The Mechanism and Protection of Microbial Corrosion in Oil and Gas Field

Di Wang

Northeastern University, China

November 21st, 2024

ICorr (UK)-CSCP (China) Webinar

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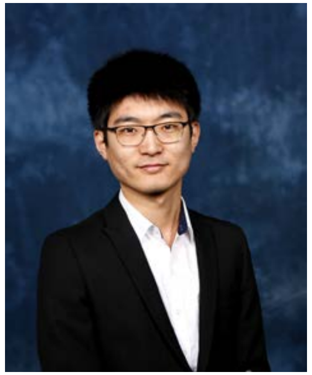
Who I'm



Di Wang

Education background

Bachelor in Chemistry @Northeastern University, China 2014

Master in Chemical Engineering @Dalian University of Technology, China 2017

Ph.D in Microbial Corrosion @ICMT, Ohio University, USA 2022

Working Experience

PostDoc in Microbial Corrosion

@NEU June 2022 – May 2024;

Associate Professor in Department of Materials

@ NEU since June 2024

Research Interests

MIC mechanism of sulfate reducing bacteria;

MIC prevention in oil and gas field;

Soil MIC under insulation of buried pipelines;

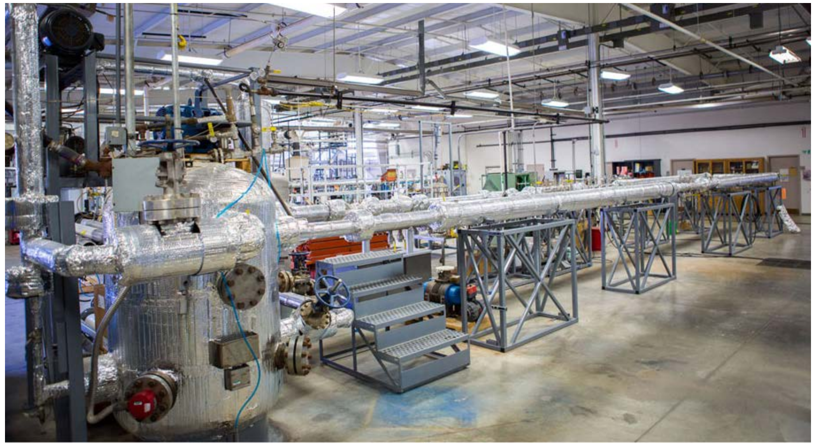
High temperature MIC research;

MIC in flow loop.

Where I'm from

Institute for Corrosion and Multiphase Technology @ Ohio University

ICMT



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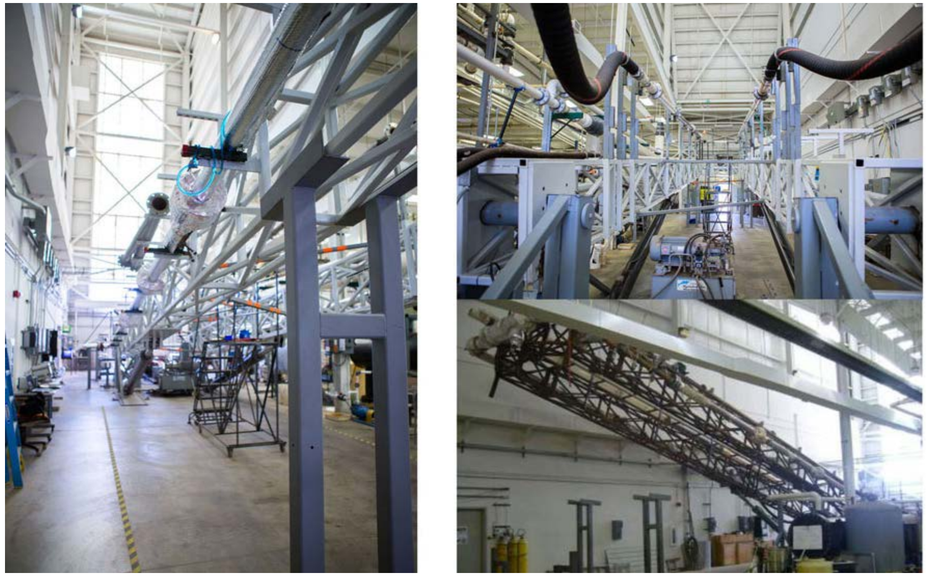


Tilting Rig Corrosion

H_2S corrosion

bhpbilliton
Apache
PETRONAS
WOODSIDE
Mi SWACO
multi-chem
A HALLIBURTON SERVICE
OXY
PERTAMINA
أرامكو السعودية
Saudi Aramco
ConocoPhillips
TotalEnergies

Sponsors

Where I'm from

Chinese Alumni from ICMT Working in Oil and Gas Industry

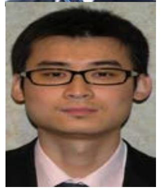
Shuai Ren, graduated 2023
Materials Scientist @Halliburton

Huiru Wang, graduated 2023
Research Scientist @Sinopec

Wei Zhang, graduated 2021
Engineer @Schlumberger

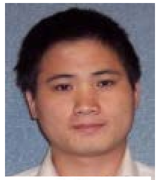
Ru Jia, graduated 2018
Engineer @ ChampoinX

Shujun Gao, graduated 2018
Corrosion Scientist @Baker Hughes



Wei Li, graduated 2016
Senior Engineer @ExxonMobil

Jing Ning, graduated 2016
Corrosion Engineer @Honeywell

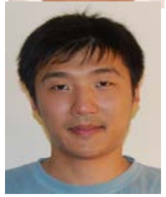


Yougui Zheng, graduated 2015
Corrosion Engineer @Shell

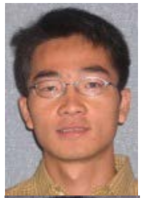
Peng Jin, graduated 2013
Corrosion Scientist @Baker Hughes

Yang Yang, graduated 2012
Corrosion Engineer @BP

Haitao Fang, graduated 2012
Application Engineer @Baker Hughes



Rao Xiong, graduated 2011
Senior Engineer @ExxonMobil



Xuanping Tang, graduated 2011
Corrosion Engineer @ BASF

Hui Li, graduated 2011
Engineer @ Honeywell

Chong Li, graduated 2009
Materials & Corrosion
Engineer @ ExxonMobil

Ziru Zhang, graduated 2008
Materials and Corrosion
Engineer @ BP

Wei Sun, graduated 2006
Materials Selection Group
Lead @ EMDC, ExxonMobil

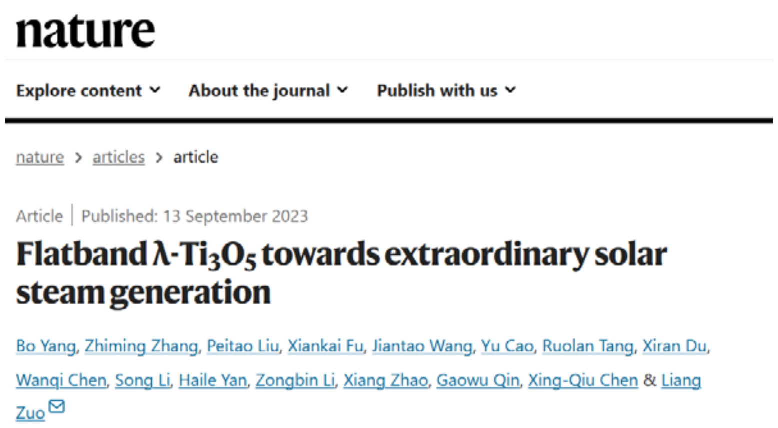
Where I'm Working for

Northeastern University of China (NEU): A hundred years of academic glory

Nurturing talent, driving innovation, and achieving excellence

Where I'm Working for

- **Department of material science and technology**
- **Ranking among the top 0.1% (Essential Science Indicator);**
- **First Nature and Science papers published in 2023;**
- **Quality control and performance optimization of material preparation and processing, Corrosion, research and development of new materials, new technologies and new processes in different conditions.**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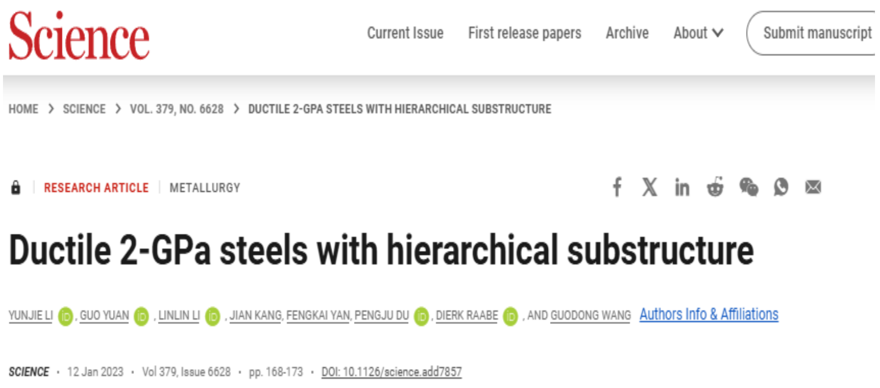
Sep 2023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RESEARCH ARTICLE | METALLURGY

Ductile 2-GPa steels with hierarchical substructure

YUNJIE LI, GUO YUAN, LINLIN LI, JIAN KANG, FENGKAI YAN, PENGJU DU, DIERK RAABE, AND GUODONG WANG Authors Info & Affiliations

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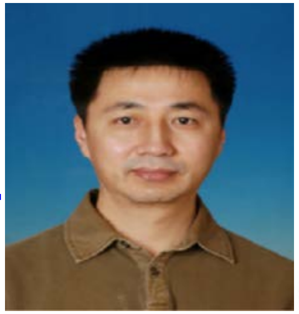
Jan 2023

Where I'm Working for

Prof. Fuhui Wang
National Outstanding Youth 1996



Prof. Derek Lovley
Distinguished professor UMass Amherst

Principle Investigator:
Prof. Dake Xu
National Outstanding Youth 2024

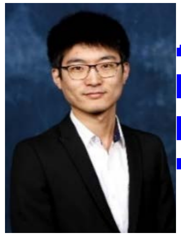
150+ peer reviewed papers
10,000+ citation
Pioneer in MIC

Prof. Yongqian Fan
Molecular biology

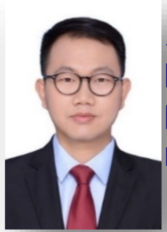
Prof. Mario Marchisio
Molecular biology

Prof. Mingxing Zhang
Microscopy

AP. Danni Zhang
Chemistry



Di Wang
Oil and Gas MIC



Zhong Li
Microbiology

Enze Zhou
Material

Xiangyu Li
Coating

Bin Yu
Antibiofouling

MIC Research Team @NEU: Faculty: 12; Postdoc: 2; PhD students: 31; Master graduate students: 65; More than 100 youth active in MIC.

Where I’m Working for

Laboratory equipment

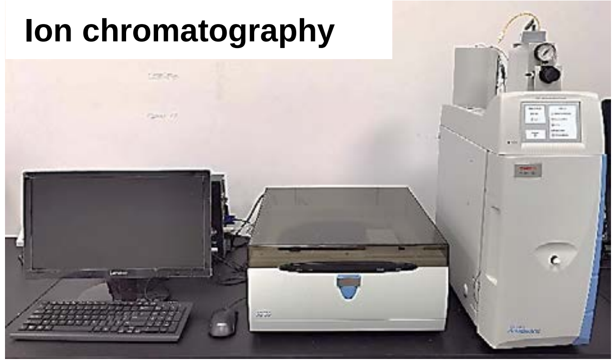
Scanning electron microscopy

Atomic force microscope

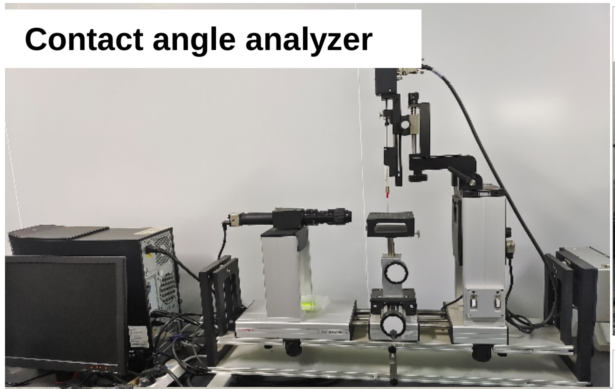
CLSM

HPLC

Ion chromatography



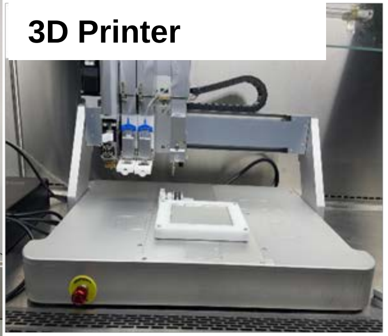
Contact angle analyzer



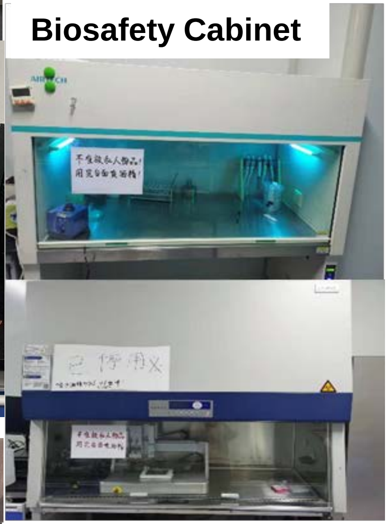
Gas chromatograph

Gamry workstation

3D Printer



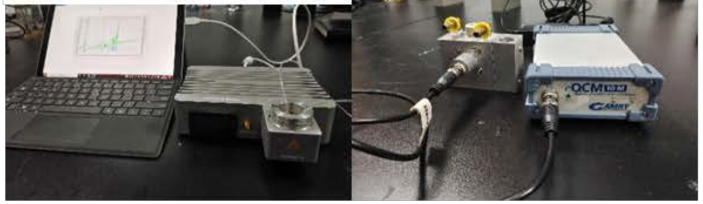
Biosafety Cabinet



CSTR

Where I’m Working for

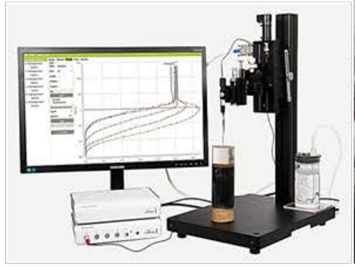
E-QCM



Chemiluminescence Imaging

Q-PCR

Microsensor



Freeze Dryer

Milli-Q water system

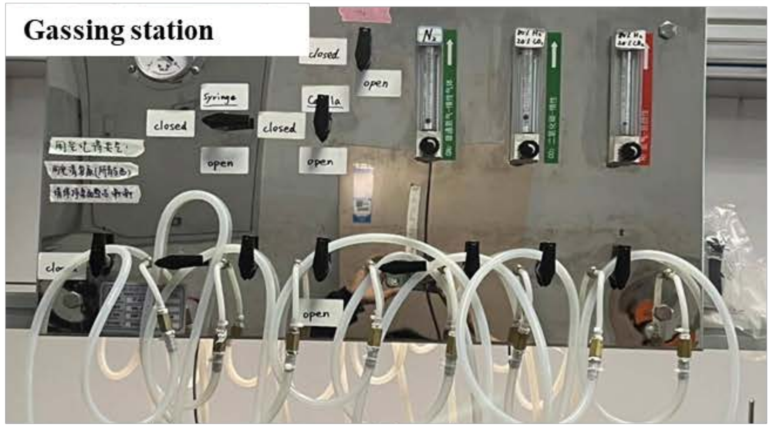
Glove box

UV spectrophotometer

Autoclave

COY glove chamber

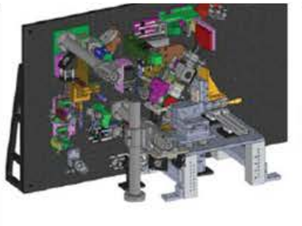
Gassing station



fluorescence inversion microscope

microplate reader

lattice light sheet microscope



Enough equipment satisfying MIC and its related fields.

Contents

The mechanism and protection of microbial corrosion in oil and gas field

Severe economic losses and significant hazards by corrosion

3.34% of the GDP caused by corrosion in China, exceeding 3 trillion CNY (330 billion GBP);

Corrosion affects all sectors of the economy and equipment.

Significant losses and threat to energy security.

Pipelines

Crude oil storage tanks

Offshore drilling platform

Corrosion under insulation

Corrosion losses account for 3% of GDP; in the oil and gas industry, 6% of GDP!

Corrosion affects every stage of the oil and gas field, impacting the lifeline of petroleum energy.

