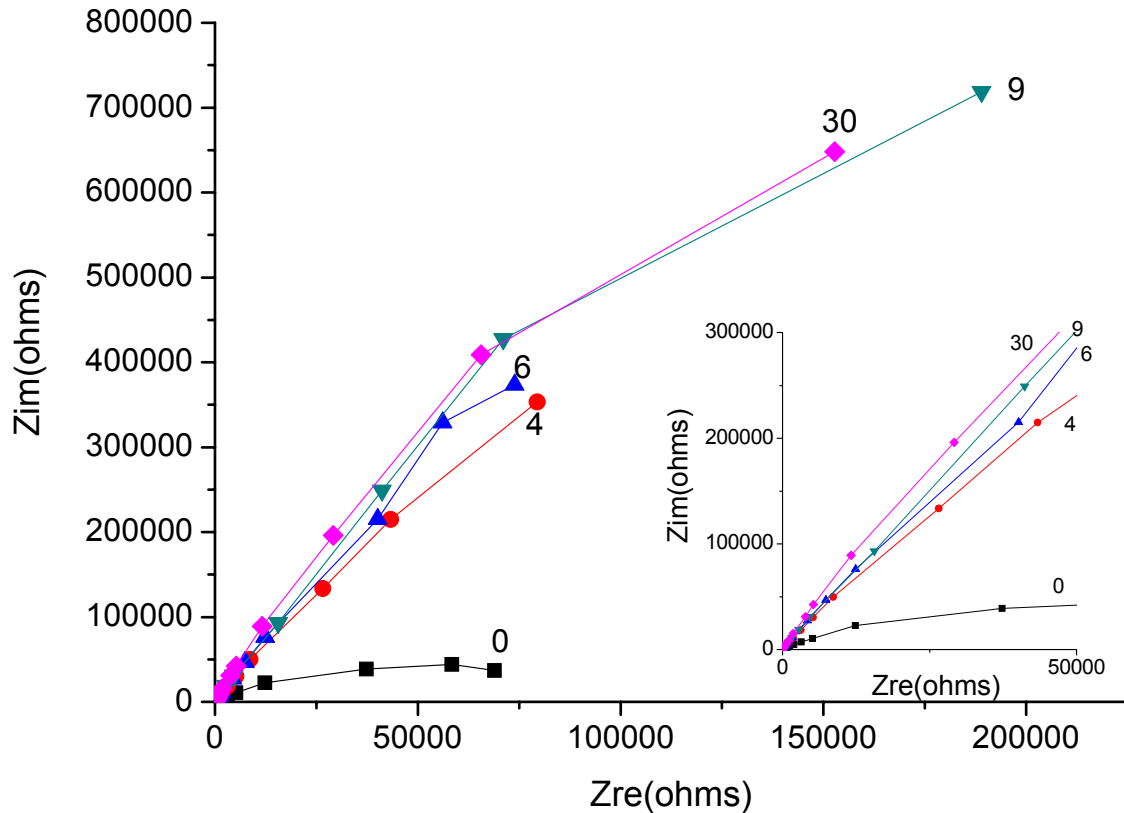
Cathodic reaction measurement



Cyclic voltammograms of 316L SS in oxygen saturated seawater(scan rate 50 mV s⁻¹).
1- 1days; 2-9days in natural seawater; 3- 9days in sterile seawater.



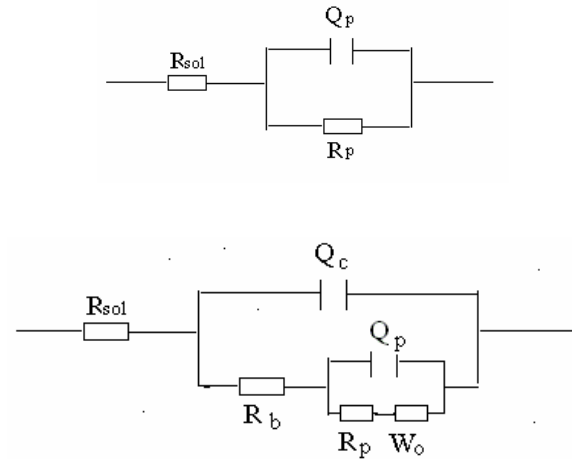
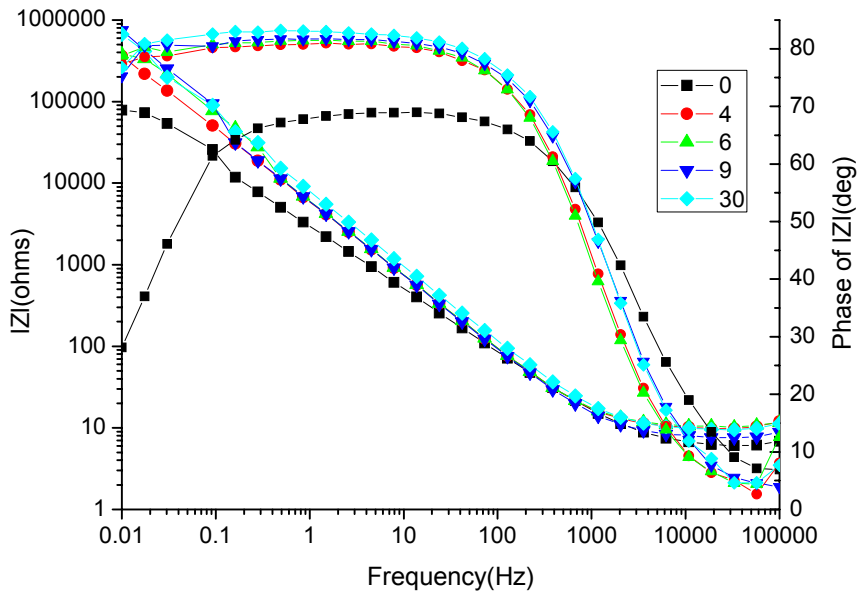
Corrosion rate measurement: Electrochemistry impedance spectra(EIS)