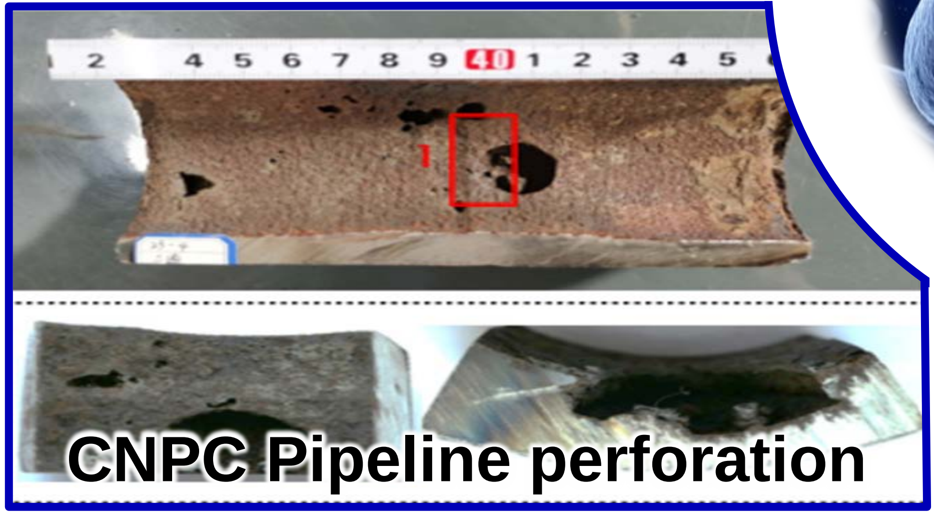
The mechanism and protection of microbial corrosion in oil and gas field

MIC accounts for >20% of the total corrosion losses in oil and gas industry

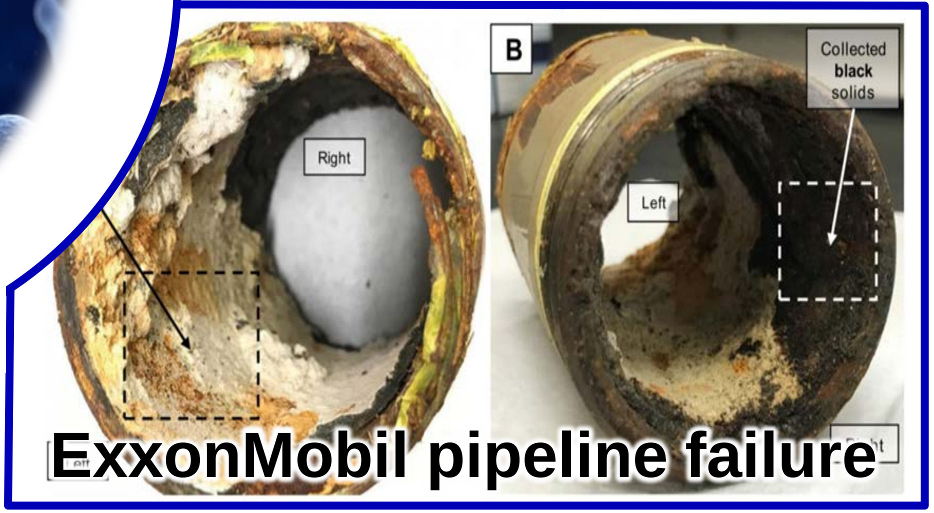
2006 Alaskan oil spill

Alison Canyon gas leak

SRB



CNPC Pipeline perforation



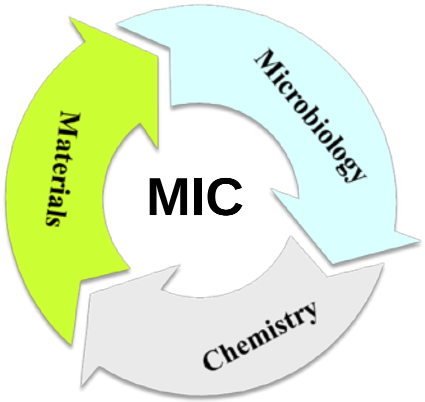
ExxonMobil pipeline failure

The mechanism and protection of microbial corrosion in oil and gas field

The Existing Problems

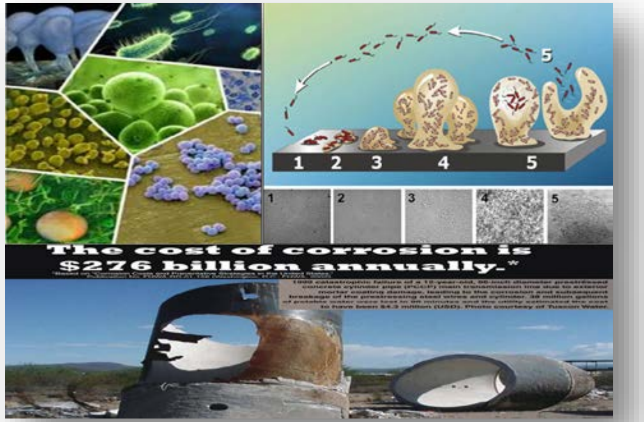
- **MIC behavior of specific materials in specific environments;**
- **Materials, biology, chemistry and other interdisciplinary areas;** → **Lack of mechanism**
- **Microbial corrosion in oil and gas fields is a common problem.**

MIC Research Difficulty



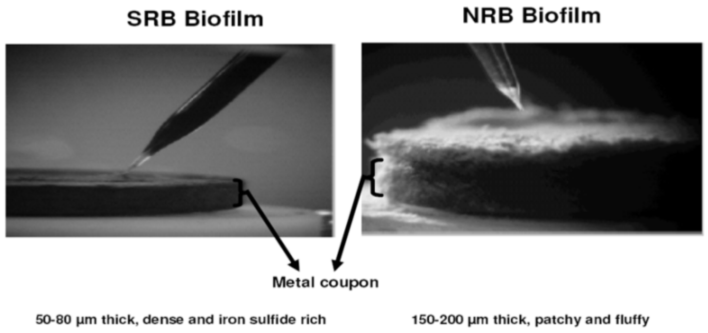
Material + Biology + Chemistry +…interdisciplinary

Typical MIC Theories



MIC mechanism is a 'myth'

MIC Detection/Monitoring



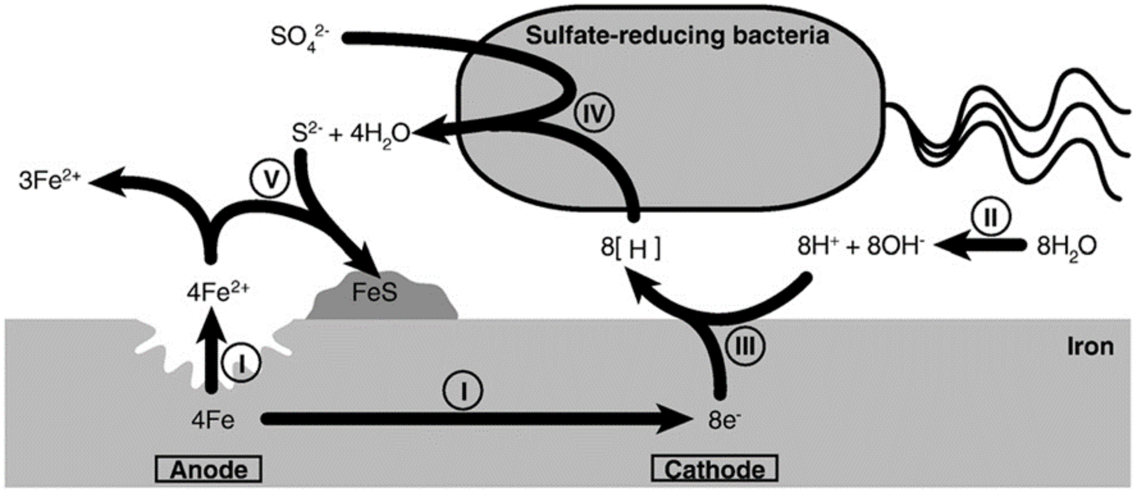
Blank of MIC monitoring

Key: Elucidating MIC mechanisms navigates the design of materials and treatment methods.

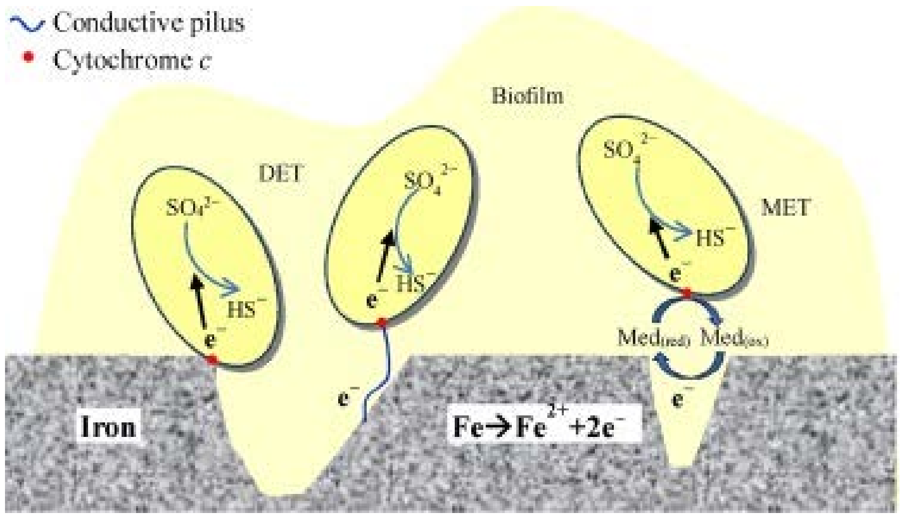
The mechanism and protection of microbial corrosion in oil and gas field

Opinion 1: **Electroactive microbes are main causes of MIC by extracellular electron transfer**

Traditional theories:
explain MIC in specific conditions



EET theories:
explain MIC in more scientific ways.

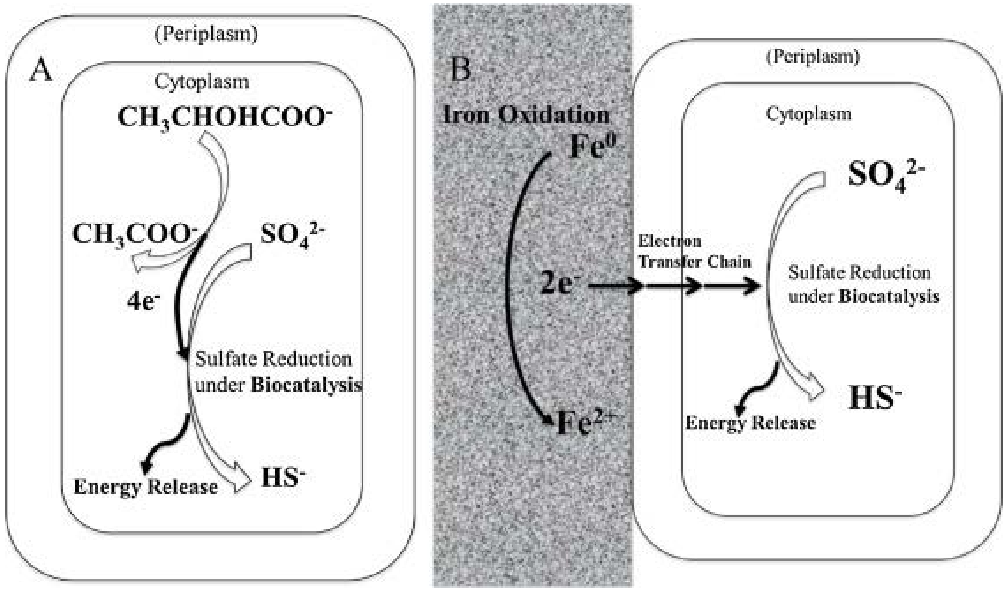


Microbes indirectly affect the concentration of hydrogen or oxygen at metal and solution interface

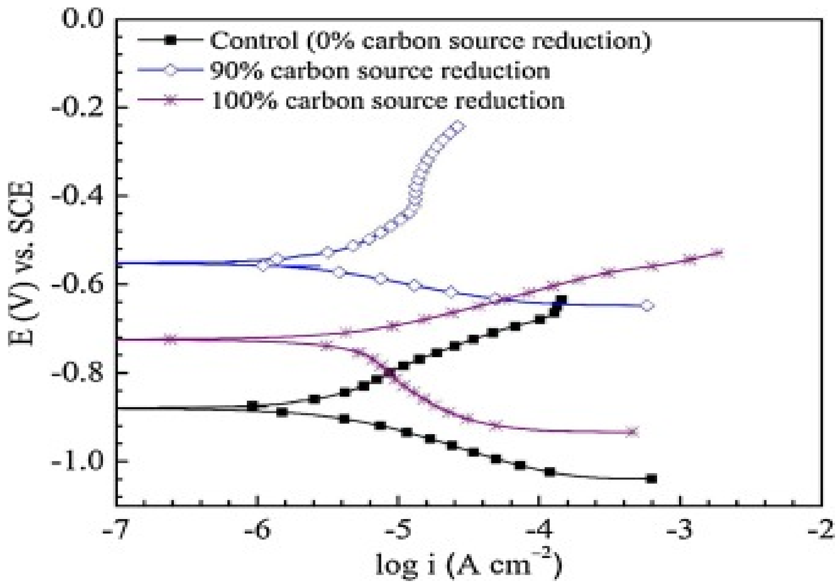
Microbes acquire electrons from metals through EET and are directly involved and regulated in the corrosion process

The mechanism and protection of microbial corrosion in oil and gas field

Opinion 2: **Microbes obtain energy from metals**



With carbon source | Without carbon source



Energy	Carbon source	Metal

Novel 'starved' experiment confirmed

More starved SRB → More severe corrosion

Classical opinion:
Microbes participate in corrosion passively;
Novel opinion:
Microbes participate in corrosion positively.

How microbes corrode metals

The mechanism and protection of microbial corrosion in oil and gas field

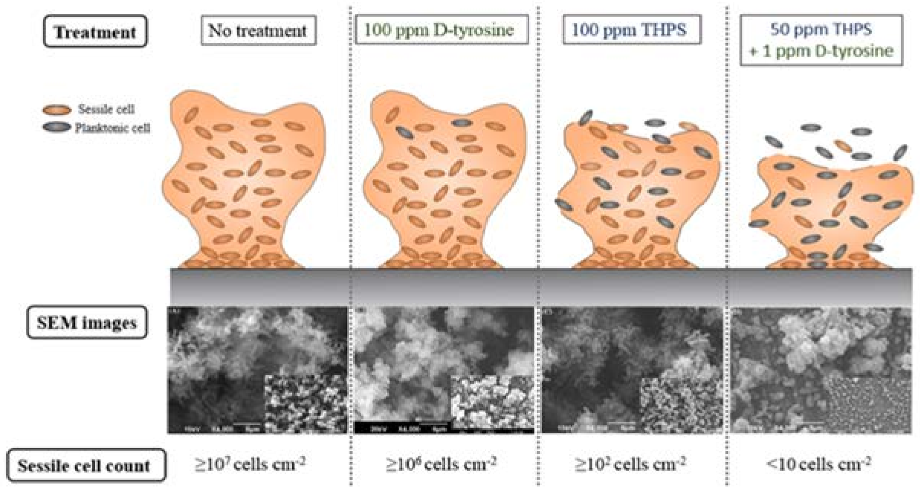
Opinion 3: Biofilm is the main reason for MIC → Mitigation of MIC = Biofilm treatment

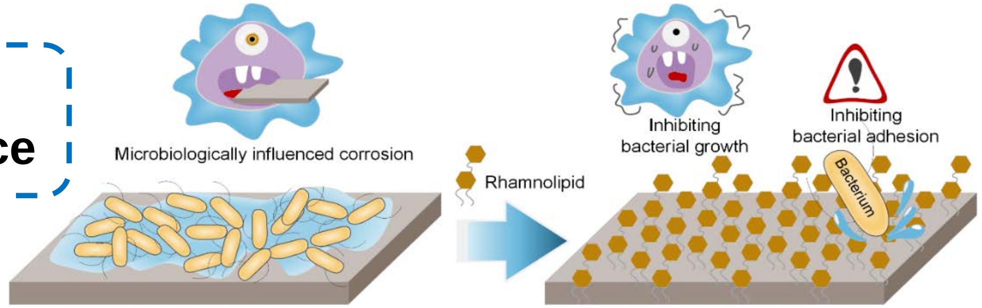
Strategy: Sessile cells in biofilm hard to be killed → Planktonic cells easy to be addressed

Problems → **Commercial biocides** → **Problems needed solved**

Drug resistance → High concentration poor efficiency

Low cost
No drug resistance



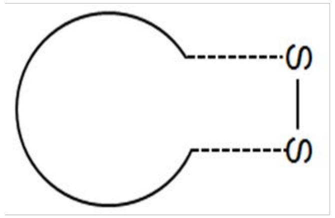


Efficacy increase

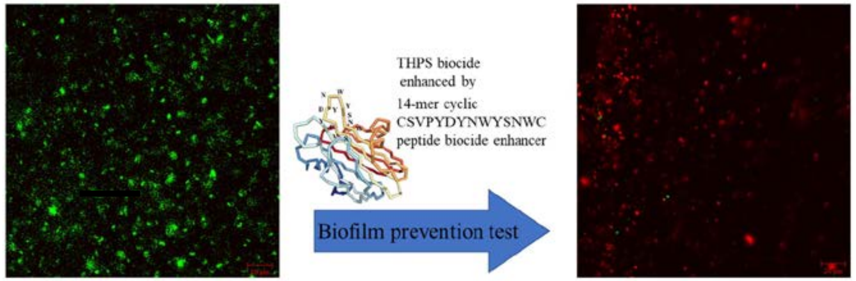
Prevent cell growth
Prevent biofilm formation
Prevent corrosion

Microbial corrosion protection in oil and gas field

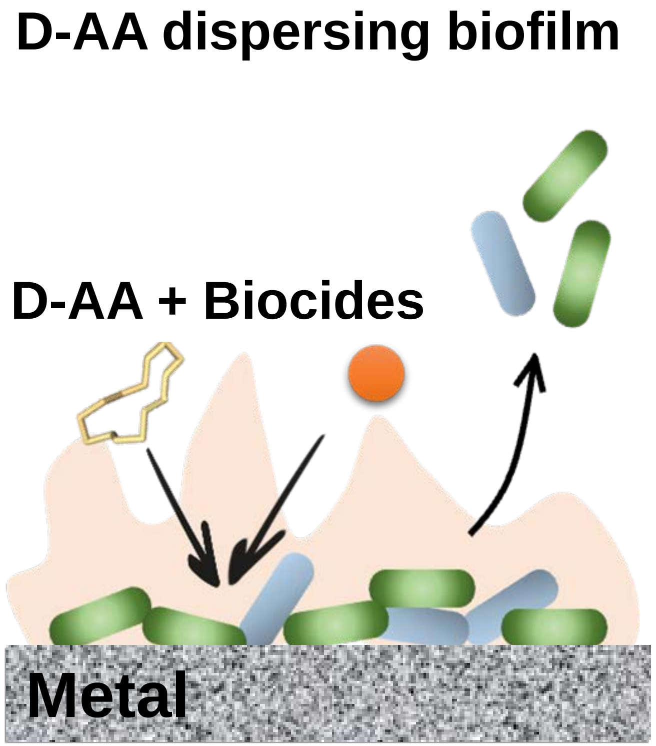
D-amino acid chain enhanced biocide on the mitigation of corrosive biofilm

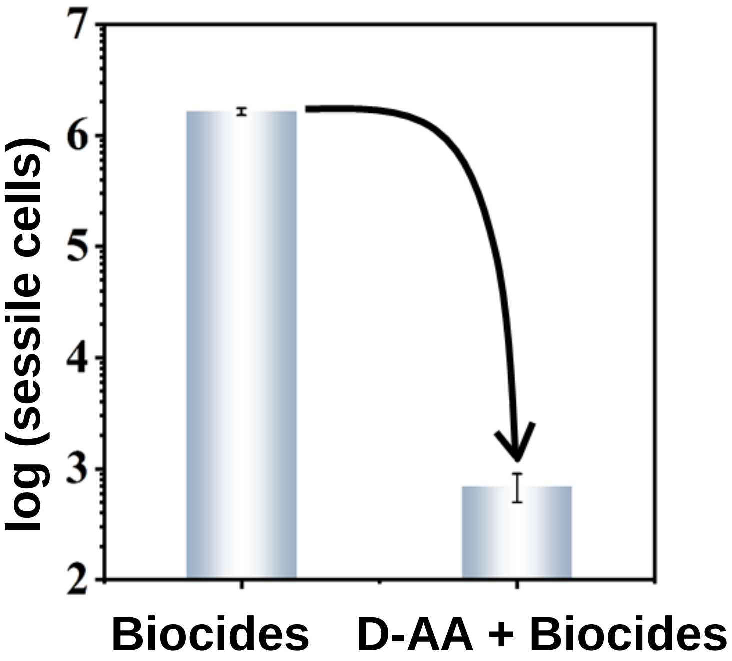


Secretions of the sea anemone



Bactericidal rate 90%





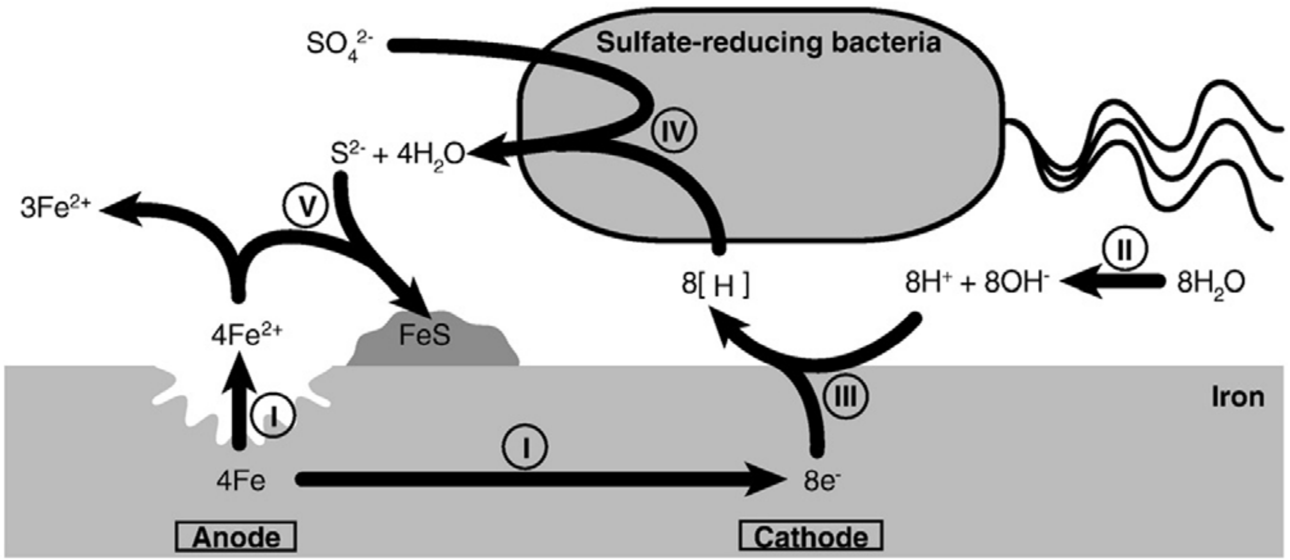
Biocide decreased sharply

Reducing biocide usage; addressing biocide overuse; achieving eco-friendly goal

Contents

The mechanism and protection of microbial corrosion in oil and gas field

Cathodic Depolarization Theory (CDT), Kühr and Vlugt in 1934



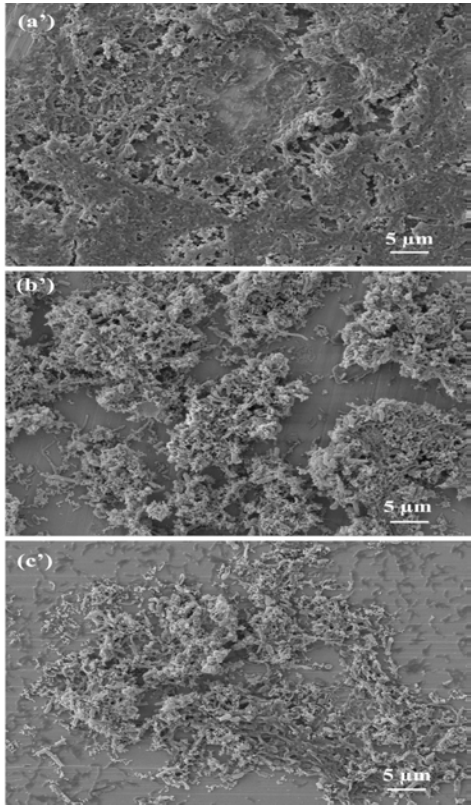
Scheme of iron corrosion by SRB based on cathodic depolarization theory (CDT)

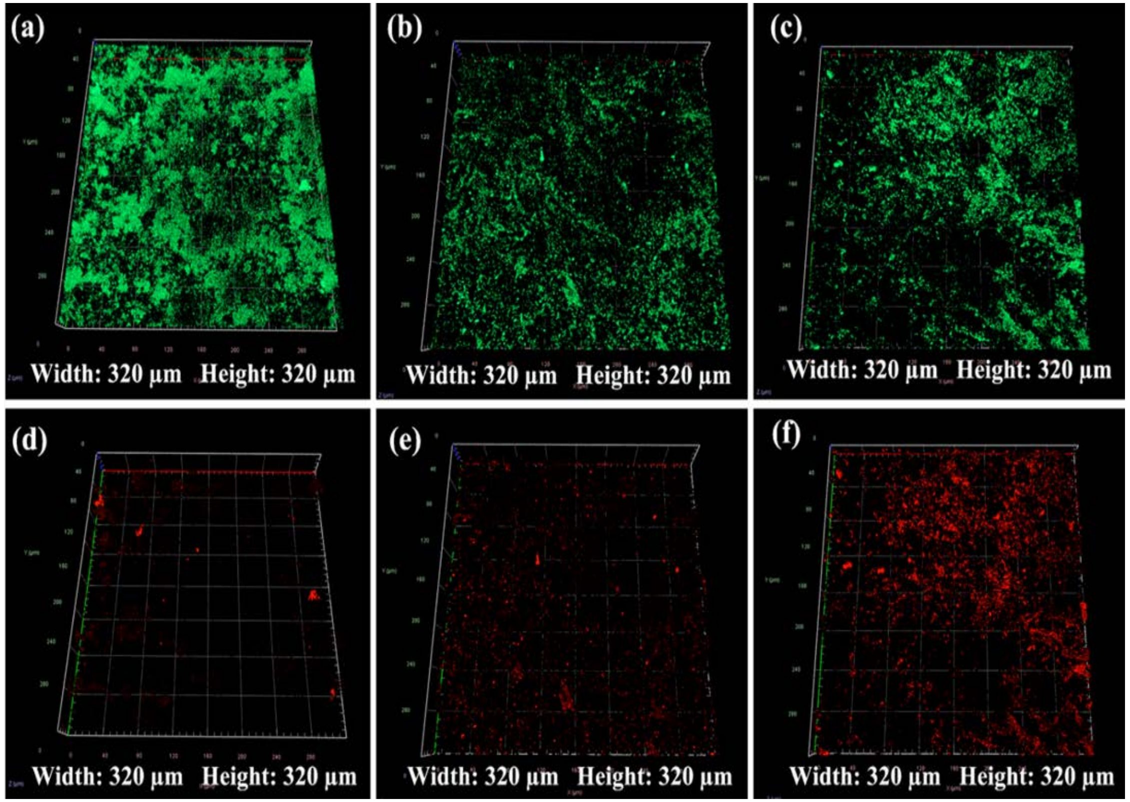
SRB secrete hydrogenase, which lowers the activation energy for the desorption of hydrogen atoms and consumes molecular hydrogen, causing a depolarization effect. This promotes the cathodic reaction, thereby accelerating corrosion.

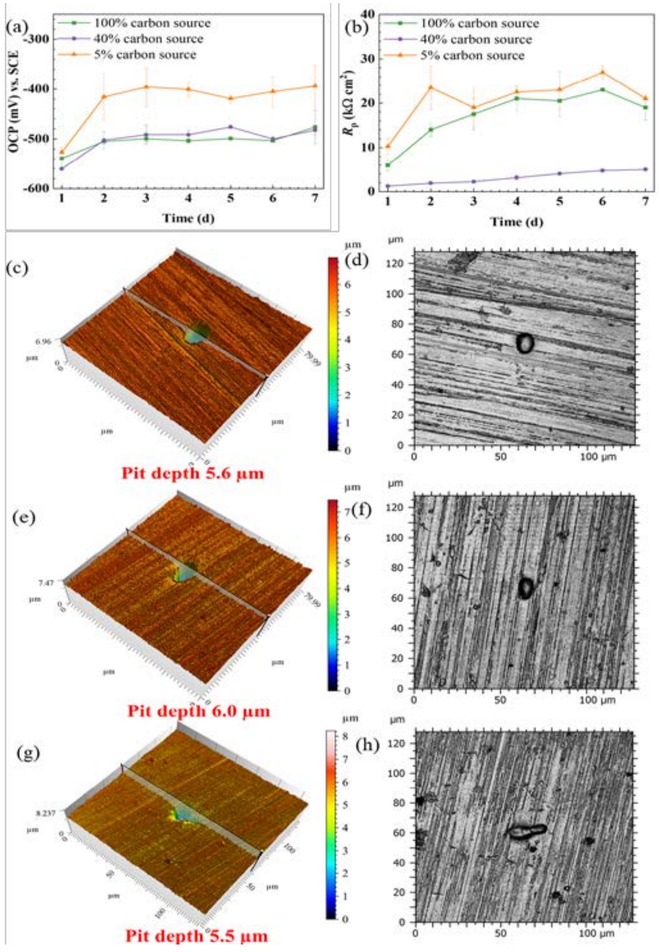
Hydrogenase is a key role.

The mechanism and protection of microbial corrosion in oil and gas field

Under carbon source starvation





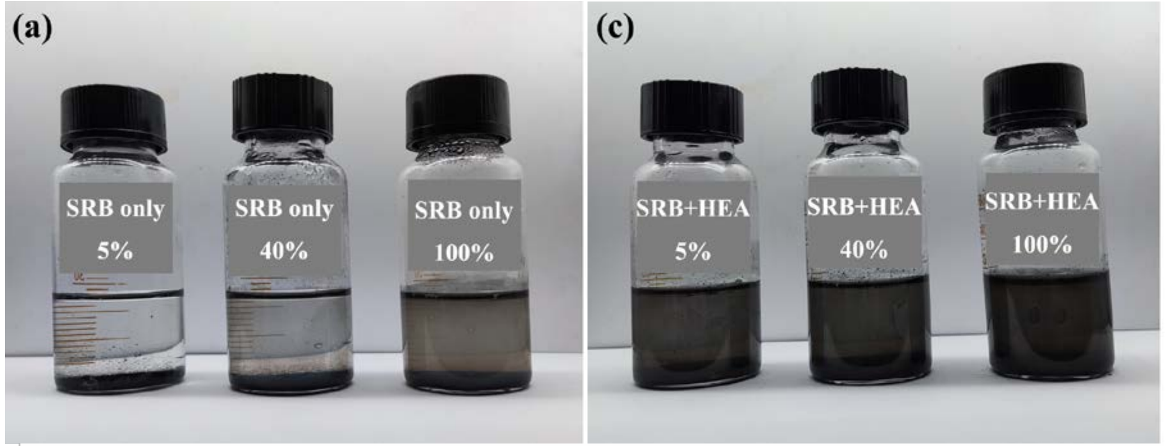


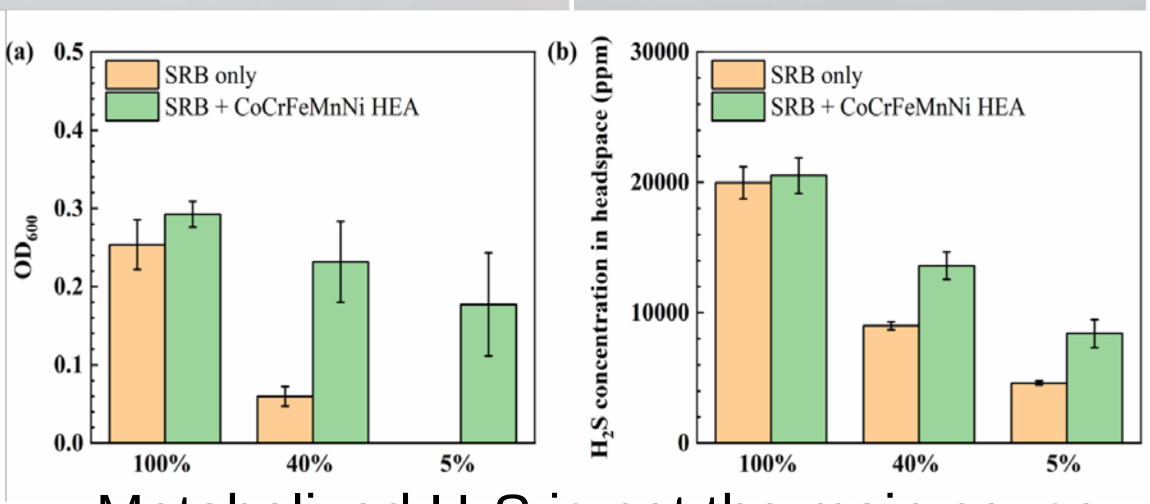
Biofilms on metal surfaces under SEM and CLSM and localized corrosion under different carbon source levels

D. vulgaris **biofilm formed with less thickness and more dead cells under starved conditions;**

D. vulgaris **induced more serious localized corrosion under starved conditions.**

The mechanism and protection of microbial corrosion in oil and gas field

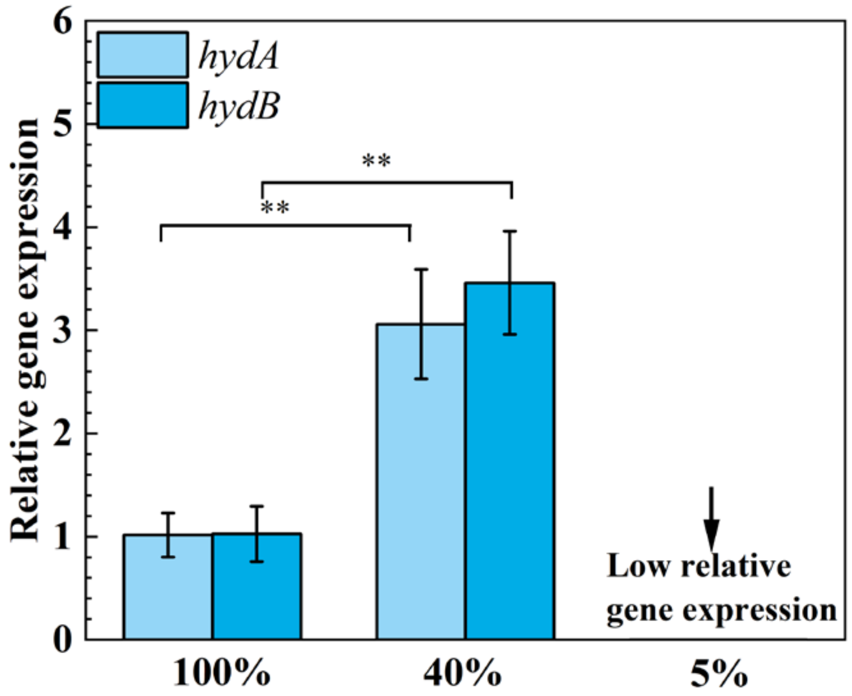




Metabolized H_2S is not the main cause

Hydrogenase genes:

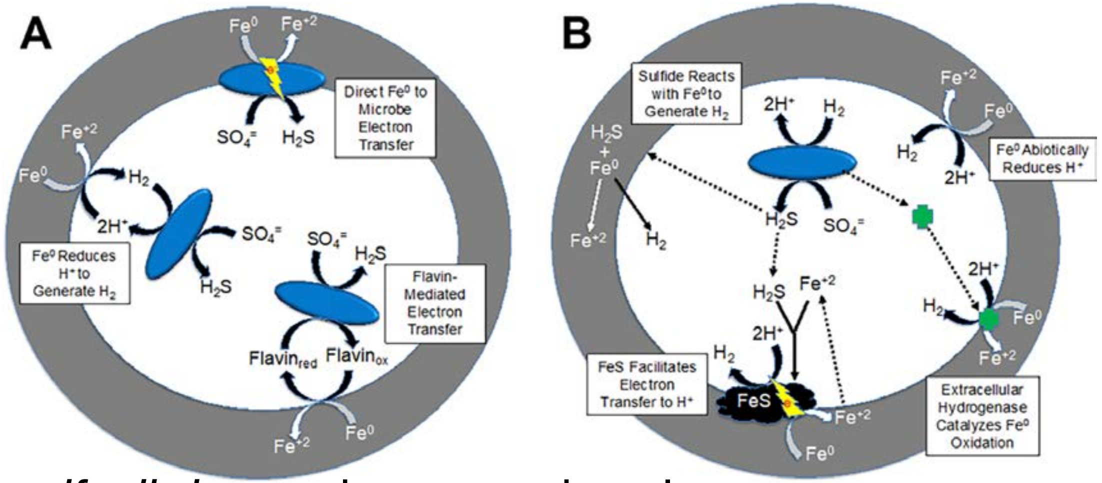
hydA, *hydB* (DVU_1769-1770)



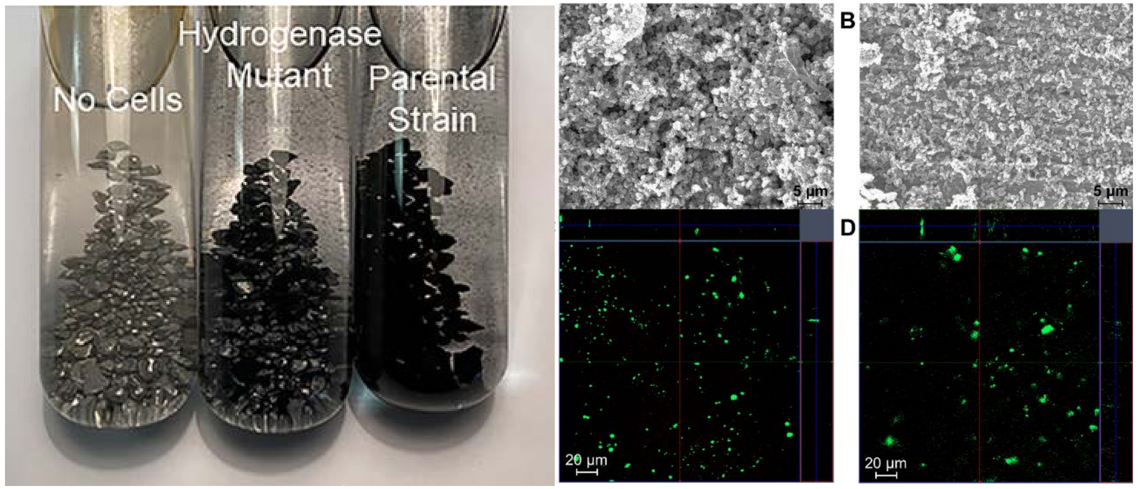
The upregulation of *hydA* and *hydB* in the biofilms under 40% carbon source increased;

The indirect electron transfer mediated by $2H^+/H_2$ might play an important role.