Nyquist plots of 316L SS immersed in natural seawater with different exposure time



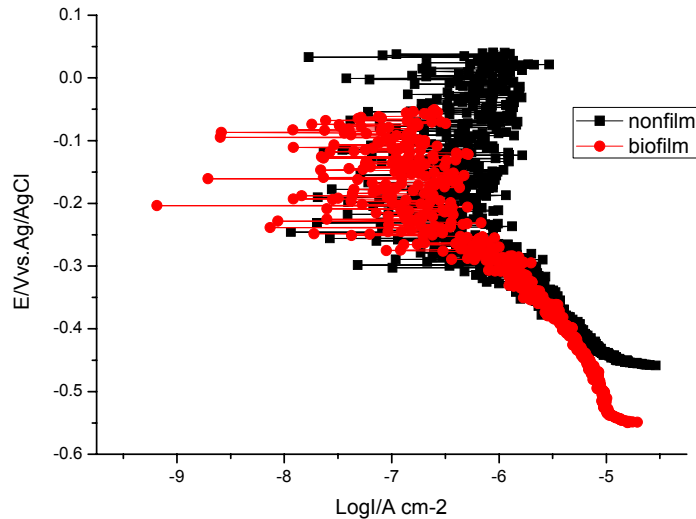
Corrosion rate measurement: Electrochemistry impedance spectra(EIS)



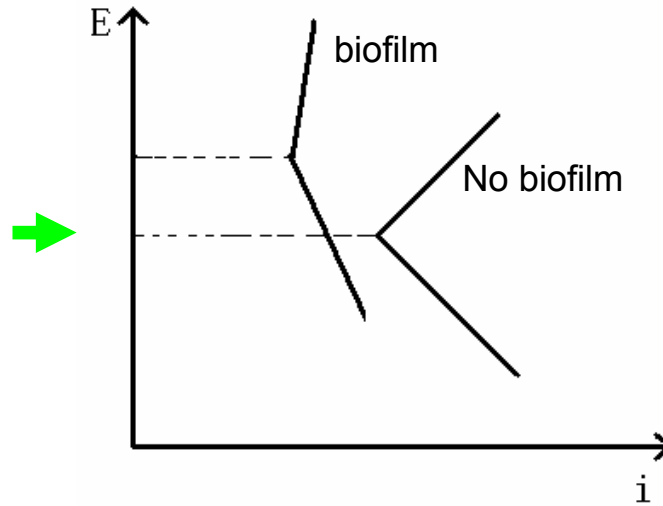
t(days)	0	4	6	9	30
Rp(k Ω cm ²)	34	359	835	2,584	4,018



Corrosion rate measurement: Polarization curve



Polarization plot of 316L SS after immersed in natural and sterile seawater for 20 days



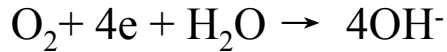
Sketch of polarization of SS in seawater with and without biofilm attachment

EIS and Polarization tests indicate that the corrosion was inhibited by aerobic biofilm!



A hypothesis for corrosion inhibition by aerobic film

Accelerate Cathodic oxygen reduction Reaction:



Where is the electron come from?

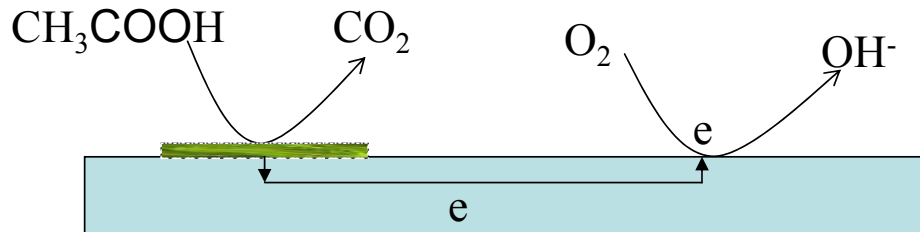
From Anodic Reaction: $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$?

Lowered corrosion rate!

No!

A hypothesis: electron transfer from Bacteria to Electrode.

Aerobic biofilm is a kind of electrochemical active biofilm.



Summary

- There exists the complex interaction between metals and bacteria.
- The ennoblement of SS may indicate the corrosion inhibition by biofilm; Stainless steel may act as electron acceptor to avoid undergo corrosion.
- Further study is needed to understand the characteristics of electrochemical active biofilm.



Acknowledgements

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Thank you very much for your attention!