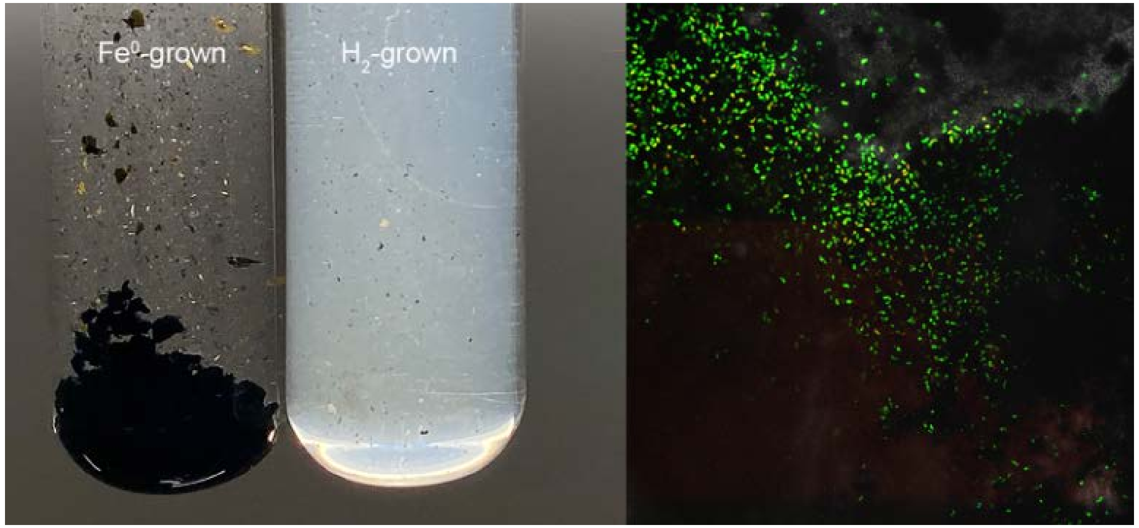
Elucidating MIC mechanisms with a hydrogenase-deficient strain of *D. vulgaris*



Desulfovibrio species to receive electrons.



Appearance and biofilm images of inoculated with either the hydrogenase mutant or parental strain.

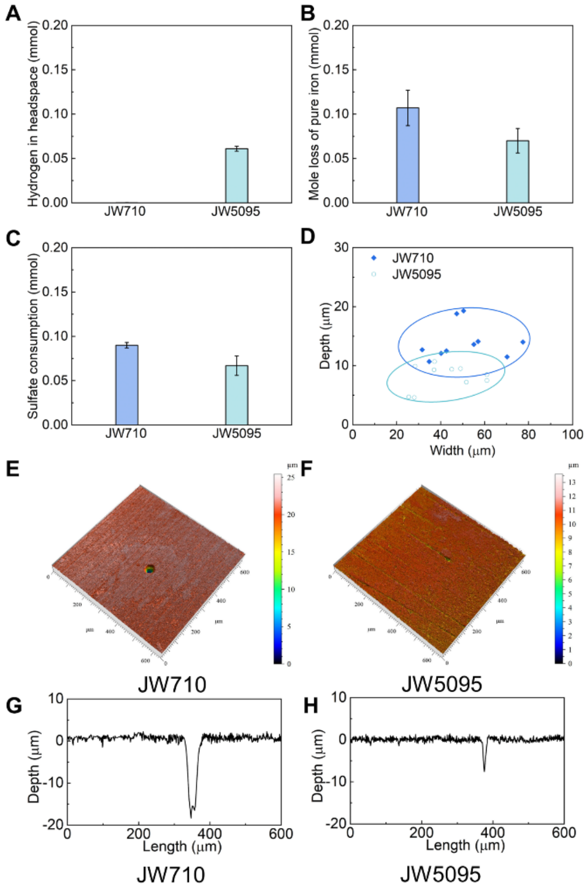


Parental strain:
Markerless genetic in wild type

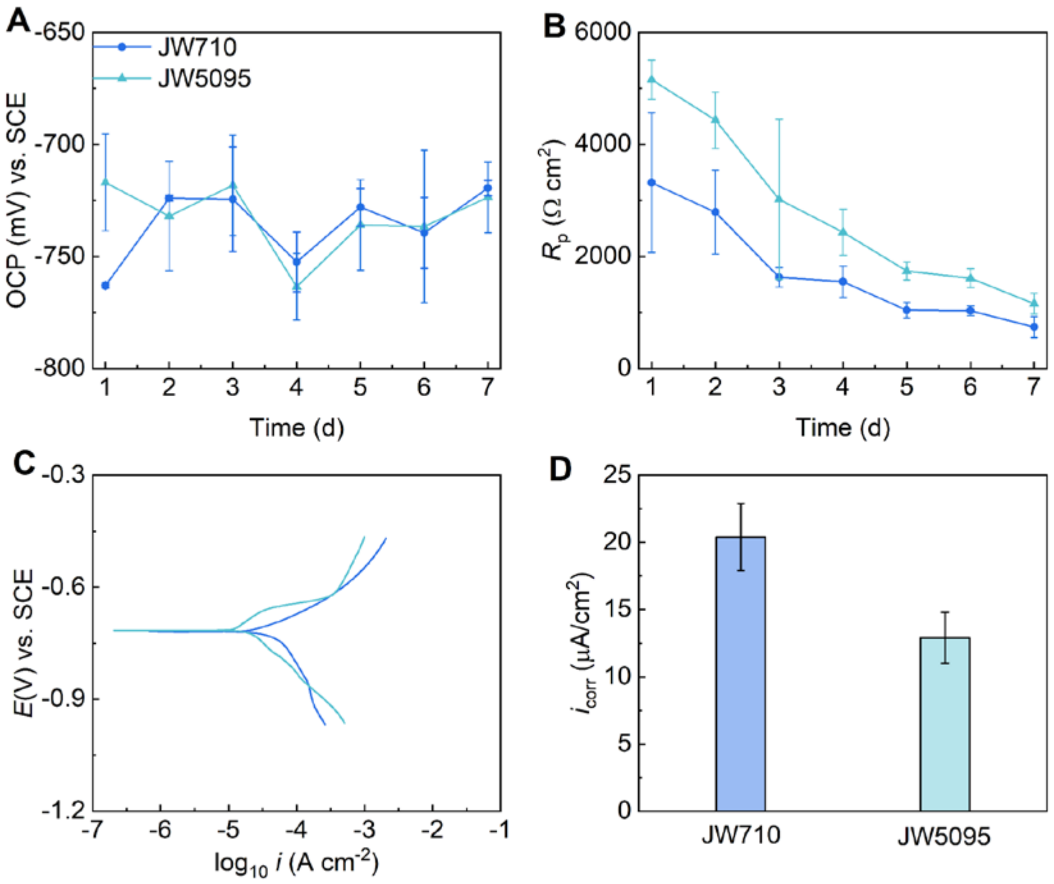
Hydrogenase mutant:
All hydrogenase genes knockout

The mechanism and protection of microbial corrosion in oil and gas field

The corrosion comparison of two strains



Metabolic and corrosion parameters

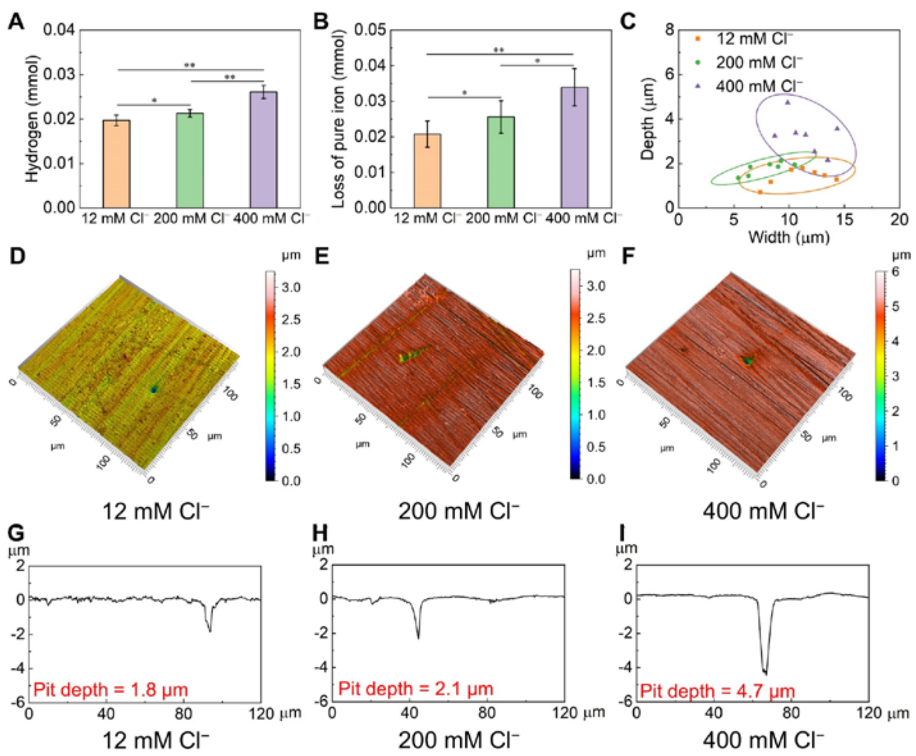


Electrochemical analysis

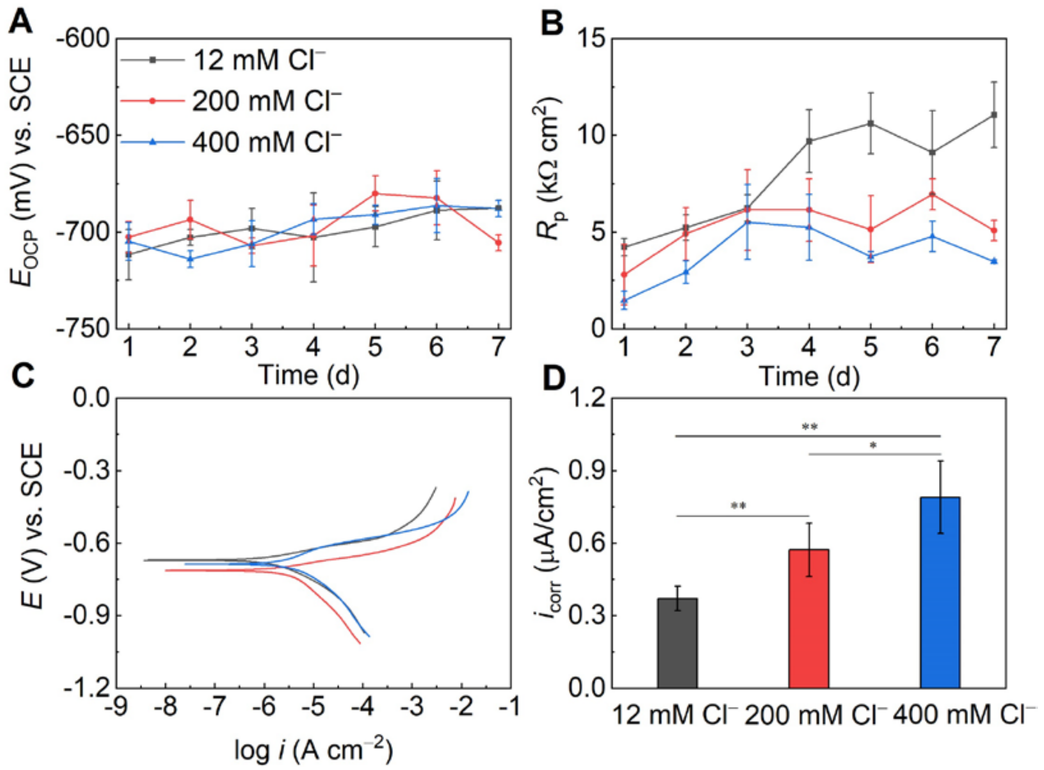
The parental H_2-consuming strain corroded more Fe^0 than the mutant strain, but hydrogenase-deficient strain also induced corrosion.

The mechanism and protection of microbial corrosion in oil and gas field

Higher chloride increases Fe^0 corrosion



Pitting corrosion



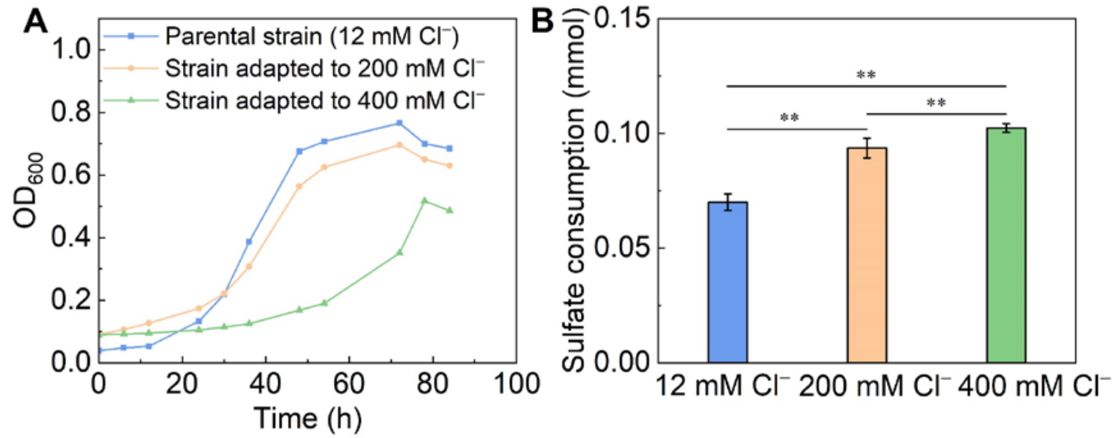
Electrochemical tests

Higher chloride concentrations promoted faster abiotic corrosion rates.

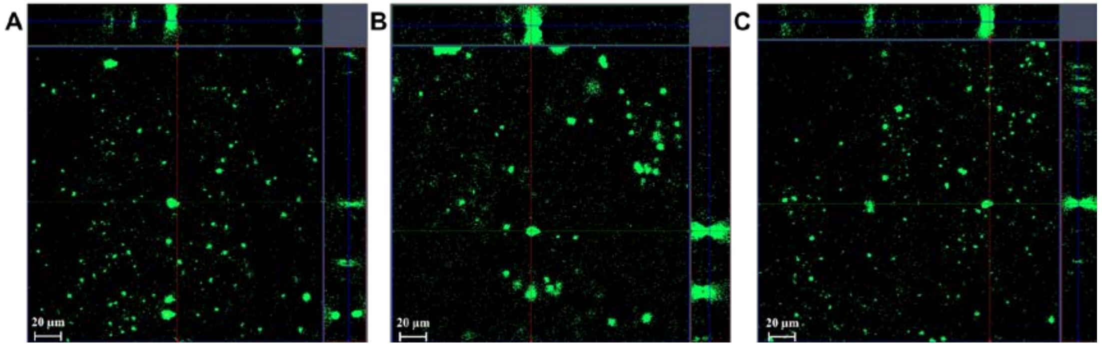
The mechanism and protection of microbial corrosion in oil and gas field

Increased chloride accelerates Fe^0 corrosion in the presence of *D. vulgaris*

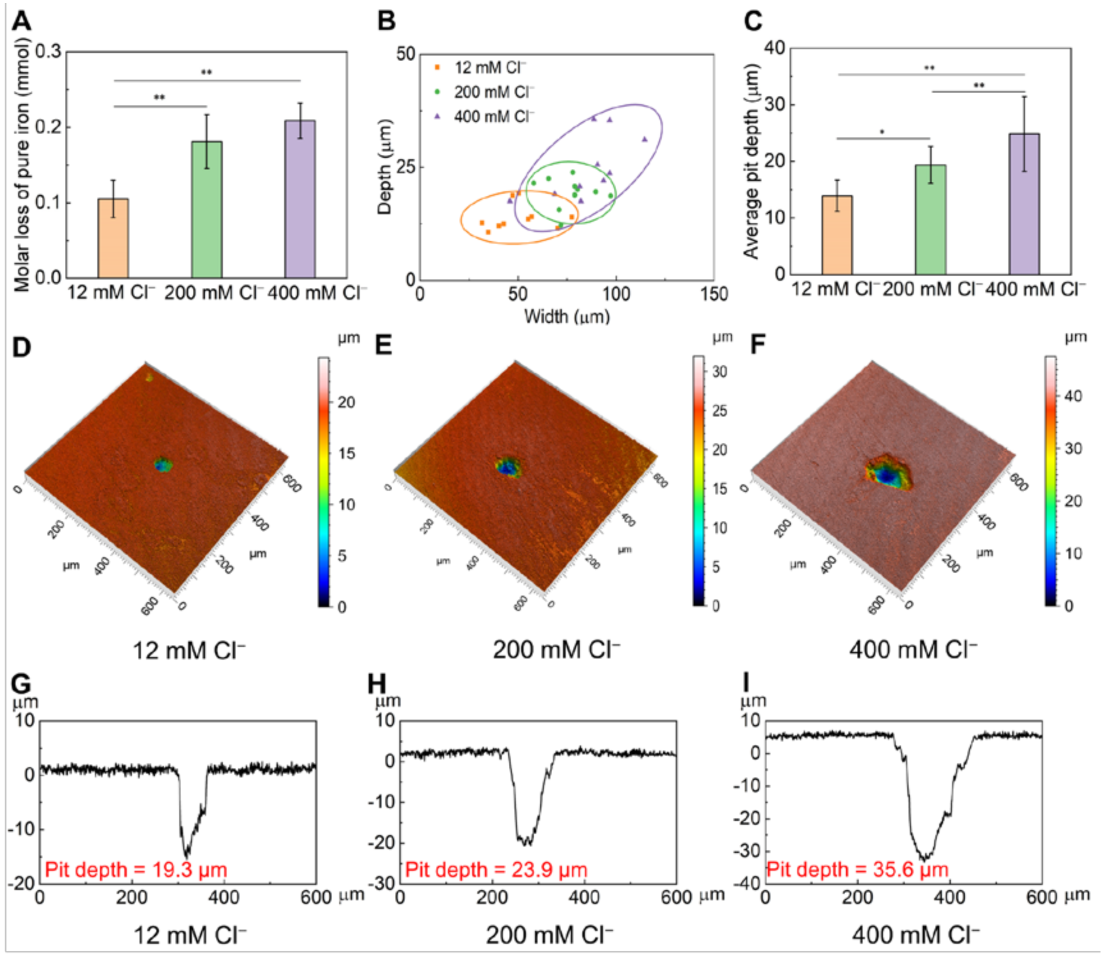
The adaption of *D.* vulgaris from fresh water to seawater



D. vulgaris growth and activity

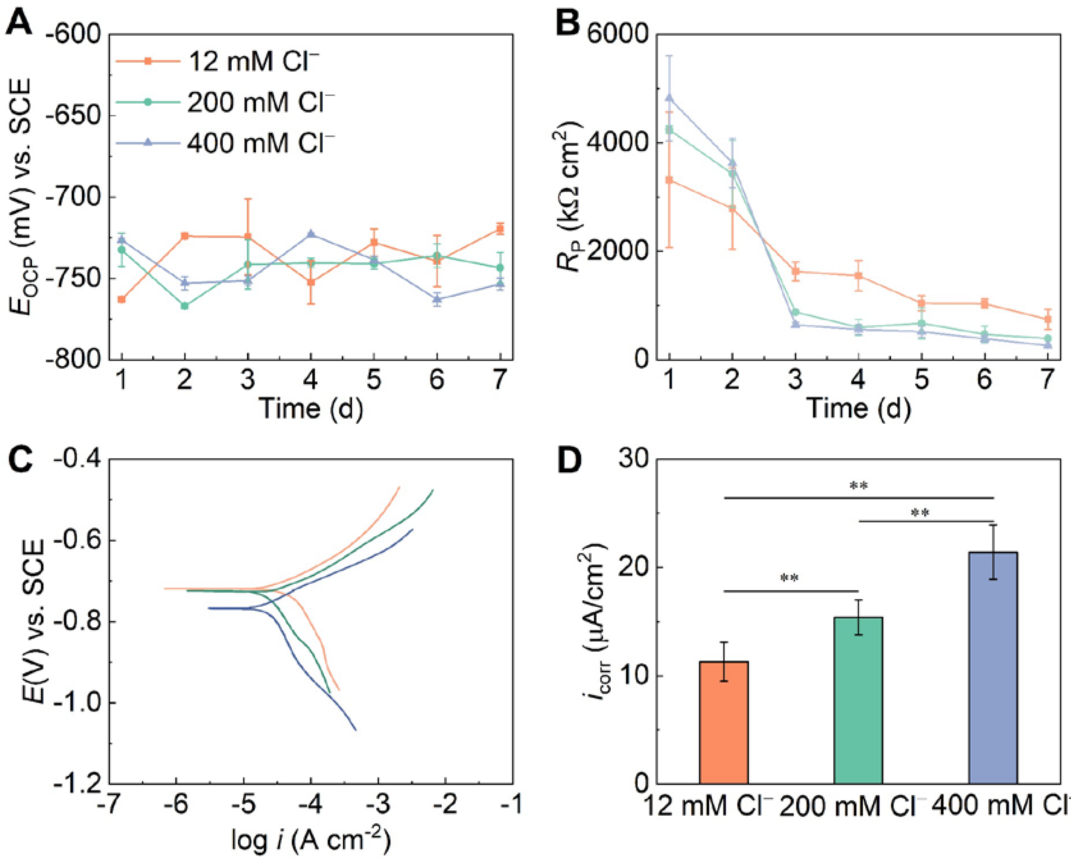


CLSM images of *D. vulgaris* cells on Fe^0.

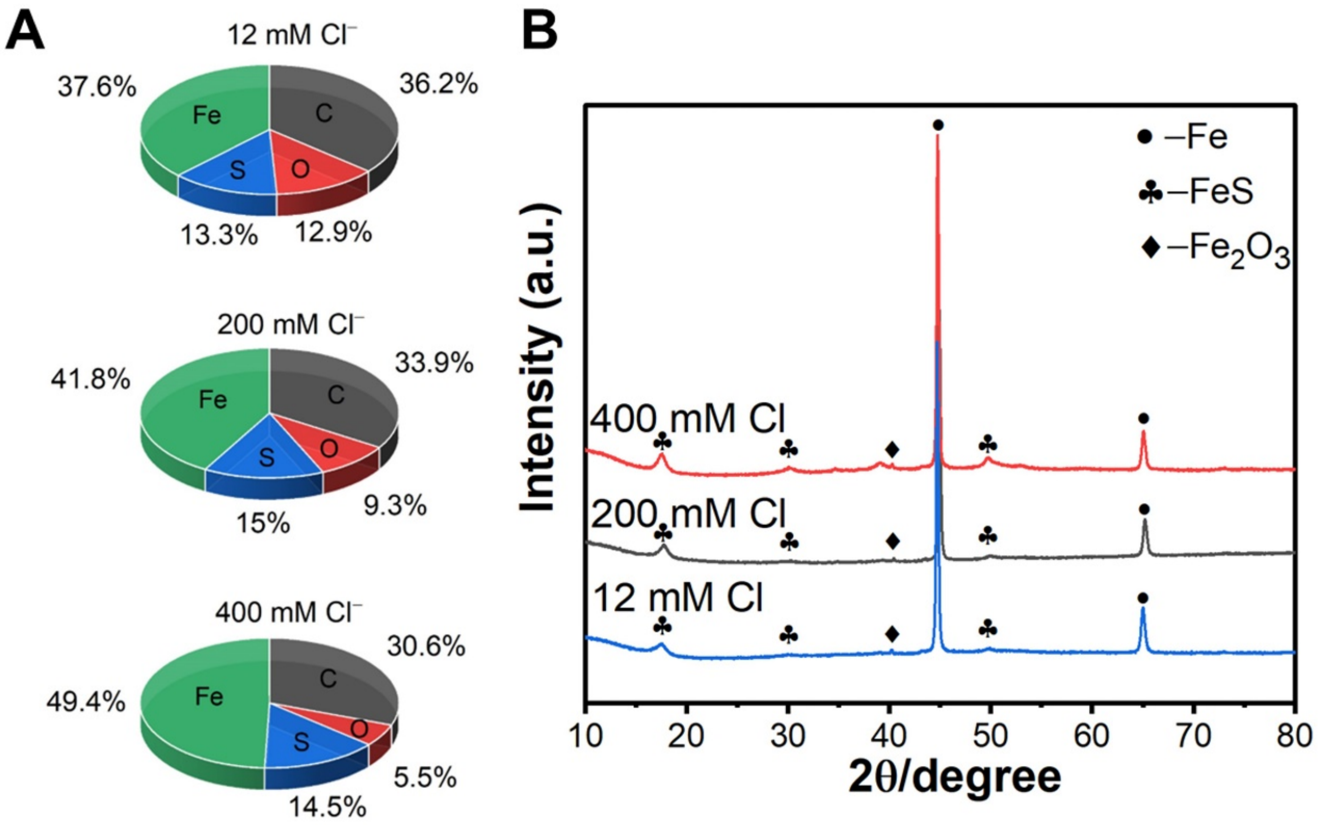


Influence of chloride on *D. vulgaris* Fe^0 corrosion.

The mechanism and protection of microbial corrosion in oil and gas field



Electrochemistry of Cl on *D. vulgaris* Fe^0 corrosion



Analysis of corrosion products with EDS and XRD

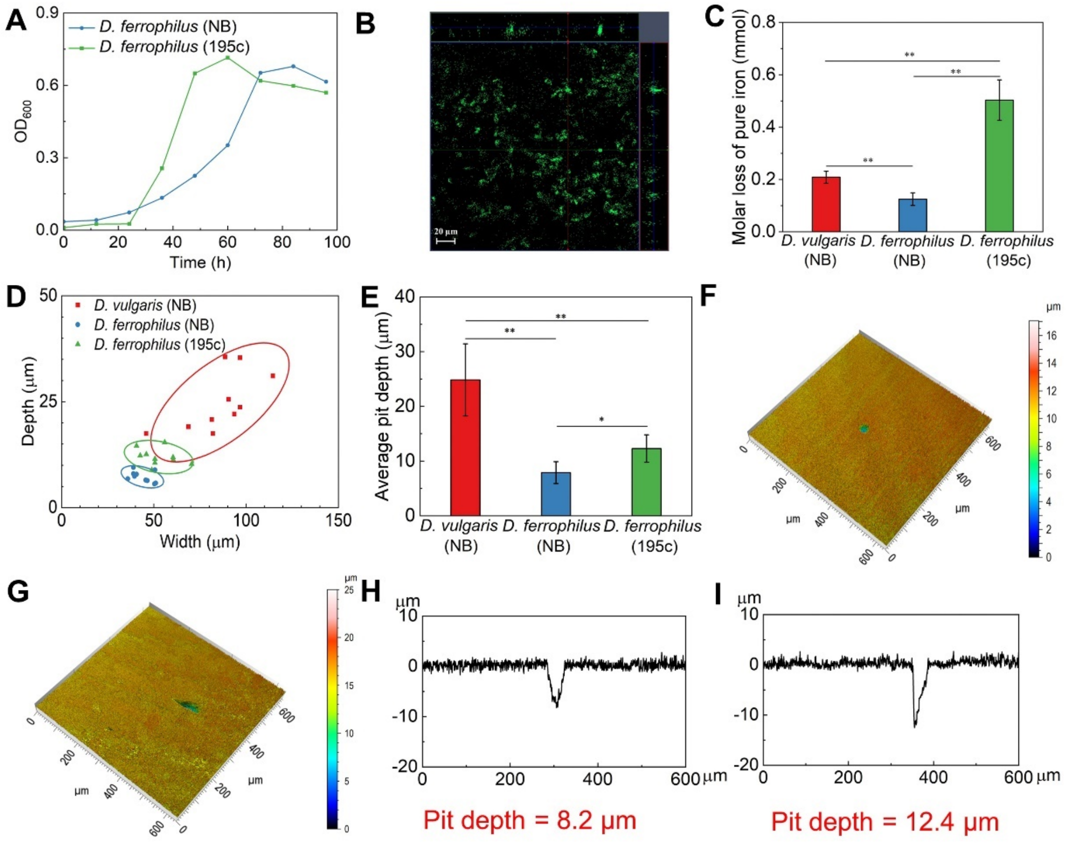
Fe^0 was corroded faster at higher c_{Cl}.

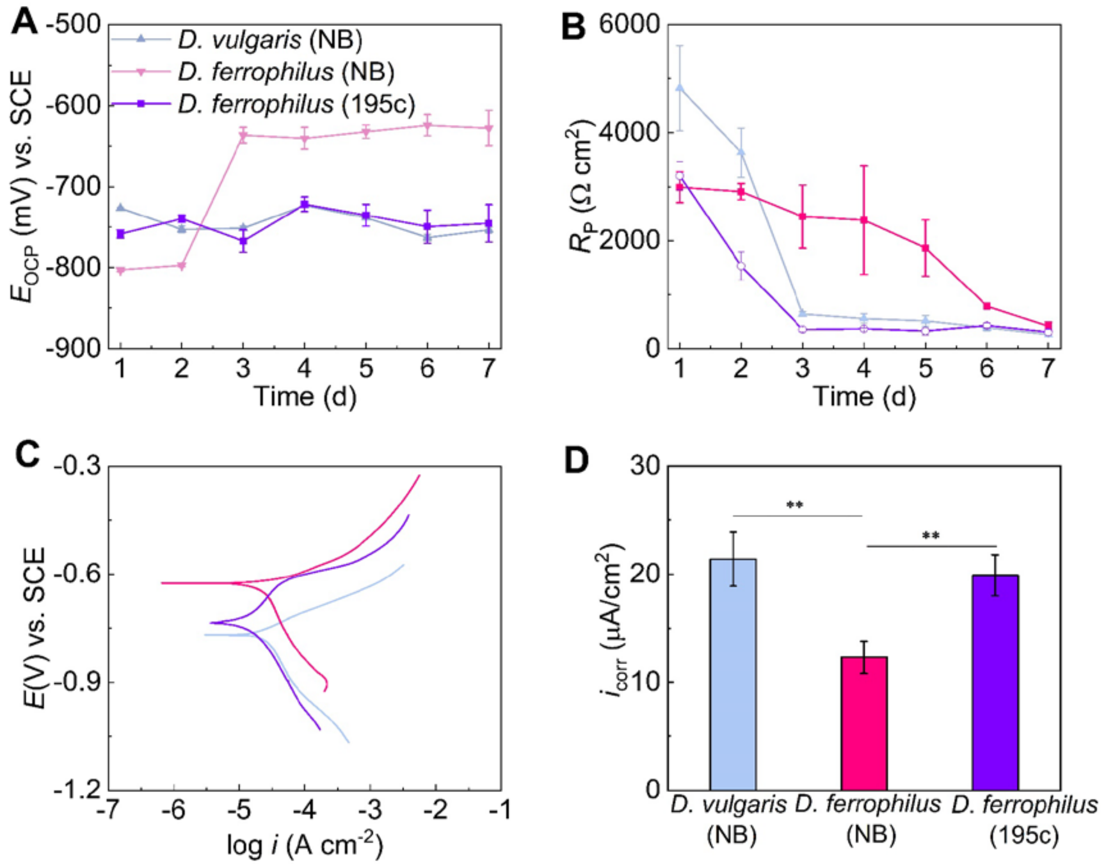
Corrosion products: iron sulfide or iron oxide;

Corrosion product formation was not influenced.

The mechanism and protection of microbial corrosion in oil and gas field

Corrosion rates in the presence of *D. ferrophilus* are media-dependent



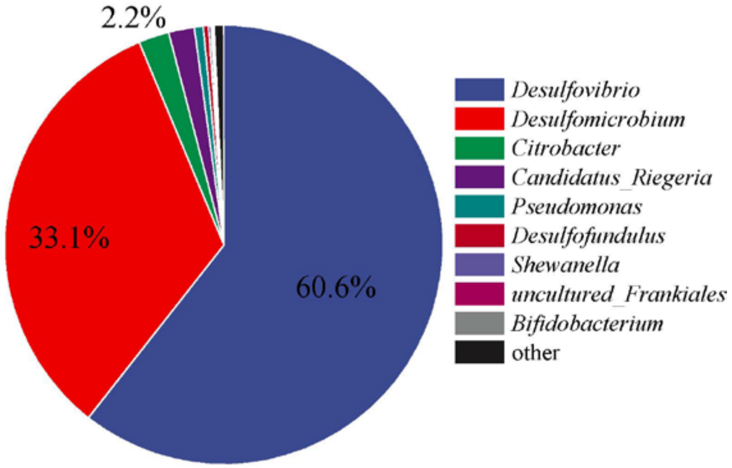


Corrosion in the presence of *D. ferrophilus* was also evaluated in the 195C and NB media.

Fe^{0} was corroded faster in the presence of *D. vulgaris* than *D. ferrrophilus* in the same marine NB medium.

Contents

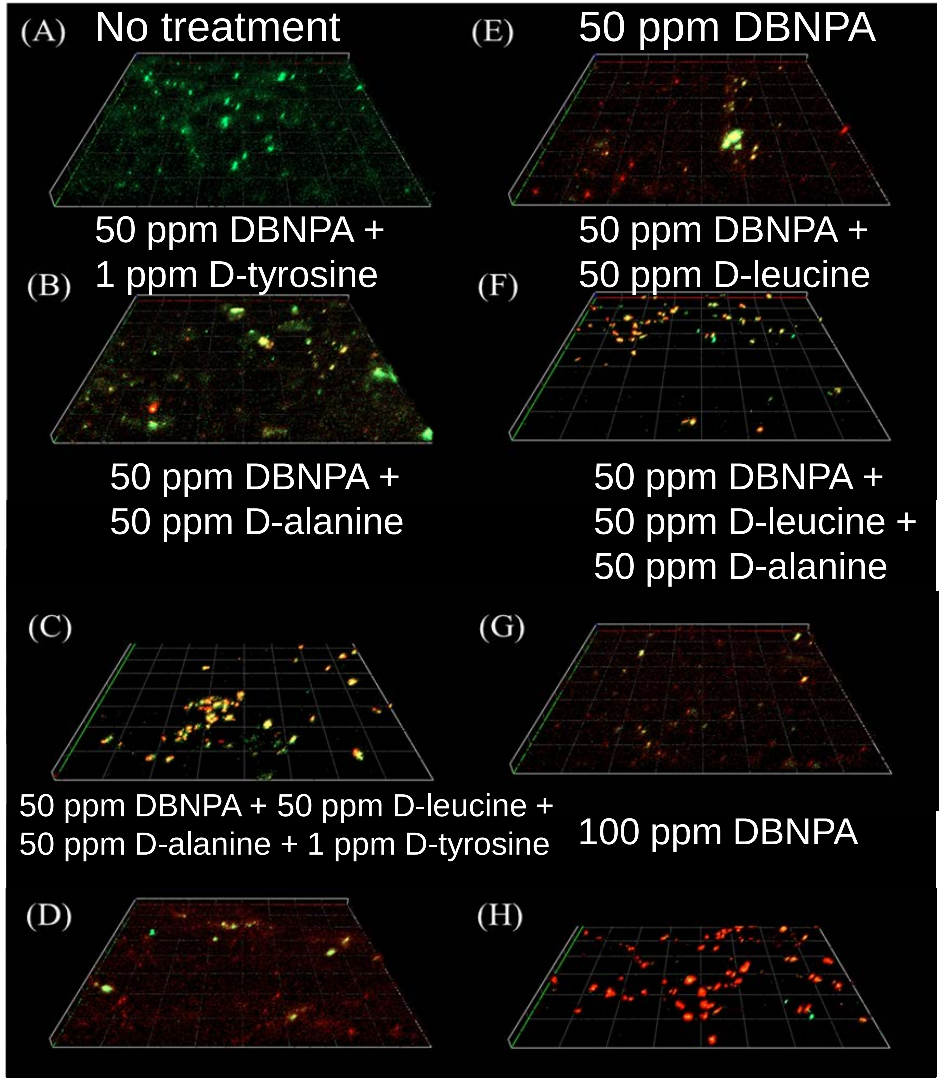
Shale microbiome MIC mitigated by biocide combined with D-AA

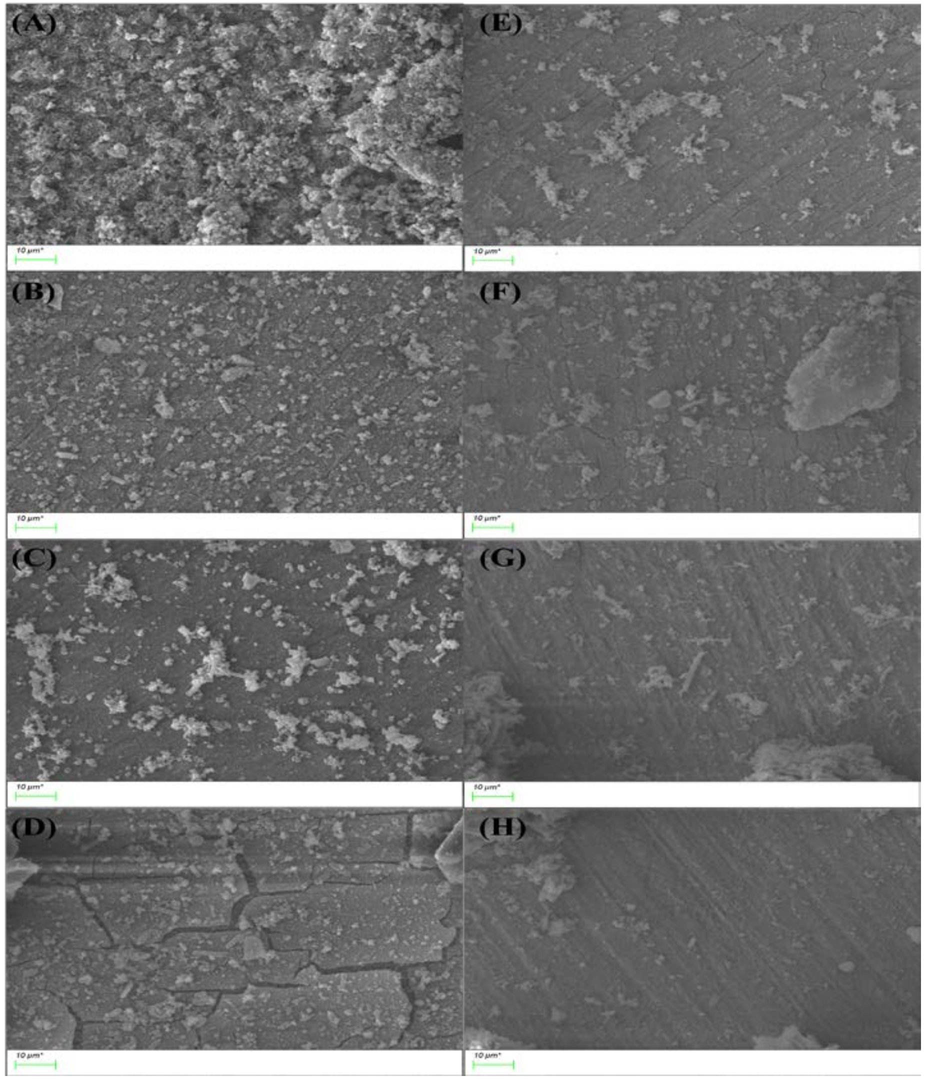


Microbial community from Weiyuan, Sichuan shale platform

Desulfovibrio and *Desulfomicrobium* bacteria dominated in tested shale gas microbiome

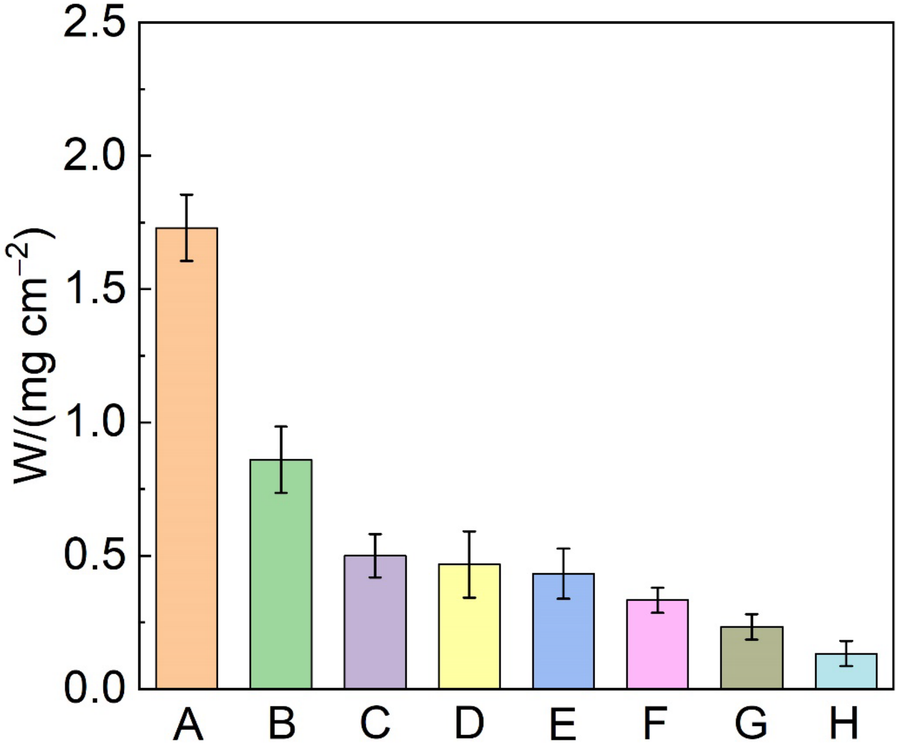
Shale microbiome MIC mitigated by biocide combined with D-AA

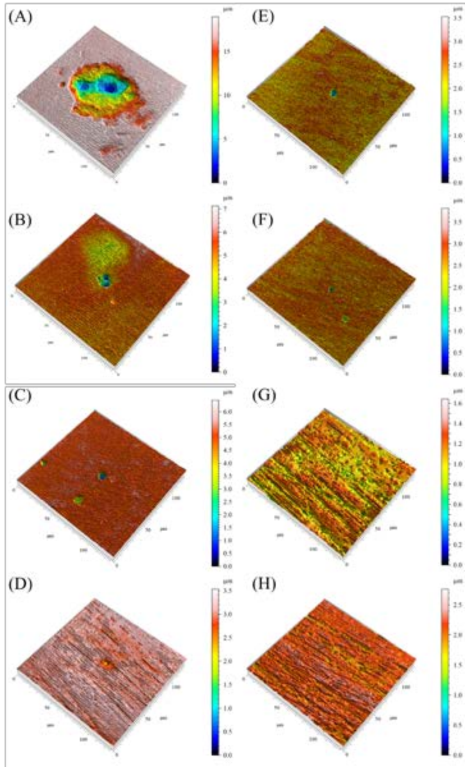


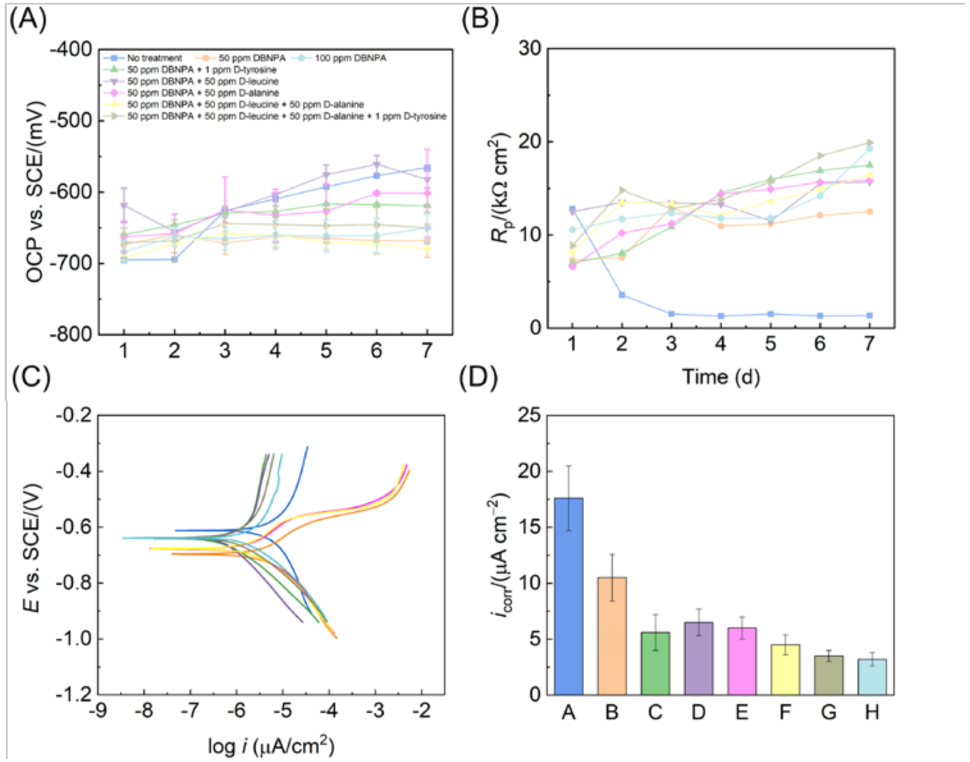


Biofilm coverage reduced with the addition of D-amino acid

Shale microbiome MIC mitigated by biocide combined with D-AA



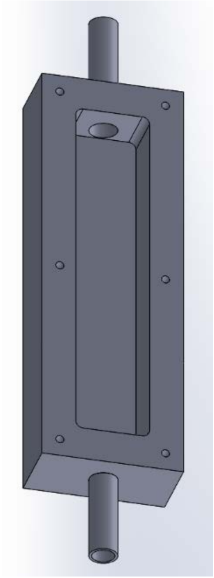




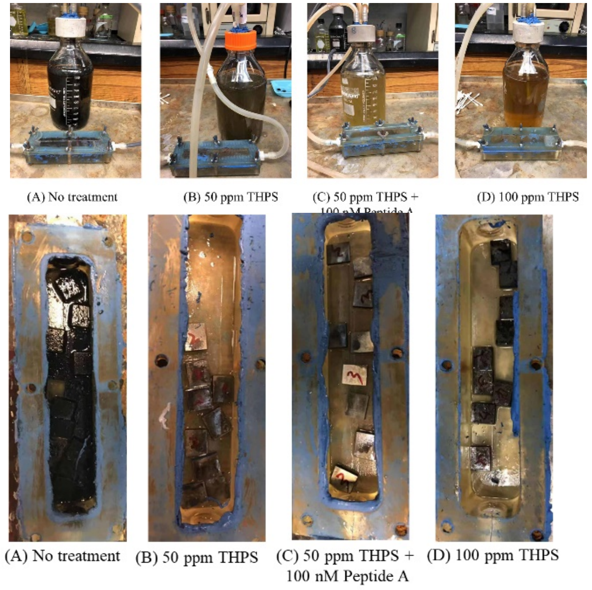
Corrosion and electrochemical analysis with different treatments

D-tyrosine at a low dosage of 1 ppm enhanced DBNPA considerably

Peptide (loop D-AA) as biocide enhancer mitigate oil MIC in flow loop

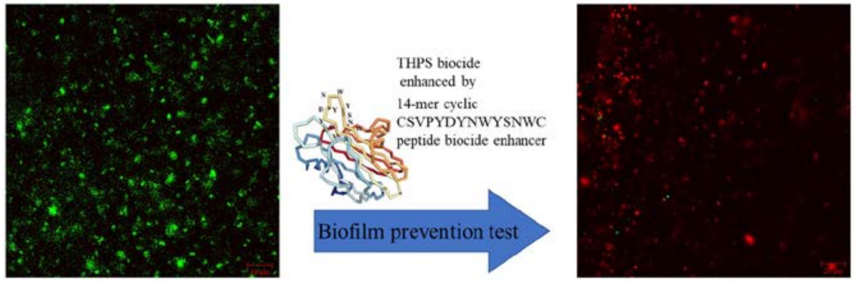


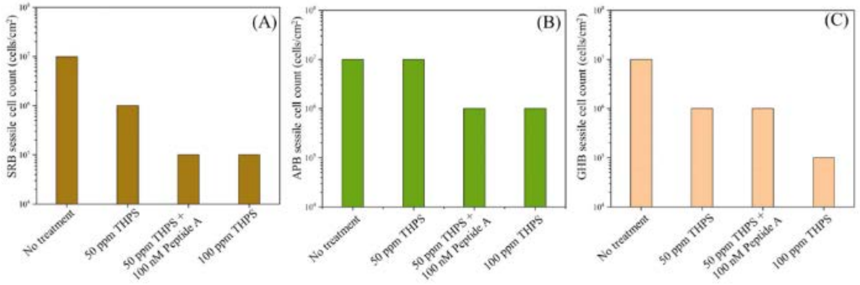
Flow loop in anaerobic chamber

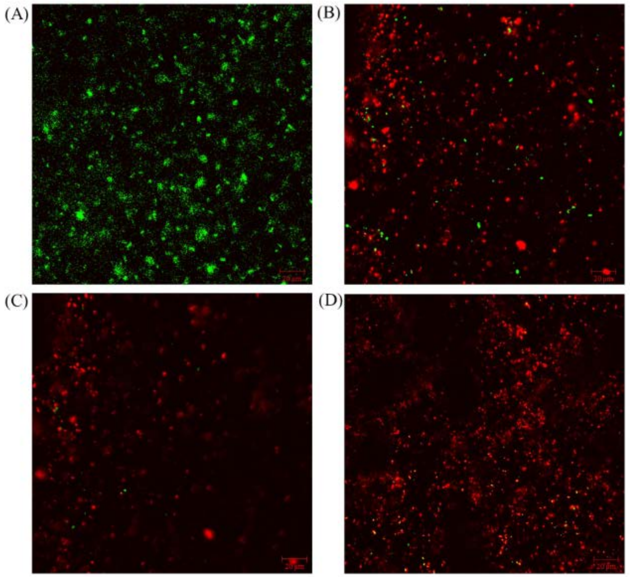


Microbial Consortium

Microbe	%
Garciella spp.	92.1
Desulfovibrio vulgaris	3.1
Bacillales spp.	3.0
Tissierella spp.	0.88
Thermoanaerobacterales spp.	0.13
Porphyromonadaceae spp.	0.11
Sphingomonas spp.	0.07
Unknown	0.63



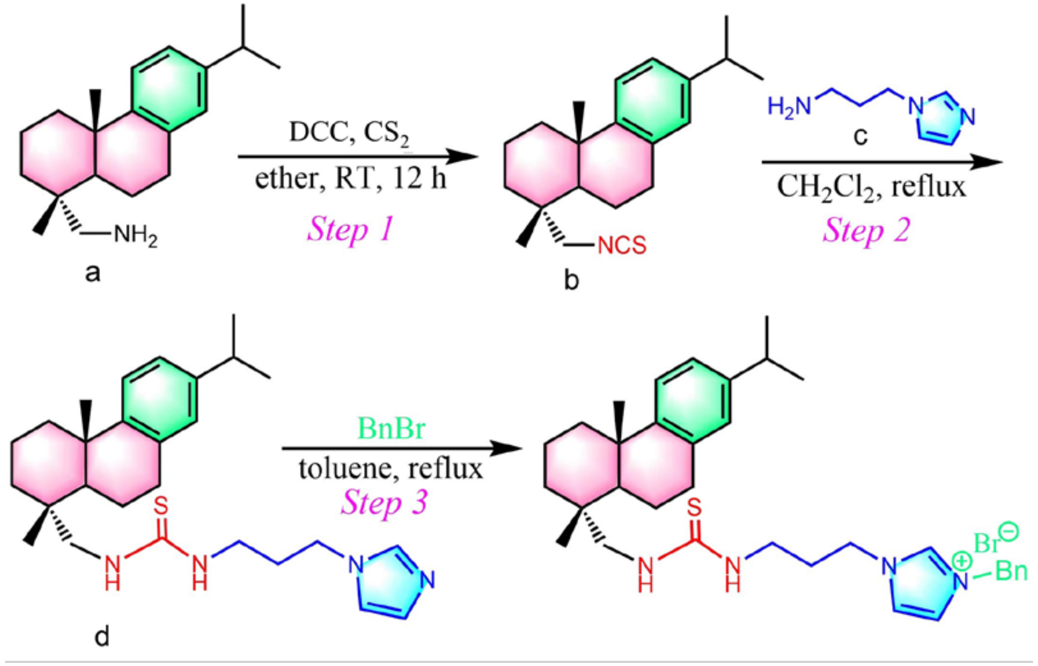




Peptide enhance DBNPA mitigated MIC caused by Consortium from oil field

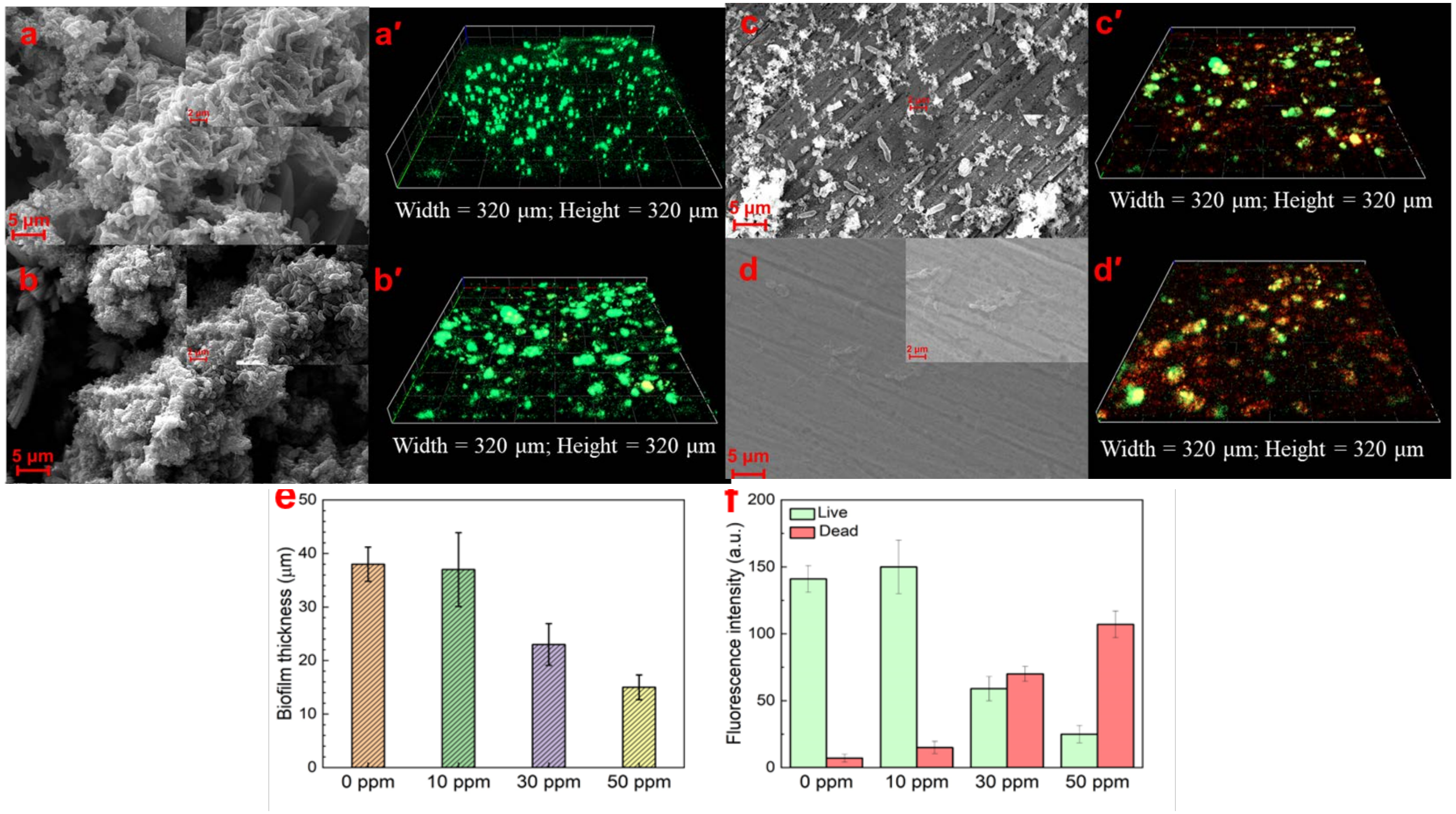
The mechanism and protection of microbial corrosion in oil and gas field

Eco-friendly RTIQAS synthesis and performance



RTIQAS synthesis

Rosin linked with QAS

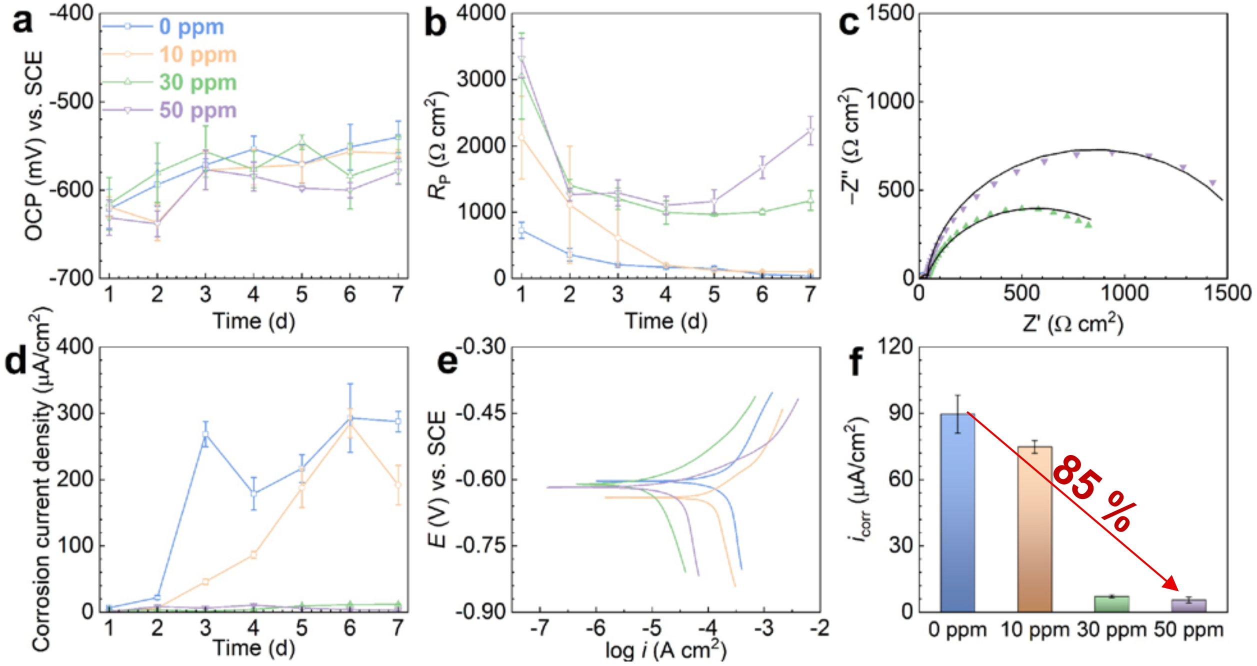


SEM, CLSM, and florescence with different treatments

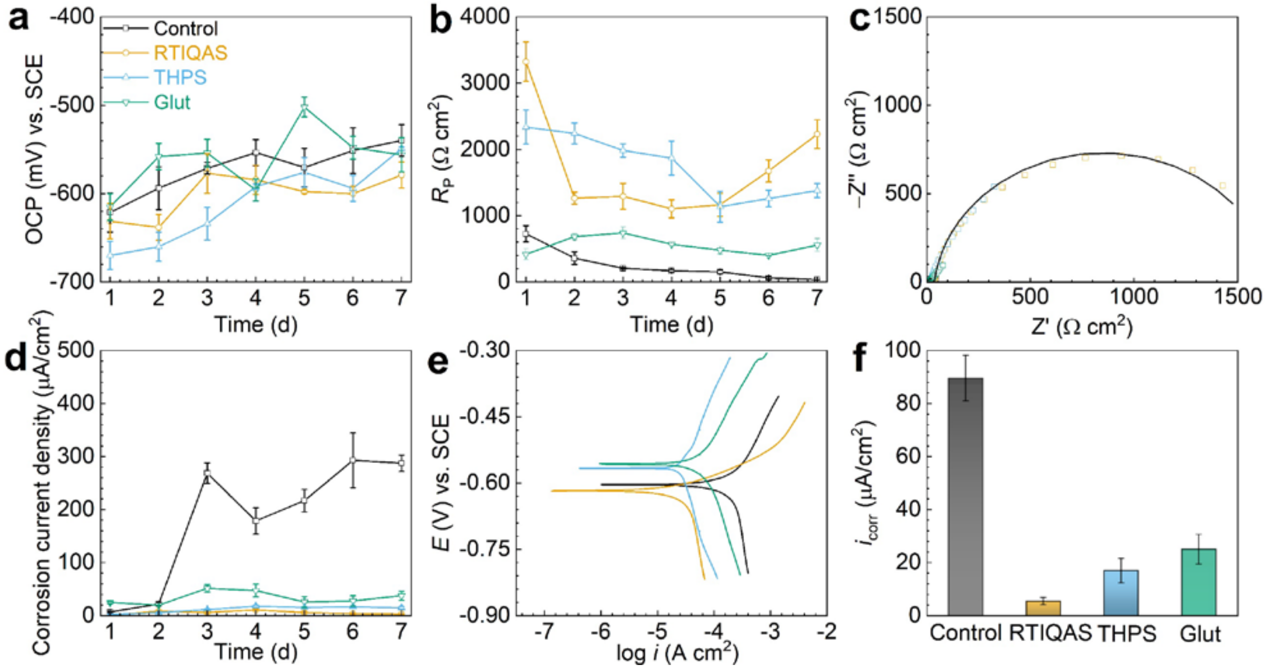
50 ppm RTIQAS killed most *D. vulgaris* cells on X80 surface.

The mechanism and protection of microbial corrosion in oil and gas field

Electrochemical tests



Different RTIQAS against *D. vulgaris* MIC



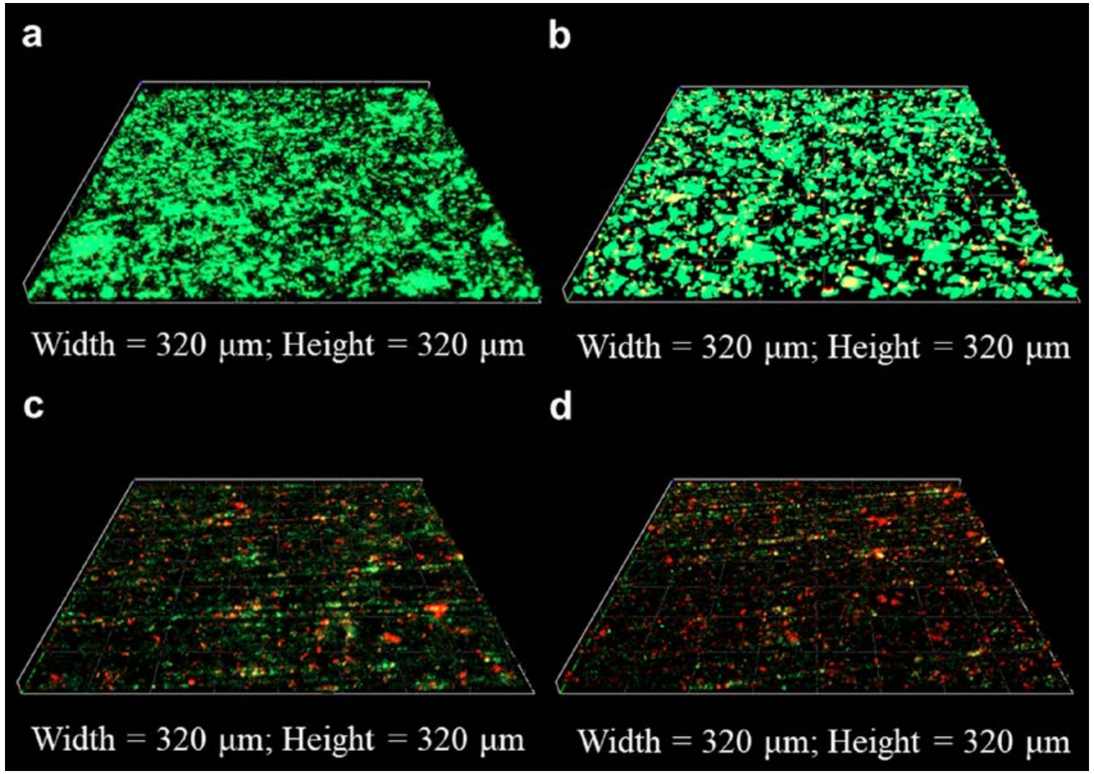
Control vs. RTIQAS, glutaraldehyde and THPS

Electrochemical data supported weight loss

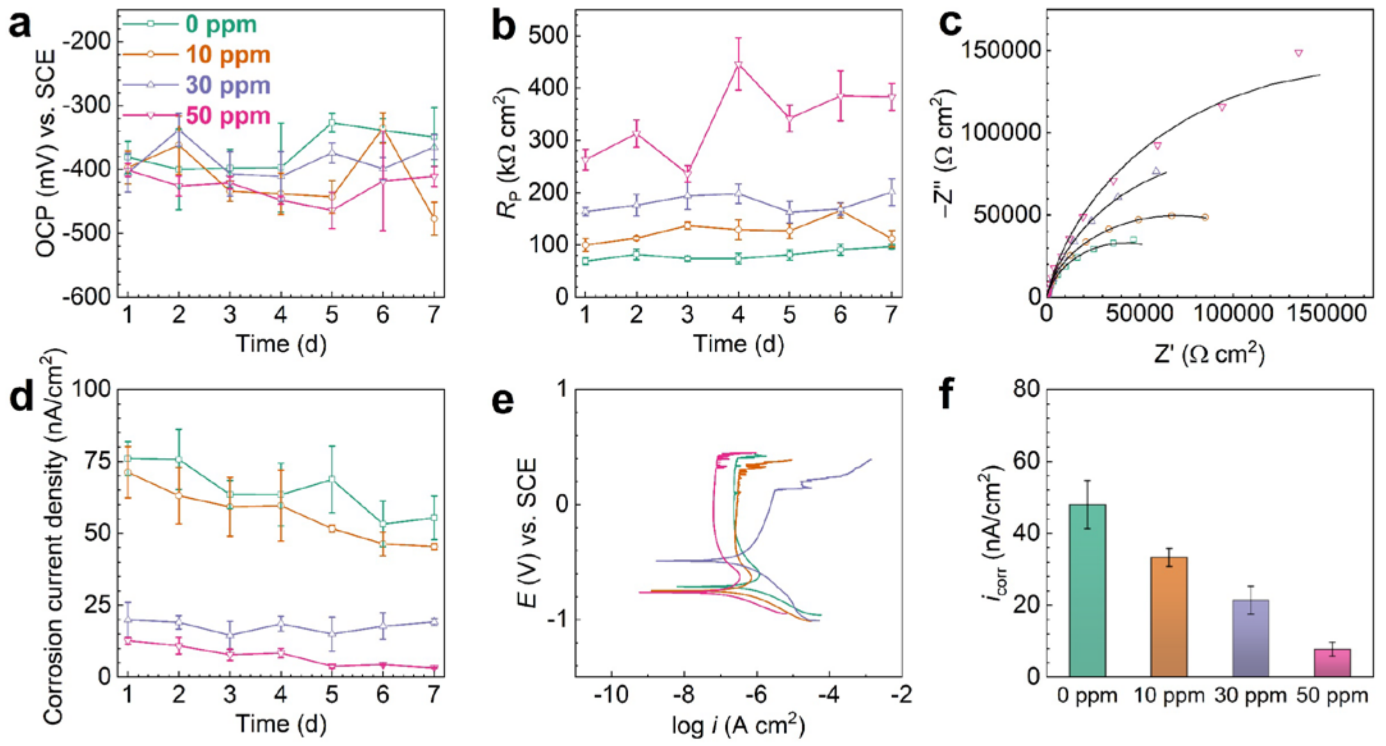
RTIQAS is better than THPS and glutaraldehyde

The mechanism and protection of microbial corrosion in oil and gas field

RTIQAS against 316L stainless steel MIC by aerobic *B. licheniformis* biofilm



Biofilm under CLSM

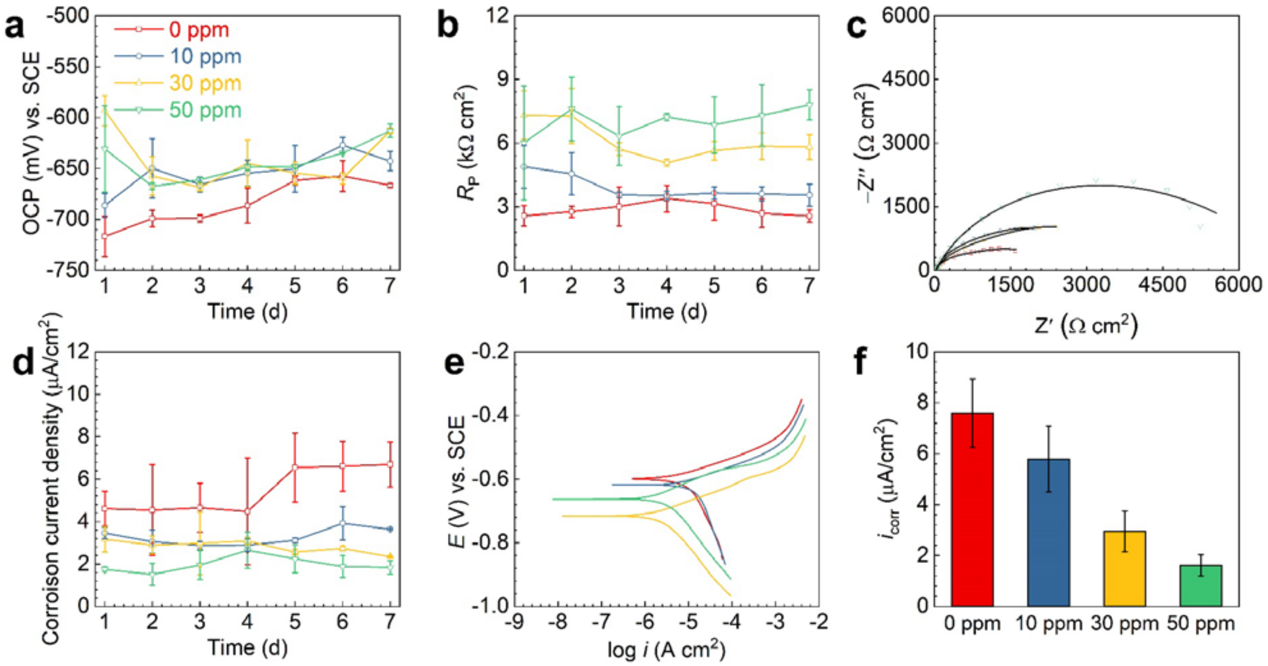


Electrochemical results

Antibacterial ability against aerobic biofilm

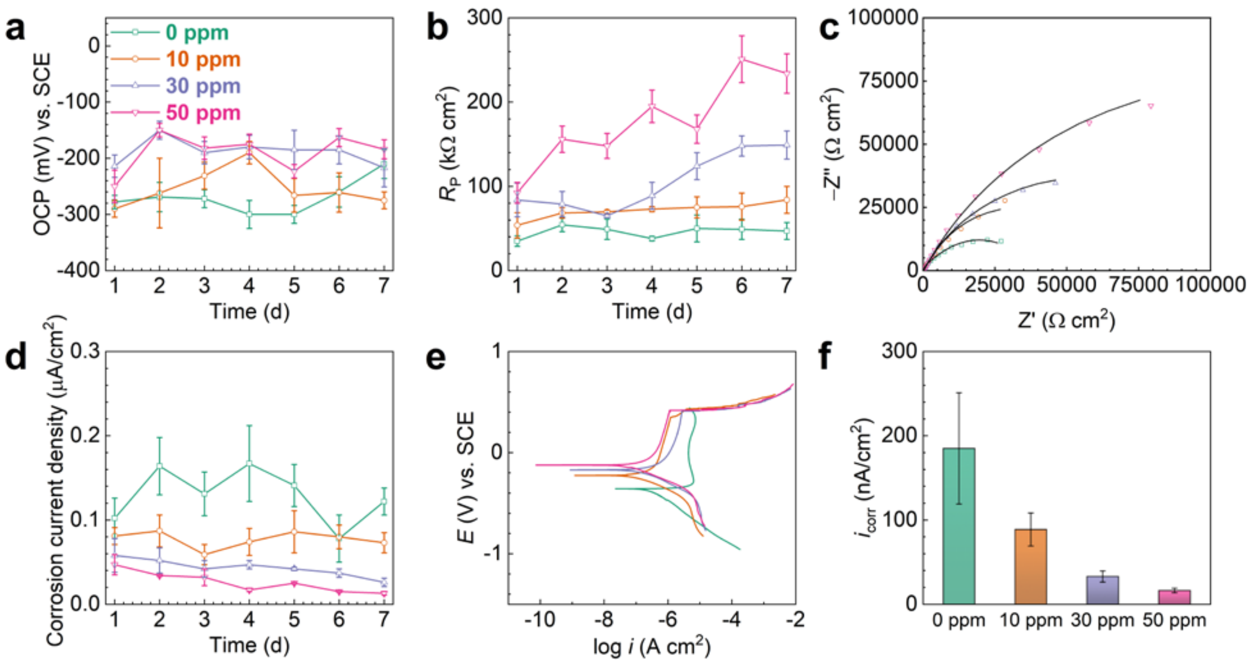
Corrosion inhibition of *B. licheniformis* MIC

Corrosion inhibition of RTIQAS in abiotic condition



X80 carbon steel in abiotic anaerobic medium

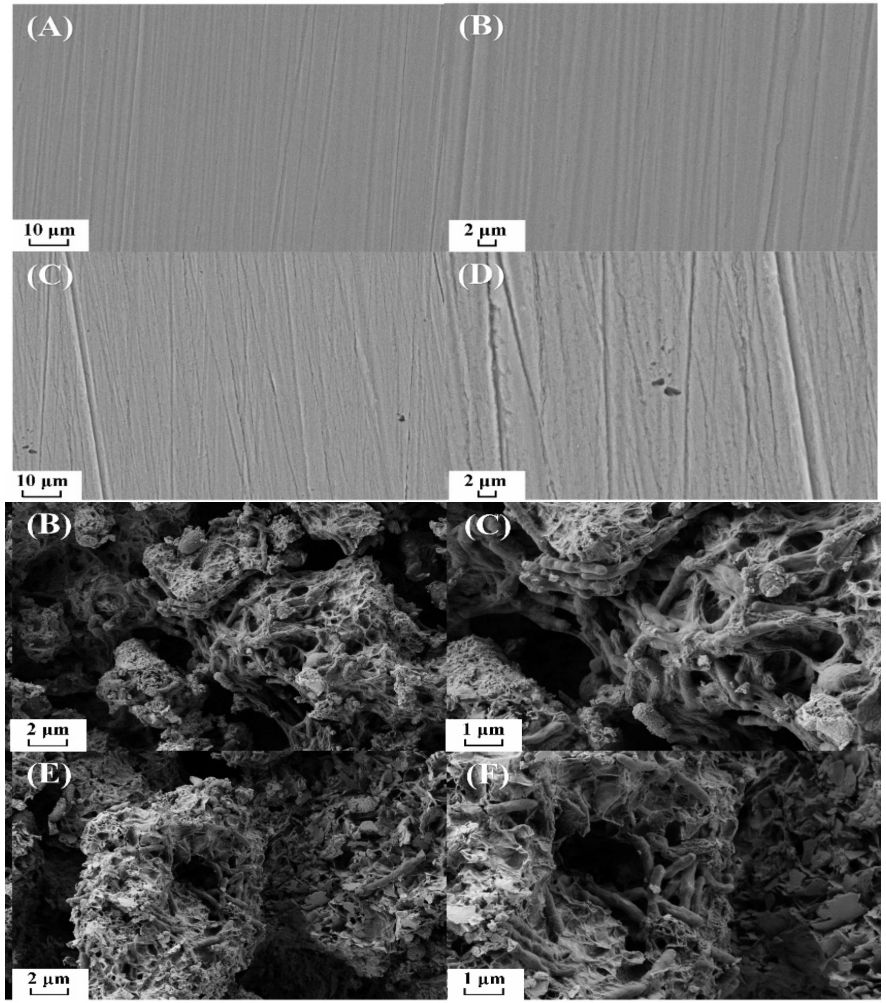
79%



316L stainless steel in abiotic medium

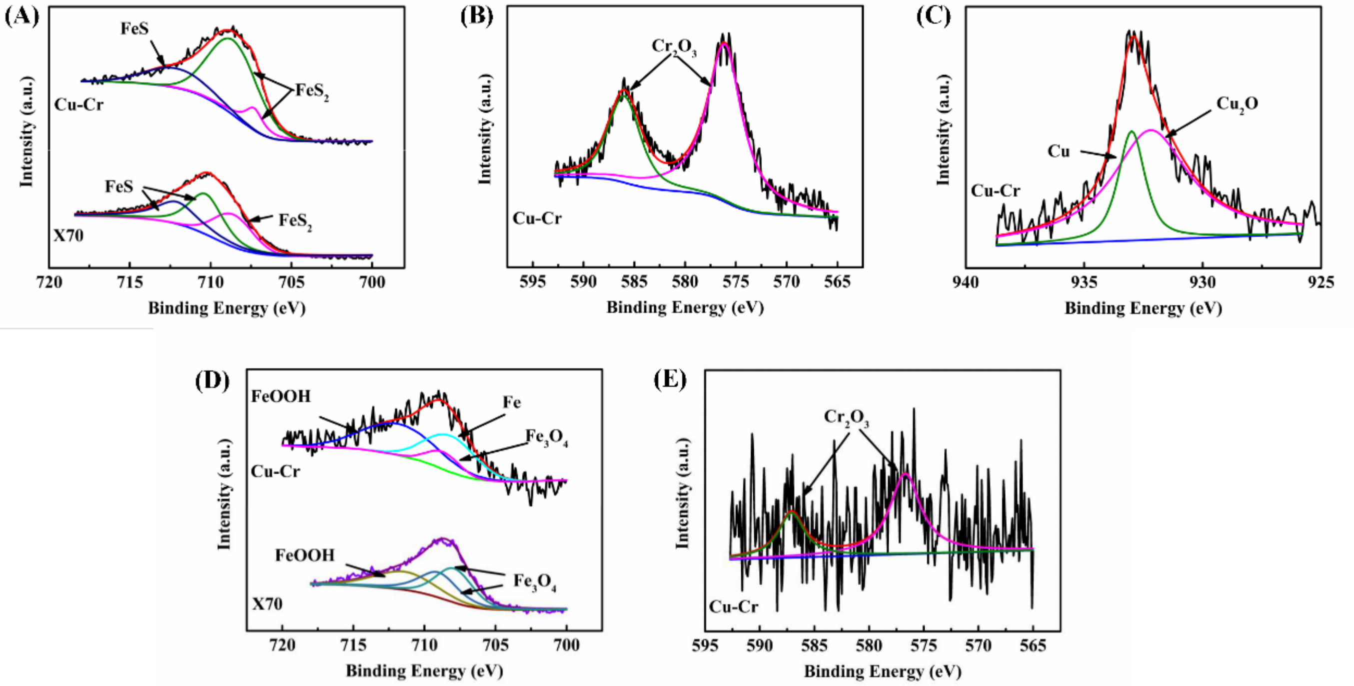
91%

Anti MIC performance of RCB steel with Cu-Cr addition produced by China Baowu



SEM comparison on X70 and RCB steels

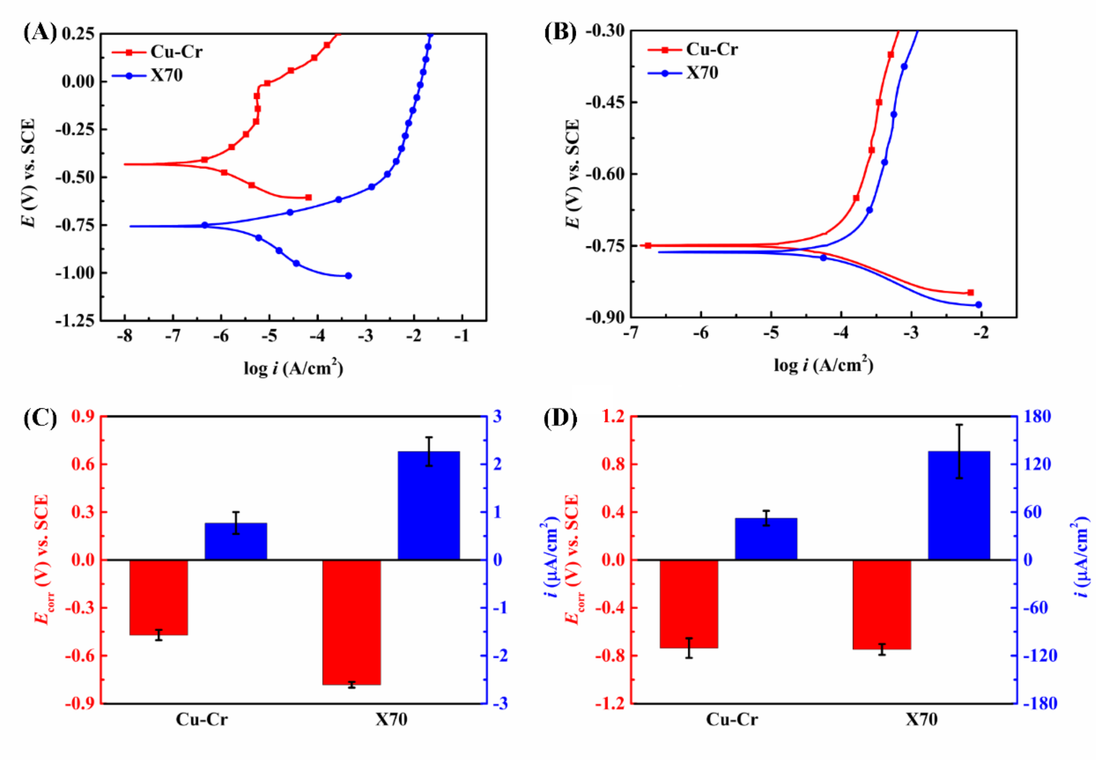
X70 vs. RCB steel with Cu(1.87)-Cr(0.54)



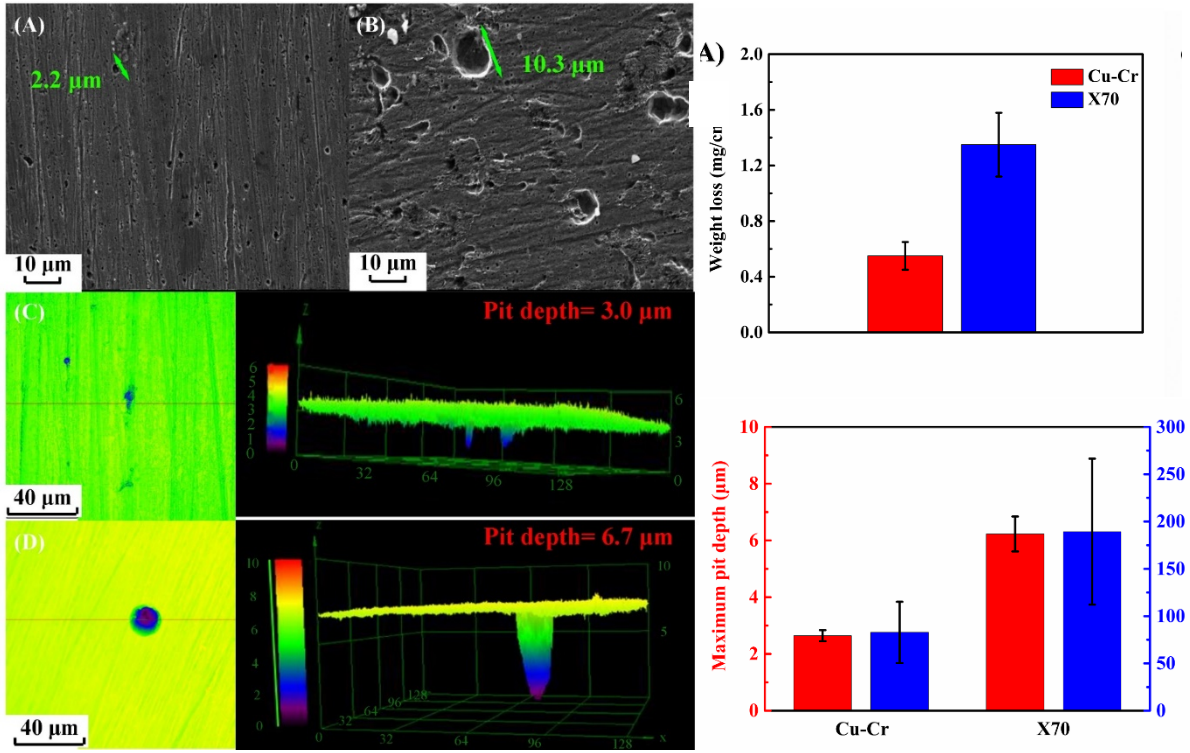
FeS is the main corrosion, Cr elements exist in the form of Cr_2O_3 on the surfaces of RCB steel

The mechanism and protection of microbial corrosion in oil and gas field

Anti MIC performance of RCB steel with Cu-Cr addition produced by China Baowu



Cu-Cr steel and X70 steel electrochemistry results



Cu-Cr steel and X70 steel corrosion in the presence of SRB

With Cu and Cr addition: i_{corr}, pitting, weight loss decreased, but MIC occurred!

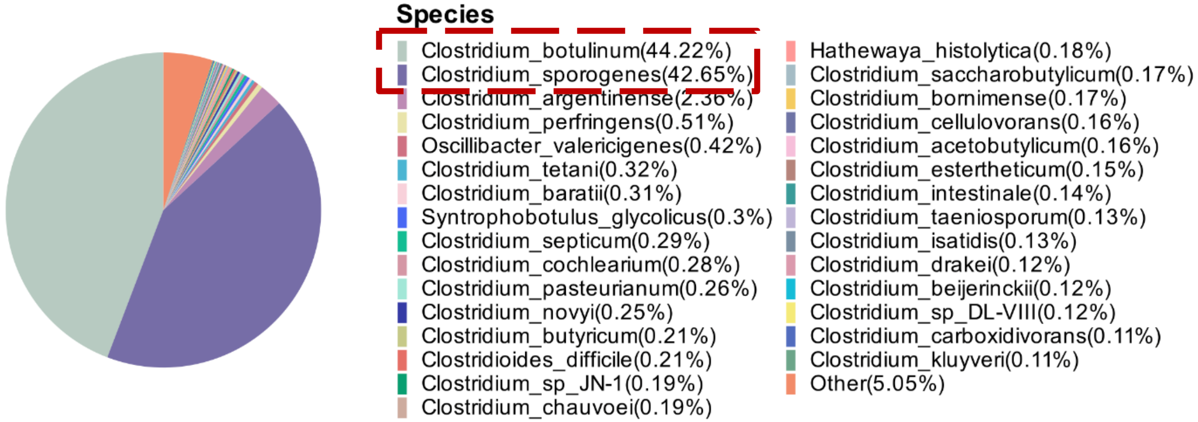
Contents

Microbial corrosion protection in oil and gas field

1 Microbiome collected from produced water of shale gas

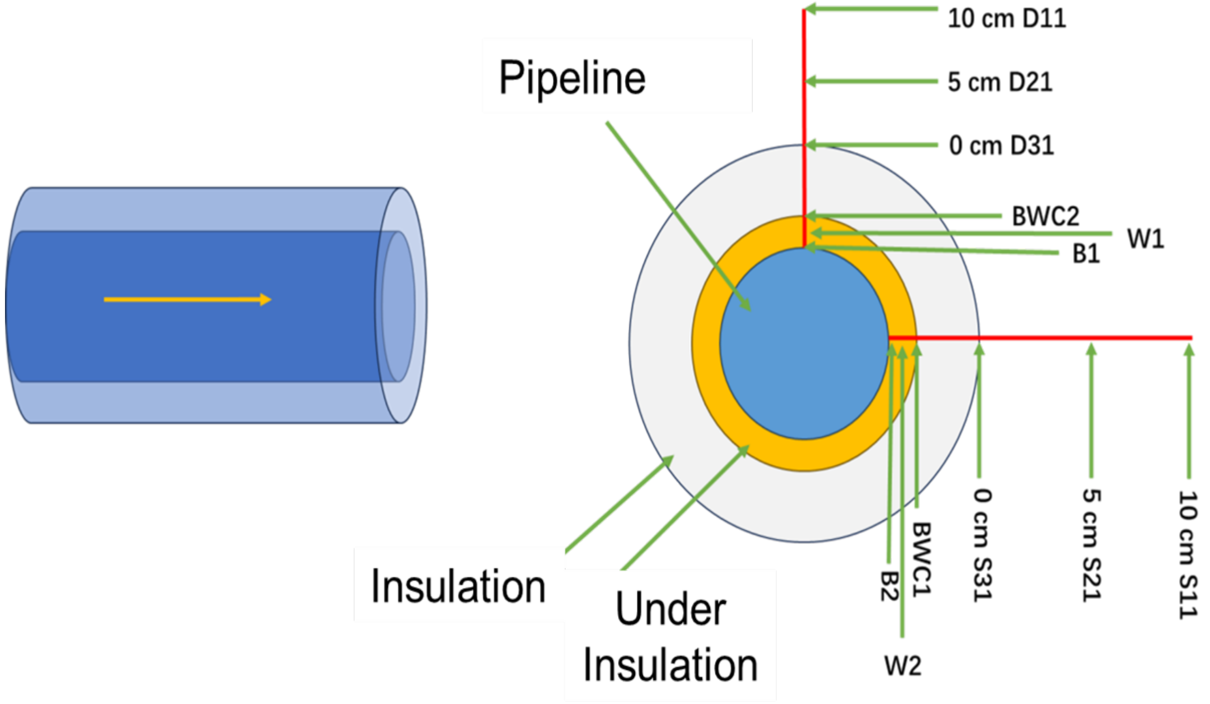
- **SRB might not necessarily present in shale gas fields;**
- *Clostridium* contributed to more than 90% of microbe composition;
- Different platforms might have different microbiomes;
- **Biocide treatment based on the microbiome composition.**





Microbial sampled collected from Weiyuan shale gas, Sichuan Basin

2 Microbiome collected under insulation



Pipeline Excavation and Repair **Schematic of sample collection**

The microbial composition in different direction are totally different.

4 Modified Postgate's B Media (MPB) might not be universally applicable

BTS BIOTECHNOLOGY SOLUTIONS

- MPB Media was formulated by SRB research pioneer John Posgate in 1975；
- MPB Media is the **NACE TM-0194 standard** for the cultivation of SRB；
- However, standard might not totally right;
- High chloride in shale gas, low chloride in MPB media.

Thanks for your attention!

Email: wangdi@mail.neu.edu.cn
Mobile/Wechat: 13644993974
www.linkedin.com/in/di-wang-239b0a338/